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- Professor Kalervo Hiltunen, Biocenter Oulu
- Professor Jari Oksanen, Faculty of Science
- Professor Matti Pietikäinen, Scientific Director of Infotech Oulu
- Dr. Susanna Pirttikangas, representative of young researchers
- Professor Helena Aksela, Department of Physical Sciences (retired in February 2013)

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**Doctoral Program Board 2014–2017**
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- Professor Heli Jantunen, Microelectronics and Materials Physics Laboratories, Department of Electrical Engineering
- Professor Timo Jämsä, Department of Medical Technology
- Professor Matti Pietikäinen, Department of Computer Science and Engineering
- Professor Juha Röning, Department of Computer Science and Engineering
- Adjunct Professor Antti Tölli, Department of Communications Engineering
- Professor Matti Latva-aho, Department of Communications Engineering
- Mikko Hintikka, doctoral student representative, Electronics laboratory, Department of Electrical Engineering

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**Scientific Director**
- Professor Matti Pietikäinen, Department of Computer Science and Engineering

**Doctoral Program Director and Assistant Scientific Director**
- Professor Markku Juntti, Department of Communications Engineering (2010–2013)
- Professor Timo Rahkonen, Electronics Laboratory, Department of Electrical Engineering (2014–2017)

**Coordinator**
- Dr. Tapio Repo, Infotech Oulu

**Secretary**
- Sari Tossavainen, University of Oulu, Department of Computer Science and Engineering
The principal goal of Infotech Oulu is to create an environment for the development of world-class research groups by promoting long-term research, researcher training, and international cooperation. An independent international panel evaluates the research groups that apply for membership of Infotech Oulu, using criteria similar to those used by the Academy of Finland. With such regular external evaluation, and with our internal quality control, we can help our research groups succeed and give them the valuable Infotech label.

Our research is held in high esteem by external funders. The total external annual research funding increased by 16.5% from the previous year to about EUR 17.5 million. Our most significant funding source is Tekes (the Finnish Funding Agency for Technology and Innovation) with its 47.2% portion. We have been pleased to notice that the greatest increase during the last few years has been in funding from the Academy of Finland, which currently represent well over 20% of our total external funding. Direct annual support from the University to Infotech Oulu was EUR 400 000 in 2013.

The University of Oulu has been experiencing organizational changes, including the formation of a new faculty in our research area; the Faculty of Information Technology and Electrical Engineering started its operations at the beginning of 2014. Other important changes have been in doctoral education. The University of Oulu had an internal application for doctoral student positions for doctoral programs in the spring 2013, and an international application for these positions followed in the autumn. The director of our doctoral program during 2010–2013, Professor Markku Juntti was selected as Dean of the University of Oulu Graduate School (UniOGS) starting from the beginning of 2014. Professor Timo Rahkonen was selected as the new Infotech Oulu Doctoral Program Director.

The number of doctoral dissertations within Infotech has grown during the past few years. In 2014, the output was 21 dissertations from the research groups of Infotech Oulu. Our doctoral program had funding for 25 doctoral student positions granted by the Academy of Finland and the Ministry of Education and Culture. Infotech Oulu research groups has obtained almost as many positions from other, national programs during the last few years. The continuation for these positions was secured as the Infotech Oulu Doctoral Program obtained 20 four-year and 14 two-year doctoral student positions from the University of Oulu, starting from the beginning of 2014. This was extremely important to Infotech Oulu, because funding for doctoral students supports most efficiently the current and future long term research that we value most. The new doctoral positions represent over one million Euros annually for research in our area. From these 34 positions, 25 are allocated only for research groups selected into Infotech Oulu for 2014–2017, and the rest for all in the research fields of Infotech Oulu. In the international call arranged by UniOGS, our doctoral program received 293 applications for these positions.

One of the principal goals of Infotech Oulu is to promote international collaboration. Both bilateral cooperation between research groups, and participation in EU and other international research programs are important. Also the value the Wireless Innovation between Finland and U.S. (WiFiUS) platform for building long-term research and education collaboration in the field of wireless networking has been recognized. We have promoted international activities by providing financial support for organizing workshops, and arranging courses and lectures given by visiting experts. We have also sponsored the mobility of doctoral students. The main funding for these activities has been obtained from the Academy of Finland, EUR 430 000 for the years 2010–2013. By the end of 2013, 34.1% of our whole staff, and as much as 37.3% of the doctoral students were from abroad. Based on these figures, our research is more international than ever. Direct strategic funding from the University of Oulu helps us in achieving our goals; one tenure track position in the Center for Machine Vision Research (CMV) and one in the Biomedical Engineering Research Group (BME) started at the beginning of 2014. In addition, a record number of four Academy Research Fellow posts were granted to Infotech Oulu research groups in 2013.

One milestone in achieving the highest level in research is the Finnish Centres of Excellence (CoE) research program by the Academy of Finland. Academy Professor Juha Kostamovaaara’s group, as a part of a joint unit Centre of Excellence in Laser Scanning Research, won CoE status for the years 2014–2019. An international Research Assessment Exercise (RAE 2013) was performed in 2013 for research communities of the University of Oulu in order to classify their scientific quality. Two Infotech groups, CMV, and BME as a part of a larger unit, both belonged to a very small number of research groups that reached the highest possible score in the most competitive category.

In 2013, the current four-year period of Infotech Oulu membership ended, and new groups were selected for the period 2014–2017. An independent international panel evaluated the applications, and nine groups were selected for the next four-year period. The six best groups receive direct funding from Infotech Oulu, but doctoral students in all the nine groups can apply for the doctoral student positions allocated to Infotech Oulu research groups. With this kind of continuous quality control procedure, we can be certain that the excellent progress of Infotech Oulu will continue.
The research of Infotech Oulu is carried out in groups. The research groups mainly operate in those laboratories and departments where their directors are working. The selection of Infotech Oulu research groups is for a four-year period, and it is based on external scientific evaluation of the research presented by the applicants. For the period 2010–2013, five groups were selected as full members, and three groups as associate members. Some of them are joint groups at the University of Oulu and VTT Technical Research Centre.

The following groups were selected to Infotech Oulu as full members:
- Circuits and Systems Group (CAS - Oulu)
- Intelligent Systems Group (ISG)
- Center for Machine Vision Research (CMV), former Machine Vision Group (MVG)
- MediaTeam Oulu
- Wireless Communication Systems Group (WICS)

and as associate members:
- Biomedical Engineering Research Group (BME)
- Electronic Materials, Packaging and Reliability Techniques (EMPART)
- Human Interaction with Advanced Mobile Services and Intelligent Environments (INTERACT)

The associate members did not receive direct funding from Infotech Oulu, but the doctoral students in these groups could apply for doctoral program positions. In addition, all the groups could apply for special funding from the University of Oulu through Infotech Oulu.

Information technology is designated as one of the four focus research areas of the University of Oulu, including machine vision and ubiquitous computing, wireless communications, high-speed electronics and photonics, biomedical engineering, and information systems. The main research areas of Infotech Oulu are
- electronics
- communications engineering
- computer science and information engineering

Funding

Infotech Oulu umbrella organization

The University of Oulu provided special funding of EUR 400 000 for Infotech Oulu in 2013. About 75% of this was directed to support for the full member groups. For the year 2013, EUR 750 000 was originally granted by the Ministry of Education and Culture to the Infotech Oulu Doctoral Program for its 25 student positions. The University of Oulu granted an additional EUR 38 000 for its coordination. The Academy of Finland granted EUR 430 000 for the years 2010–2013 for arranging courses given by visiting experts, and for covering traveling costs of doctoral students when taking part in conferences or working abroad. EUR 108 000 was awarded for the year 2013. The total funding was EUR 1 296 000 in 2013. During the past few years, Infotech Oulu has been able to apply for special funding from the University of Oulu (funding for infrastructure and for international recruitment of researchers). Adding this special funding, the total funding was EUR 1 686 000. The table below shows the funding in 2013, excluding any funding that the research groups may have been awarded in their own right.

<table>
<thead>
<tr>
<th>Source</th>
<th>EUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>University of Oulu; basic funding</td>
<td>400 000</td>
</tr>
<tr>
<td>- doctoral program coordination</td>
<td>38 000</td>
</tr>
<tr>
<td>Ministry of Education and Culture</td>
<td>750 000</td>
</tr>
<tr>
<td>Academy of Finland</td>
<td>108 000</td>
</tr>
<tr>
<td>total</td>
<td>1 296 000</td>
</tr>
<tr>
<td>University of Oulu; infrastructure</td>
<td>390 000</td>
</tr>
<tr>
<td>all total</td>
<td>1 686 000</td>
</tr>
</tbody>
</table>

Research groups

The research groups are mainly funded externally. The total sum of annual external funding for the full members was EUR 14.0 million in 2013. Total external research funding, including that for the associate members, was EUR 17.5 million. Only about a quarter of the research work is financed through internal funding in the form of salaries of professors, research assistants, etc., excluding their estimated time used for teaching. The main source of financial support is Tekes, the Finnish Funding Agency for Technology and Innovation, representing almost half of our external funding.

The following table shows the total external funding of the research groups in 2013. All the funding of the full member groups is channeled through the University, whereas the total funding includes also some funding channeled through VTT. The external research funding increased 16.5% from the previous year.

<table>
<thead>
<tr>
<th>Source</th>
<th>full members</th>
<th>all</th>
</tr>
</thead>
<tbody>
<tr>
<td>Academy of Finland</td>
<td>3 349 000</td>
<td>3 887 000</td>
</tr>
<tr>
<td>Ministry of Education and Culture (doctoral programs)</td>
<td>785 000</td>
<td>986 000</td>
</tr>
<tr>
<td>Tekes</td>
<td>6 918 000</td>
<td>8 287 000</td>
</tr>
<tr>
<td>other domestic public</td>
<td>503 000</td>
<td>615 000</td>
</tr>
<tr>
<td>domestic private</td>
<td>1 556 000</td>
<td>2 031 000</td>
</tr>
<tr>
<td>international</td>
<td>844 000</td>
<td>1 737 000</td>
</tr>
<tr>
<td>total</td>
<td>13 955 000</td>
<td>17 543 000</td>
</tr>
</tbody>
</table>

Personnel

The number of personnel in the full member research groups of Infotech Oulu was 269 at the end of 2013. The total number of personnel, including the associate members, was 361. There was a small increase from the previous year. Personnel from abroad represented 34.1% (+3.0%) of the total staff, and 37.3% (+3.6%) of the doctoral stu-
The table below shows the total number of personnel in different positions. The number of professors also includes acting professors, FidiPro professors and VTT’s research professors. The number of University nominated professors participating in the activities of the groups was about 25. The category “others” includes Master’s level students, secretaries and other support staff. Almost 97% of the personnel worked at the University of Oulu, and the others at VTT. One of the groups had an associate director from VTT.

<table>
<thead>
<tr>
<th>Position</th>
<th>full members</th>
<th>all</th>
</tr>
</thead>
<tbody>
<tr>
<td>professor</td>
<td>23</td>
<td>35</td>
</tr>
<tr>
<td>other senior or post-doctoral researcher</td>
<td>64</td>
<td>91</td>
</tr>
<tr>
<td>doctoral student</td>
<td>129</td>
<td>177</td>
</tr>
<tr>
<td>other</td>
<td>53</td>
<td>58</td>
</tr>
<tr>
<td>total</td>
<td>269</td>
<td>361</td>
</tr>
<tr>
<td>person years</td>
<td>226</td>
<td>276</td>
</tr>
</tbody>
</table>

### Publications

The number of the publications of the research groups in 2013 are represented in the following table.

<table>
<thead>
<tr>
<th>Publication</th>
<th>full members</th>
<th>all</th>
</tr>
</thead>
<tbody>
<tr>
<td>journal article (refereed), original research</td>
<td>100</td>
<td>169</td>
</tr>
<tr>
<td>conference article (refereed)</td>
<td>200</td>
<td>244</td>
</tr>
<tr>
<td>review article, literature review, systematic review</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>book section, chapters in research books</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>non-refereed scientific articles</td>
<td>7</td>
<td>19</td>
</tr>
<tr>
<td>scientific books (monograph)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>publications intended for professional communities</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>patents and invention disclosures</td>
<td>37</td>
<td>38</td>
</tr>
</tbody>
</table>

In addition, the publications have been classified based on their quality, according to the Publication Forum Project (http://www.tsv.fi/julkaisufoorumi). The total number of top level journal articles is 41, leading level 51, basic level 68 and not listed 9. Corresponding figures for conference proceedings are 8 in the leading level, 149 in the basic level and 87 not listed.

### Infotech Oulu Evaluation

Evaluation of Infotech Oulu was arranged in 2013. The purpose of the evaluation was to select the research groups of Infotech Oulu for the period 2014-2017.

The application period for Infotech Oulu ended in spring. In the second phase, the evaluators came to Oulu in the autumn, and the evaluation panel interviewed the research groups. The final choice of membership in Infotech Oulu was made by the Infotech Oulu Board based on the proposal of the evaluators.

The evaluators are internationally renowned scientists in information technology: Professor Hans Burkhardt, Department of Computer Science, Albert-Ludwigs-University Freiburg, Germany; Dr. Mark Craig Reed, University of New South Wales, and Australian Defence Force Academy, Canberra, Australia; Professor Hannu Tenhunen, Royal Institute of Technology, Stockholm, Sweden, and Professor Bernard C.Y. Tan, National University of Singapore (took part only in remote evaluation).

For the following four year period, the following nine groups were selected for Infotech Oulu:

- Biomedical Engineering (BME)
- Biomimetics and Intelligent Systems (BISG)
- Center for Machine Vision Research (CMV)
- Circuits and Systems (CAS)
- Communications Signal Processing (CSP)
- Electronic Materials, Packaging and Reliability Techniques (EMPART)
- Networking (NET)
- New Generation Optoelectronics for Measurement Applications (NeGOMA)
- Radio Access Technologies (RAT)
Background and Mission

The Circuits and Systems group consists of about 25 researchers working at the Electronics Laboratory of the Department of Electrical Engineering at the University of Oulu. Its main activity is in the field of electronic and optoelectronic circuit and system design. The main interest of the group is devoted to certain novel devices, circuit topologies and functional units, although the group is also interested in applications, especially in the field of electronic/optoelectronic measurements and telecommunications.

The main research fields are:

• time-to-digital converters and timing circuits
• generation and detection of powerful and high-speed electrical and optical pulses/transients, and breakdown phenomena in semiconductors in general
• development of pulsed time-of-flight laser range finding and Raman spectrometer technologies, especially for industrial applications
• radio telecommunications, including linearization of power amplifiers, AD/DA conversion and baseband blocks, frequency synthesis.

Scientific Progress

In the following, some details and results of the work of the group are given in selected important research fields.

Time-to-digital converters and optical receiver circuits

A sub-ps-level resolution CMOS time-to-digital converter based on time domain successive approximation interpolation

The proposed time-to-digital converter (TDC) aims at adjustable sub-ps-level resolution with high linearity in the ms-level dynamic range. To achieve sub-ps-level resolution with cyclic time domain successive approximation (CTDSA) within a clock cycle, the propagation delay difference is implemented by digitally controlling both the unit load capacitors and the discharge current of the load capacitance. The TDC uses only a CTDSA as an interpolator with a 5 ns dynamic range within a clock cycle for sub-ps-level resolution and a counter for ms-level dynamic range without a DLL, as shown in Figure 1. The measurement result, i.e. the time interval between the start and stop signals, is obtained by combining the results of the counter (CTR) and the interpolator. The counter gives the number of full clock cycles between the start and stop signals, multiplied by the number of LSBs within the clock cycle.

Figure 1. TDC with ns-level DR & sub-ps-level resolution.

The key functional blocks of the CTDSA architecture of Figure 2 are the two digital-to-time converters (DTC) for binary controlled delay adjustments, the phase detector (PD) for decision-making, and shift register (SREG14) for storing the conversion result. The multiplexers, monostables and DTCs form two loops, highlighted in Figure 2, in which the two signals representing the residue propagate during the cyclic conversion process.

Currently, the layout design of the proposed TDC is in progress. The layout design of the most crucial part, DTC, is in the post layout simulation phase.

Algorithmic time-to-digital converter based on frequency switching

A two-stage TDC is being developed aiming for a single-shot precision close to one picosecond. A coarse time quantization is done by a reference clock counter. The quantization error of the reference clock counter is then
measured by two interpolators. These interpolators are based on a cyclic/algorithmic approach, thus they can achieve very high resolution. In each cycle, the time residue is quantized by a ring oscillator counter. The quantization error of the ring oscillator is then amplified by switching the frequency of the ring oscillator. The following amplified time residue is then measured again by the ring oscillator counter. This procedure continues as long as necessary to achieve the desired resolution.

Based on schematic level simulations and Monte Carlo analysis, the peak-to-peak nonlinearity error is expected to be around 2-3 picoseconds. The standard deviation of the nonlinearity error is about 1 ps. Figure 3 shows the simulated nonlinearity errors due to mismatch and process variations.

The layout of the new circuit is currently being designed using a 0.35 µm CMOS process.

A CMOS time-to-digital converter based on internal averaging

A new digital time-to-digital converter is under development with 65 nm CMOS technology. The goal is to reach picosecond-level measurement precision for the time interval between two timing signals, start and stop. The new architecture includes a stabilized delay line, counter, passive time sample generation unit and a total of 128 individual registers for interpolation, see Figure 4. The stabilized delay line creates time samples with 20 ps resolution. The delay line uses a successfully tested reference recycling method, which makes the use of a 100 MHz reference frequency possible, and decreases the length of the delay line to 16 delay elements. The counter counts the rounds of this delay line between the timing signals and provides a long measurement range. A passive time sample generation unit uses four resistors connected in series, which are added between the delay line delay elements. Four consecutive time samples can be recognized between the resistors when the reference signal propagates in the main delay line. Hence the mean interpolation resolution becomes 20 ps / 4 = 5 ps. The timing signal arrival is delayed to 64 different phases, each of which register the prevailing time sample from the passive time sample generator. So, a total 64 different interpolation results are obtained for both start and stop signals. The factors deteriorating the interpolation precision, mainly integral nonlinearity, vary during the 64 consecutive interpolations, and the resulting average error approaches zero when the average interpolation result is calculated. Theoretically, the improvement in precision when using 64 individual interpolators for each timing signal is \( \sqrt{64} = 8 \), which means that precision better than a 1 ps single-shot could be possible. The development is in the schematic design-phase, so the measurement results can be expected by the end of 2014.

An integrated CMOS receiver channel with TDC for pulsed time-of-flight

An integrated receiver channel is under development for a pulsed time-of-flight (TOF) laser radar, based on a 0.35 µm CMOS process. The goal is to integrate a high-performance receiver channel and a multi-channel TDC (time-to-digital converter) on the same IC chip.

The receiver channel has been designed to cover a wide dynamic range of 1:100 000. The timing walk error (dependence of the timing moment on the pulse amplitude) is compensated for in the time-domain by measuring both the width and the slew-rate of the received pulse echo with a multi-channel TDC. As the relationship between the generated walk error and the pulse width/slew-rate is known in advance (calibration measurement), accurate distance measurement can be done. The operation principle of the compensation method is shown in Figure 5. Timing marks (stop 1 and stop 2) are discriminated using a threshold voltage \( V_{th}(\text{low}) \). A higher reference level \( V_{th}(\text{high}) \) is used to discriminate the timing mark (stop 3) for the slew-rate measurement.
The walk compensation principle based on the pulse width and slew-rate measurement.

Figure 5.

The block diagram of the receiver channel is shown in Figure 6.

Figure 6.

Pulsed time-of-flight ranging based on a digital transient recorder

The sub-ps resolution TDC developed requires a high SNR at the receiver side, which is very often not available, for example for very long distance measurement, or ultra-low power operation. Our other approach for laser ranging is to record the received optical pulse in digital memory as early as possible in the receiver, then to apply various digital filtering and detecting techniques, see Figure 7.

Figure 7.

Our research suggests using a 2-level comparator in favor of a multi-bit ADC. Statistical analysis of ADCs with random input shows that a comparator introduces only a 20% drop in SNR.

Various digital pulse detection methods have been investigated, and their performances are analytically quantized. An optimal transceiver architecture is suggested which requires narrow optical pulse and matched or derivative matched filter. The relationship between transmitted optical power and energy/measuring time/digital clock speed and measurement resolution/distance is established.

Generation and detection of electrical/optical transients

Improvement in the gain-switched high-energy picosecond laser diode pulse shape using saturable absorber implementation

A saturable absorber (SA), by means of an unpumped section, is introduced in a previously proposed Fabry-Perot semiconductor laser with a strongly asymmetric DH bulk structure and a relatively thick (80 nm) active layer. The focused ion beam technique (FIB) is used here to remove a part of the anode metal contact (Figure 8, inset right). The structure, with a 30 µm long SA, suppresses oscillations at the trailing slope of the optical pulse and decreases the optical pulse width compared to the structure before SA implementation (Figure 9). The improved gain-switched single optical pulse is trailing oscillation free with ~80 ps full width at half maximum (FWHM) and ~35 W peak power, which corresponds to ~3 nJ optical pulse energy. The intensity – time profile was measured with a spectrograph equipped streak camera. The pump current pulse applied here is 17 A in amplitude and 1.3 ns in duration provided by an optimized silicon avalanche transistor based driver circuit (Figure 10) at a pulse repetition rate of 1 kHz. The package is intended for laser ranging and other optoelectronic measurement applications, especially for single photon measurements.

Figure 8.
Figure 9. Measured pump current pulse of 17 A in amplitude and 1.3 ns in duration, with a corresponding optical response pulse from a strongly asymmetric DH bulk high-speed laser diode, based on “improved” gain-switching (approx. 850 nm). The optical pulse from the structure before SA implementation ($l_{SA} = 0$) and with 30 µm long SA ($l_{SA} = 30 \mu m$).

Figure 10. Laser diode and driver circuit board (area approx. 1 cm²).

High-Speed Avalanching BJT as High-Current Drivers for LDs and UV LEDs, and as High-Power Pulsed Emitters for Sub-THz Imaging

For nanosecond/sub-nanosecond pulse durations, the GaAs-based avalanche bipolar junction transistors (ABJT) suggested, and investigated in Electronics Laboratory within the last 15 years, are apparently the best active high-voltage/high-speed switches, but their reproducible technology has been thus far under development, and commercialization of this device still requires significant investments and time. Si ABJT’s have been most frequently used for nanosecond pumping of pulsed laser diodes, but Si avalanche transistors with a switching time of less than 2 ns are missing, and designing of a new generation of Si ABJT’s producing even shorter pulses with a high (1-30 A) current amplitude is a very challenging task that requires deep physical understanding to be achieved for this sophisticated operation mode.

What is peculiar is the fact that a comprehensive physical description of the Si ABJT transient at high current densities was absent until the last decade, and the first reliable 1-D and 2-D description of the process we presented recently. (The point is that only modern numerical methods of physics-based transient modeling allowed the principal features of the old phenomenon to be understood, while rough assumptions utilized in 1950’s - 70’s in analytical models led to erroneous conclusions, which remained popular for several decades). Furthermore, despite the age of the phenomenon exceeding half a century, its importance in modern nanosecond and sub-nanosecond optoelectronics applications continues to grow. This makes the task of deep physical investigation of an avalanche switching timely and challenging. We have experimentally proved lately that the parameters of short-pulsing avalanche switching in a Si ABJT cannot be explained (or predicted) without consideration of fairly complicated 3-D transient phenomena. Several interesting findings were made concerning significant and non-monotonic change in the switching size along the emitter-base fingers during fast stage of the switching transient due to two competing physical mechanisms: channel shrinkage and turn-on spread (see Figure 11). Here, of principal importance is the peak current density value, which has to be as high as possible for fast switching with low residual voltage, but at the same time should not exceed the destruction level due to local overheating. Very recently we have additionally shown that 3-D dynamics is of principal importance not only during high-current switching stage, but also during switching delay.

Figure 11. Switching transient (a), current density profiles and (b) normalized current density profiles (c) shown for fast switching stage in a Si avalanche transistor. Instants corresponding to the curves in (b) and (c) are related to the transient in (a) as follows: 1-4.2 ns; 2-6.2 ns; 3-6.8 ns; 4-7.3 ns; 5-8.4 ns; 6-9.3 ns. Curve 7 in (c) shows the shape of the optical excitation. Please note that the normalized curves in (c) first shrink from initial excitation profile (curve 7) to current density profiles 1 and 2, and then spread to profiles 3, 4, 5, and 6. Together with the temporal profile of the collector current (a), the size variations in (c) cause changes in the current density, and the last one controls the switching speed at each particular instant.
The last finding gives an approach to optimal chip design of novel, unique switching devices aiming at 0.2-2 ns range of the current pulse durations with amplitudes ranging from several to a few dozen amperes, see Figure 12. Such miniature, cost-effective devices are missing; demand for such switches is growing, while design principles for those devices have been missing, as well as a physical understanding of their operation. It is worth noting that technologically new devices will fit well to the state-of-the-art of Si technology, and the physical principles of their operation and corresponding design ideas are the main bottleneck in developing the new generation of Si ABJTs.

Figure 12. Layout of an avalanche transistor (a), and measured radiative recombination pattern (b) which marks the switching channels at short-pulsing mode (2 ns / 10 A / 82 pF). (c) and (d) illustrate the reason for the triggering inhomogeneity consisting of crowding of the current of injected electrons near the corners of the emitter-base interface. (c) corresponds to a large radius R of the curvature corresponding to the corners A, B, C, D in (a), and (d) corresponds to the “sharp” corners E and F.

Together with high-current/short pulse generation, a very promising (and the apparently most important) application for the avalanche switching in GaAs BJT is the generation of pulsed broadband terahertz emission. Periodical nucleation and annihilation of ultra-narrow, powerfully ionizing “collapsing” domains is believed to cause the THz emission observed in our experiments. The task of design, development and investigation of high-power pulsed (ns/sub-ns) emitters for a new generation of active sub-THz imagers should be divided into several directions and stages, and this is the major part of our strategic TEKES project (MIWIM), which starts in 2014. The main direction is the design and development of BJT GaAs-based structures combined with properly designed sub-THz antennas, and using them together with miniature, fast, room-temperature quasi-optical detector based on a Schottky diode. The solution of a large number of the related tasks is underway, and the first laboratory examples of transmission sub-THz imaging utilizing not only transmission intensity, but also propagation delay of the pulses across the object with temporal resolution of ~10-30 ps have been presented in several plenary and invited talks. The results from our first prototypes of millimeter-wave radars are at a very early stage however, before their public release as it concerns various technological and experimental details.

Multiphase time-gated single photon avalanche diode (SPAD) arrays for Raman spectroscopy

Raman spectroscopy is based on inelastic scattering, or Raman scattering, of monochromatic light, usually from a CW (continuous wave) laser in the visible, near infrared or near ultraviolet range. Unfortunately, the Raman spectrum is masked in most otherwise potential cases by a strong fluorescence background. This is due to the fact that the probability of Raman scattering is much lower than that of fluorescence. As a result, in spite of the obvious advantages of Raman spectroscopy, this strong fluorescence background has so far restricted its use in most potential applications in the fields of the agricultural, food and oil industries, security control and crime investigations, for example.

It is possible to suppress the fluorescence background to a great extent, if intensive short laser pulses are used to illuminate the sample instead of CW radiation, and by recording the sample response only during these short pulses. The suppression is due to the fact that Raman scattering is introduced immediately after the collision between the photons and the sample material, unlike fluorescence, which is emitted after a delay characteristic to the sample. Thus, by “time-gating” the measurement for only the period of the laser pulse, most of the fluorescence is blocked out from the recorded spectrum.

The block diagram of the pulsed Raman spectrometer and the principle of fluorescence suppression are shown in Figure 13. The material to be measured is excited by means of a pulsed laser, emitting short 70-150 ps (FWHM) and spectrally narrow (~0.2 nm) pulses at an average power level of a few mW. The SPADs of the detector array (SPAD-IC) are enabled by the trigger pulse from the pulsed laser just before each laser pulse, and the photons are counted during short time periods (Δt1, Δt2, Δt3, Δt4), in order to suppress the fluorescence and effective dark count rate (DCR).

Figure 13. Block diagram and time gating principle of the proposed Raman spectrometer.
A multiphase time-gated 2*4*128 single photon avalanche diode (SPAD) array has been designed and fabricated in a standard high-voltage 0.35 µm CMOS technology for the above spectrometer. Each of the two columns consists of four parallel connected SPADs. A 50 ps -100 ps time resolving capability can be achieved by using the multiphase time-gated structure. Raman spectra of an olive oil sample are shown in Figure 14, measured with the 2*4*128 SPAD array demonstrating the fluorescence suppression.

A time-gated 4*128 SPAD array with a 3-bit 512 channel flash 80 ps-TDC has been also fabricated in a standard high-voltage 0.35 µm CMOS technology for Raman spectroscopy. In this design, each of four columns works independently so that the dark count rate performance of the active area required can be improved by using separate SPADs in a row, instead of one larger SPAD. Additionally, photons can be detected by all these SPADs separately, and thus a possible noisy detector in a spectral row can be excluded from the final result. The flash type 512 channel TDC measures the arrival time of photons of every pixel (4*128) so that Raman photons and fluorescence photons can be distinguished at each of the spectral points, and thus the level of fluorescence background can be further suppressed.

A third version of the time-gated SPAD array has been also designed with the same technology as the earlier versions, however with a larger array of 16*256 pixels and a 3-bit 256 channel TDC. The resolution of the TDC is approximately 50 ps. The layout of this IC is shown in Figure 15. The design is under fabrication and the tape out date will be at the end of February 2014.

Circuit analysis and linearization techniques

Distortion contribution analysis algorithm VoHB

A general-purpose distortion contribution analysis called VoHB (Volterra on Harmonic Balance) has been under development for a decade, and it is currently available as a plugin for the commercial AWR-Aplac circuit simulator, where it can use all the device models available in Aplac. VoHB runs at a VCCS (voltage-controlled voltage source) level to be able to calculate frequency-domain mixing effects. Each VCCS is modeled as a polynomial that is fitted using the simulated large-signal spectra obtained directly from harmonic balance simulation. With the help of the polynomial models it is easy to calculate the distortion propagation and hand-to-hand mixing through the circuit to an arbitrary node. During 2013, the fitting methods were considerably improved.

The first problem comes from the internal structure of many modern device models: they no longer resemble the classical pi model. As the designer needs to know what VCCS or VCQS is causing each contribution, a first attempt was made to canonize the presentation of the results: independent of the actual structure of the transistor device model, its nonlinearities were modeled by one conductive and one capacitive source in both the input and output ports. This gives the designer sufficient information, and is independent of the actual modeling. In a way, this is quite similar to the concept of input-reduced noise contributions.

Another big issue was the reliability of the fitting. It has already been shown that the strength of the polynomial model is sufficient also for highly nonlinear applications, and the effects of frequency domain fitting, scaling and spectral weighting have been verified. Yet, a too narrow data trajectory, when transistor input and output signals look very similar, easily causes the polynomials to have excessive curvature in the operation regime, and this was not satisfactorily solved until 2013.

Quite nonlinear or reactively loaded transistors can usually be fitted using the data available from a normal multi-tone harmonic balance RF simulation. If the device is very linear, or has more than two controlling ports, we need to break the correlation between the input signals used for fitting, and this means running an additional characterization simulation. Here the basic idea is to broaden the output load-line by adding some tones to the output that are not found in the input signal. Signals in the fundamental band broaden the load line, and signals in the 2nd harmonic band can be used to shape the load line asymmetrically so that the drain voltage trajectory is broad enough, but they still avoid reverse biasing of the body diode and operation in the breakdown region. This is illustrated in Figure 16. This task has been done in partial co-operation with Prof. Pedro’s group at University of Aveiro, Portugal.

Figure 14. Raman spectra of olive oil with the commercial (red) and our Raman spectroscopy (blue).

Figure 15. Layout of the 16*256 SPAD array with 256 channel TDC.
The design of supply modulated RF transmitters

The work on supply modulated RF transmitters has continued by designing a new supply modulator circuit using the traditional asynchronous hysteretic feedback taken from the current polarity of the assisting linear amplifier, see Figure 17. The circuit has 1.8 W maximum output power, 19 MHz bandwidth and max. 65% power efficiency. The power dissipation and synchronization behavior with the input signal were thoroughly investigated, and a lot of time was spent in minimizing the EMI emissions of the modulator. The modulator was used to test several known predistortion techniques with and without memory, using a linear 1 GHz, 1 W envelope tracking amplifier.

External Funding

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Doctoral Theses


Selected Publications


Biomedical measurements and power management

The design of an integrated, low power 16-channel neural signal recorder / excitation circuit is a co-project with Department of Biophysics, at the University of Oulu. The design was mostly completed during 2013: the power dissipation, bandwidth tuning and noise properties of the receiver channels were solved, but a real-time recording through an SPI serial bus caused some re-thinking, and a 32-sample buffer memory was implemented on the chip. The circuit will be processed in an AMS 0.35 µm process in the early months of 2014.

Christian Schuss is doing his PhD on efficient energy harvesting for low power applications. During 2013 he cooperated with University of Graz in optimizing a car-roof photovoltaic energy harvester, and with Department of Information engineering by providing indoor photovoltaic energy harvesting measurements.

Sun Jia is doing her PhD thesis on efficient modeling and power minimization techniques of switched capacitance blocks in AD and DA converters. In 2013, she tested the idea of using passive charge-sharing in speeding up the settling of SC blocks. It appeared that especially the residue amplifiers of a pipeline AD converter can easily be boosted by pre-charging their load capacitances so that passive charge sharing pulls most of the charge from the input capacitors, which effectively bypasses the slew-rate limited settling phase.

Personnel

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S. Vainshtein, G. Duan, J. Kostamovaara, “How high-speed transient in a Si avalanche transistor can be improved by smart chip design, Annual Journal of Electronics (ISSN 1314-0078), pp.172-175, 2013.

S. Vainshtein, G. Duan, J. Kostamovaara, “How high-speed transient in a Si avalanche transistor can be improved by smart chip design”, Annual Journal of Electronics (ISSN 1314-0078), pp.172-175, 2013.

S.N. Vainshtein, J.T. Kostamovaara."Collapsing field domains in electron-hole plasma of GaAs, and examples of the phenomenon application from superfast voltage switch to sub-THz imaging", Plenary talk at Saratov Fall Meeting - SFM’13 Symposium Optics and Biophotonics (http://sfm.eventry.org/report/671), September 25-28, 2013, Saratov, Russia


Background and Mission

The main scientific objective of the basic research conducted in the Intelligent Systems Group is to generate new, applicable knowledge on intelligent systems, and to generate positive societal impacts by applying this knowledge using scientifically plausible methods and state-of-the-art technology. We conduct research on spatial computing, collective intelligence, sensor networks, optimization of industrial processes, mobile robotics and cybernetics, human-computer interaction (HCI), human-robot interaction (HRI), computer networks, and security in complex information processing systems.

Our strategic research themes, whereby we aim to conduct world class basic research, are: 1) Safety and security on all levels of intelligent systems, 2) Data mining, with a special focus on optimization of industrial processes and well-being, 3) Human-environment interaction with a special focus on novel physical user interfaces, robot-environment and human-robot interaction, 4) Mobile robotics and cybernetics, with a special focus on spatial computing, adaptation, and field robotics, and 5) Sensor networks, with a special focus on understanding behaviour and patterns in our everyday environment.

We have conducted basic research related to these research themes for over ten years. Our team consists of two professors, seven post-doctoral researchers and 24 doctoral students. The annual external funding of the group is more than two million Euros, in addition to our basic university funding. There have been 17 completed doctoral degrees from the group. From the research of the group, eight spin-out companies have been established so far: Codenomic, Clarified Networks, Hearth Signal, Nose Laboratory, Nellilab, Atomia, Probot and IndoorAtlas.

We co-operate with many international and domestic partners. In applied research, we are active in European projects. In addition, several joint projects are funded by the Finnish Funding Agency for Technology and Innovation (Tekes) and industry. We were a research partner in the Data to Intelligence (D2I), Internet of Things (IoT) and Cloud Software ICT SHOKs. In the Cloud Software Program ICT SHOK, we are responsible for cloud security CoP.

In the II City project, we collaborated with the University of Lapland and Sonic Studio from Piteå, Sweden, and in the Pervasive Service Computing project with Shanghai Jiao Tong University from China. These projects were funded by the European Union (Interreg IV A North) and the Academy of Finland (the MOTIVE program). Also we are collaborating with the Tokyo University of Agriculture and Technology in the Interactive Context-aware System for Energy Efficient Living project, funded by the Academy of Finland.

We are active in the scientific community. For example, Prof. Juha Röning is acting as visiting professor of Tianjin University of Technology and as the Robot Science Advisor of Tianjin Science and Technology Center for Juveniles. He served as a member of the Board of Directors in eRobotics and as a member of the SAFECode International Board of Advisors, and as a chief judge in the euRathlon 2013, which took place between 23rd and 27th September in Berchtesgaden, Germany. euRathlon is a new outdoor robotics competition which invites teams to test the intelligence and autonomy of their robots in realistic mock emergency-response scenarios. During the reporting year, the group organized two workshops on security, the 11th Finnish Vulnerability Researcher Meeting on November 18th, and the 7th International Crisis Management Workshop and Winter School (Crim’13), which brought together both Finnish and international information security experts. A workshop on Human Activity Sensing Corpus and Its Application (HASCA2013) was also organized by Susanna Pirttikangas in conjunction with Ubicomp’13.

Prof. Jukka Riekk gave an invited talk at the National E-learning Conference in Helsinki. Several doctoral students continued their research visits during 2013 as well: Teemu Leppänen completed a one-year research visit to the Institute of Industrial Science, at the University of Tokyo, Japan, and Mikko Polojärvi visited Hokkaido University in Japan. Several members of the group co-chaired workshops and were also on the committees of international conferences.

Scientific Progress

Research on mobile robotics

This research includes several topics to support technologies of mobile robotic systems: motion planning, localization, energy management, information representation and development of a mobile robot system. A practical robotic system is being build that can operate indoors among people.

The Finnish Academy and European Regional Development Fund (ERDF) funded Minotaurus robot combines the theoretical and practical aspects of creating service robotics of the future. Both projects are in co-operation with the Center for Machine Vision Research (CMV). Another platform is being developed to realize a mobile robot that operates in a harsh outdoor environment.
Dynamic motion planning

Making improved motion planning in a real world environment is being studied. The planner combines perceptions from several sources, local obstacle avoidance with dynamic model and the performance capabilities of the robot, as well as the capabilities and limitations of the perception system. The developed system has been tested both indoors (using the Minotaurus robot) and outdoors (using the Modular Outdoor platform, Figure 1).

Figure 1. A real robot and its model using simulation software. For raw location, the robot uses a Kinect sensor and detection of visual clues like room signs and room numbers. Also a laser scanner profile is used for matching with prior knowledge of the corridor shape profile. Later, technology using magnetic field quality for localization will be merged to the robot.

Local obstacle avoidance gets its input from several sensor systems, combines the information to knowledge of the current state of the environment, and plans a route among obstacles. The perception modules include laser scanners, data processing and several vision algorithms using a Kinect range camera. These can detect obstacles and humans in the environment. Several obstacle avoidance algorithms can be run in parallel, and the same algorithms can be run with varying parameters, from which the best result for the current situation is selected (Figure 2). This improves the planner so it is able to find a proper route, even when one of the algorithms might fail, or some parameters are not suitable for the current situation. Further the parameters of each algorithm are tuned online, using genetic algorithms to be able to adapt to new conditions.

The robot uses a graph based navigation map for finding raw route points, and an RRT (Rapidly-exploring Random Tree) for finding a free path from the current location to the next route position. Indoors, the graph is predefined from the floor map. Outdoors, the graph is generated from the Open Street Map data.

A dynamic model of a robot is used to set restrictions for the path planner and predict the forces that would affect the robot as it moves along the planned route. The restrictions come from environmental parameters and the robot’s performance capabilities. The dynamic model can be continually adjusted, based on the difference between the robot’s predicted and actual behaviour. The algorithms for the dynamic model are developed using a highly accurate physics simulator.

Magnetic field localization and SLAM

The objective of our indoor localization research is to develop methods for exploiting magnetic field anomalies in positioning. The idea is based on analysis with various indoor magnetic field datasets showing that indoor magnetic fields provide sufficient spatial variation and temporal stability to permit inference about sensing locations, given noisy measurements. In recent years, we have published various papers presenting magnetic field localization in robotic and human contexts (Figure 3).

Based on the magnetic field localization studies, a new start-up company, called Indoor Atlas Ltd., was founded in 2012. This company offers indoor positioning technologies for various application areas. The company has generated high interest in international technology magazines.

In our research on magnetic field localization and SLAM, we have put a strong emphasis on light-weight methods running entirely on mobile platforms, such as Android smartphones and tablets. Compact map representation and effective algorithms are essential when using devices with very limited resources, and we have developed methods
to tackle the problems arising from very sparse data and high uncertainty levels produced by low-cost and noisy smartphone sensors. Our work is continuing toward an autonomous mobile robot system based solely on smartphone sensors that is able to intelligently build a map of the magnetic environment (Figure 4).

Social robot scenarios are particularly difficult because of the dynamic (often crowded) environment. Magnetic field localization is not affected by surrounding people like laser scanners and cameras for example, and it is therefore very promising in these kinds of scenarios. While our method is used to localize the robot, the other sensors can be assigned to handle the social tasks. We have also developed localization methods that are usable by both robots and humans equipped with similar mobile devices.

**Winter operability for electric vehicles**

Intelligent battery systems for robots and light-weight electric vehicles are being developed partly in the WinTEVE project. The focus is on developing scalable battery powered systems with integrated energy management, improved energy efficiency and the ability to operate in varying conditions, such as those experienced during winter. In addition, interest is in gaining a better understanding of power usage and operational times of the related equipment, such as mobile robots. Work has included a study of upcoming battery technologies that might drastically improve the capacity and power to weight ratios in the near future, as well as making of systems that can profile and control power usage in robots. For example, robots may need to turn off unnecessary sensors, when they are not needed, to conserve energy. Artificial neural networks are being utilized for creating better models for representing the true state of the charge and condition of the battery system. Further, the models can be used for predicting the capacity and energy available for the upcoming operating periods as a part of forward planning and task scheduling.

*Energy efficient model predictive control* relates to the development of intelligent battery systems, where the goal is to optimize energy usage in varying equipment and operating conditions. In mobile robotics, surveying the environment utilising flying drones in conjunction with a ground unit, utilizing Simultaneous Localisation And Mapping (SLAM), is considered in tasks related to movement surface classification and route planning processes. Machine learning is employed in adaptation of models related to predictive control for automatizing optimal route learning and planning. This work may be further expanded to full electric cars, operating in large road networks, by generating automated mappings of road conditions, for example road surface classification based on recorded energy consumption, traction and slope (Figure 5). The classification data may then be used by model predictive route planning algorithms for internal and external car control, aimed at driving energy prediction, congestion avoidance and possibly for larger scale traffic flow optimization. Weather and its effects on energy consumption is one of the focus points for this research, especially for full electric vehicles (FEVs).

Figure 4. An iRobot Create equipped with a Samsung Galaxy Nexus smartphone utilizing the same magnetic map for localization as the person holding an Asus Nexus 7 tablet. The same localization unit can be used by both humans and robots in social robot scenarios.

Figure 5. Mapping of consumed (red) and braking regenerated (green) energy of an electric car during a single driving session.

To further improve energy efficient control, our outdoor robot platforms are being upgraded with energy harvesting capabilities by hardware development, primarily utilising braking energy collection via advancing technologies like super-capacitors (Figure 6). Much of the required hardware has been manufactured during 2013; initial testing and control system development should, therefore, be performed during 2014. In order to achieve the highest ef-
Efficiency possible for mobile platforms, the research needs to combine the results of dynamic motion planning, intelligent battery management, SLAM and model predictive control.

Figure 6. Outdoor robot combined with a possible supercapacitor braking system (red).

**Autonomous water quality sensing**

Currently, collecting a large amount of water quality data using either field sensors or sampling bottles requires enormous manual efforts. Not only the time spent on changing environmental conditions, but also positioning and route planning bring challenges, especially when these are required to be performed in-situ. A typical task for such a case would be searching for pollution leaks, or modelling how some water quality parameter is distributed over a lake or shore.

Our research on autonomous water quality sensing aims at cost-efficient sensing strategies in terms of sensing time and modelling accuracy controlling robotic vessels in the target water environment. The key approach is to apply our previous research on indoor magnetic field exploration to the water quality sensing, where an additional challenge follows from the multiple variables (called water quality parameters), such as dissolved oxygen, turbidity, electrical conductivity, pH and fluorescent dissolved organic matter. Also, in many cases, this information is required to be measured from different depths so that the spatial models are three dimensional.

In order to operate in water environments, following from the Tekes TULI project (projects aiming to commercialize research innovations), two unmanned surface vehicles were constructed during 2013 (Figure 7). These robotic platforms enable users to monitor through video-surveillance sensing tasks; meanwhile, all the information is transferred to the database and can be visualized through a web service. A new spin-off Aquamarine Robots Ltd. was founded in December 2013. This company offers robotic vessels and an aquatic information system to collect, store and visualize relevant information from freshwater and mining environments.

**Research on human-robot interaction**

Key aspects are putting research results into practice, and integrating them as a part of the operation of the robot. The main challenges are representation of information, and adapting a set of algorithms to the current state in the surrounding environment. The human friendliness of the outward appearance of the robot is driving the design of the robot. Studies on interaction with a machine have continued from various perspectives. The capability of the Minotaurus robot has been improved with new sensors, perception processing and physical capabilities. The robot is also capable of engaging in simple dialogs using English or Finnish. Now we are adding the ability of recognizing and picking up objects from a surface upon request (Figure 8).
The robot is based on a Segway RMP200 platform, and equipped with several sensors to receive information from the environment and humans. Two Kinect sensors are used as a 3D vision camera, one looking towards the floor and one looking forwards. Multiple 2D scanning lasers are additionally used for close distance obstacle avoidance, and for refining the estimation of the robot’s movement. Further, the robot is equipped with several microphones to reason the source direction for audio and for speech recognition.

This year a commercial arm has been implemented on the robot (Jaco Kinova). The arm was originally developed for wheelchair operation, and it provides a good reachability-weight ratio. The arm is flexible and the robot can reach the ground, tables and even higher located objects using it. Further research has also been done in the areas of perception and dynamic motion planning. The robot can now find objects on a table and calculate the best possible grasping pose.

During the year, the Minotaurus robot was demonstrated in several events, including Robottipäivät in Tietomaa and the University Science day at the University of Oulu.

Interaction with a machine has been studied from various perspectives. The combination of machine vision, speech recognition and synthesizing, touch and touchless interactions, along with the robot’s operation in the environment requires a software platform that processes, distributes and stores information efficiently. Real-time Linux based operating system services, along with general purpose representation for information (called Markers) have been developed to support integration of the algorithms. Marker representation is used for representing the output of sensor processing algorithms, for representing a model of environment and obstacles around the robot, and for representing information related to the robot’s tasks.

The Evolutionary Active Materials

The Evolutionary Active Materials (EAM) project, which is funded by the Academy of Finland, is a joint effort between the Computer Science and Engineering laboratory (CSE) and the Microelectronics and Materials Physics laboratories. The aim of the EAM project is to develop novel, evolutionary computation (EC) based design methods for active and versatile materials and structures. The first components are being developed through a novel holistic design process utilizing constantly increasing computation power, the development of multi-physics simulators, and EC techniques, such as genetic algorithms.

During 2013, a Cymbal type piezoelectric actuator was optimized by using a combination of a genetic algorithm and FEM modelling software Comsol Multiphysics. From the optimized results, maps of electromechanical capabilities of different structures were generated. The blocking force of the actuator was maximised for different values of displacement by optimizing the height of the cap and the length flat region of the end cap profile. By using values obtained from a genetic algorithm optimization process, a function was formulated for design parameters. Using the function, a map of displacement, the steel thickness and the height of the end cap the optimized length of flat region was constructed (Figure 9). A similar map with the length of the flat region for the optimized height of end cap was created (Figure 10).

Also parameters of a new structure called “mikbal” were optimized with a genetic algorithm. The advantage of mikbal compared to Cymbal is its ability to generate large displacements using less piezo material than Cymbal. With a 25 mm piezo diameter and 40 mm steel diameter mikbal produces 114 µm displacement. Cymbal with 25 mm diameter generates only a 67 µm displacement and Cymbal with 40 mm produces 189 µm.

Research on human-environment interaction

Our current work on human-environment interaction focuses on physical user interfaces and human-robot interaction. In physical user interfaces, mobile terminals are used as physical objects rather than as traditional I/O devices. Our current studies concentrate on touch-based interaction: users interact with the local environment by touching objects with their mobile terminals. The touch-based user interfaces employ NFC technology (i.e. RFID technology for mobile phones): an act of touching brings an NFC reader near an NFC tag, and hence the data in the tag is read and delivered to the system. The objects that can be
touched are advertised in the environment by NFC icons, graphical icons resembling the icons of the graphical user interfaces of computers and other user terminals.

In 2013, we have focused our research on building innovative user interfaces for learning environments in which learner’s engagement, social interaction and collaboration among learners are emphasized.

We have also continued the development of two novel NFC devices, an Activity Pad and an NFC Mouse, together with Offcode Ltd, an Oulu based embedded systems company. This work was carried out in the Active Learning Spaces project funded by Tekes and coordinated by the University of Tampere. Moreover, we developed applications for the Activity Pad and the NFC Mouse in the Digital Services ICT SHOK, this project is also together with Offcode, the University of Tampere, and several other project partners. Furthermore, we continued our participation in the Future School Research Second Wave project that is funded by the European Social Fund and the City of Oulu, and coordinated by the Faculty of Education at the University of Oulu. We are also developing applications for NFC phones in these three projects.

The Activity Pad combines a 4x6 grid of programmable NFC readers together with printed sheets of A4-sized paper to allow teacher-driven creation of interactive learning applications featuring application-specific tangibles, and promoting co-located interaction. Teachers and students create study material using traditional methods; drawing on paper and molding objects from clay, for example. Once the material has been generated, a student first places a sheet of A4 paper on the pad; this paper presents a task, for example, a sentence with some missing words. The pad identifies the task in question from an NFC tag attached to the paper sheet. Then the student performs the task by placing pieces of paper or other objects augmented with NFC tags on the task paper. The pad reads the information from the tags and provides visual (LEDs) and audio feedback. Teachers can program their own pad applications easily by drawing a task paper, placing the paper and correct objects on the pad, and recording the correct answer (Figure 11).

The NFC Mouse is a portable device that enables reading NFC tags from the environment. Applications are stored in the device’s memory. A child starts an application by touching the corresponding NFC tag. Then s/he solves the given task by finding objects from the local environment and touching the NFC tags attached to these objects with the mouse. The device provides auditory, haptic and visual feedback (LEDs). We have also developed an intuitive GUI to program both devices by connecting jigsaw pieces. No knowledge of any programming language is needed to program the devices.

For NFC phones, we are developing situated mobile learning applications for adult education and training. This work is performed in the Active Spaces project together with Context Learning Finland. The applications enable learning experiences in which the virtual and real (i.e. physical) environments are interconnected. We have continued the work started last year, implementing and testing another application in order to instruct social workers about fire safety. NFC tags are placed behind posters on a training centre, and scenarios are prepared for each tag location as multimedia presentations. Each poster presents a situation that is linked to the physical place where it is located. When a trainee touches a tag with a phone, the application presents the corresponding multimedia presentation. Trainers can monitor the progress of the learners at any time.

In the Digital Services ICT SHOK, we have developed a second version of NFC-ACT, an authoring tool targeted at primary school teachers. This PC application can be used to create NFC-enabled learning games for mobile phones. The games follow the same structure: a game presents a challenge on the phone screen and the child solves the challenge by touching the correct NFC tag among the tags placed on objects in the environment. Teachers create games by defining the application flow and the multimedia content to be shown on the screen at each stage. This tool can also be used to write the NFC tags using an external NFC reader, and to deploy the games to children’s mobile phone using Bluetooth. Furthermore, in this project we have tested a peer-to-peer WiFi connectivity solution in order to distribute learning content among a group of children and their teachers using low-end phones. Children solve questions proposed in exercises and send the results to teachers.

In the Future School 2nd Wave, we have continued our collaboration with researchers from the Department of Education and with teachers to create NFC based learning games for pupils with heterogeneous backgrounds (ages from 7 to 12, different nationalities). Our aim is to enhance learning Finnish, which the target group is acquiring as a second language. The teachers have used the games as tools to introduce vocabulary (colours, body parts, Christmas words, etc.) to the pupils.

We have also created a similar NFC based application for cognitive stimulation of elderly. We collected audio and pictures from well-known people, TV programs, and events from the 50 s and 60 s to stimulate short-term and long-term memory recall. We printed pictures and placed
NFC tags behind them. When the users touched the tag with the phone a corresponding audio was triggered. Our research results show that this type of application also promotes social interaction among the elderly.

We continued our work on a general purpose data visualization framework in the Internet of Things ICT SHOK. The purpose of this framework is to simplify the creation of systems that connect user-specific data from data sources to visualization applications, or other applications that modify their behaviour based on data input. In 2013, we used this framework to build a new prototype. Our agenda was to work with games and game-like concepts where users can play with their data. Instead of merely seeing visual improvement, users can now turn their behavioural progress into virtual furniture and game pieces. In our prototype, users furnish and energize a virtual office (Figure 12).

Figure 12. This chaotic office is from our month long testing period with Laturi Corporation. Coloured portions of the office are energized.

In general, motivational games can be more involving than simple visualizations. In addition to creating the game prototype, we were able to discover design principles that should be taken into account when creating games and other interactive applications that use sensor data in what can be described as an after-the-fact fashion.

We also started working on a general framework for visualizing the status of IoT systems in two different methods: a 3D virtual environment implemented on the RealXtend platform, and a 360-degree panorama picture in mobile phones. We started exploring the visualization possibilities by using data from a home environment provided by a ThereGate device (Home Energy Management System (HEMS) gateway), Finwe Key2phone (a lock system operated by mobile phones) and taxi traffic information collected from sensors in the city of Oulu. We are developing a general architecture for collecting, storing and visualizing data acquired from the home environment. Figure 13 shows an example of the power consumption visualized in the RealXtend environment and panorama pictures visualizing power consumption and taxi activity. Visualized data can help the user form a general picture of the underlying system. For example, visualizing real-time power consumption on home appliances can motivate people to use the devices in a smart and more energy-efficient way.

We continued exploring smart space interaction, specifically how knowledge-based technologies enable smart spaces not only to adapt their behaviour according to the actions of users, but also to initiate interaction when necessary. Moreover, we continued exploring the usage of metareasoning concepts in ubiquitous systems. A real prototype of a traffic-related system, which implements our ideas, is under development. Also, we started to explore how metareasoning concepts can support ubiquitous learning systems, making them more useful for both students and teachers.

Research on situation awareness

Understanding behaviour and patterns in our everyday environment is essential in human-computer interaction, and our approach is to utilize different kinds of sensor networks to enable advanced services that utilize this knowledge. Naturally, the possibilities that emerge from collecting data from the environment bring also challenges as big data processing requires special knowledge about big data storage and distributed data processing. One of our most interesting application areas is traffic, as several different actors produce large amounts of data continuously. In 2013, we continued work in the Internet of Things ICT SHOK and the Data to Intelligence ICT SHOK.

In the Data to Intelligence SHOK, we are working on collecting, processing and storing traffic related data from the city of Oulu region. We have built a Cloud service for storing real time information collected by taxi cabs operating in the city. We have developed, together with our project partners (several ITS companies and universities), the Oulu Traffic Pilot that realizes data collection from moving objects, digital maps, weather and environmental sensors, and it visualizes the cleaned and analysed information on a web client (Figure 14). Together with our partners, we are designing more flexible ways of storing, processing and possibly selling the data and analysis results.
We are studying adding semantics to Internet of Things systems, specifically how the benefits of semantics can be enjoyed without sacrificing energy efficiency and short latencies. We utilize the existing Semantic Web technologies, as their interoperability allows application developers to use nodes implemented and deployed by others. In 2013, we built a system connecting sensor nodes to knowledge-based components and in this system evaluated different data formats in terms of their semantic expressivity and resource consumption. This work suggests to IoT application developers data formats offering the best compromise between the usually conflicting characteristics of good expressivity and modest resource requirements. Moreover, we are studying an approach to transforming one well-known sensor data format SenML (Media Types for Sensor Markup Language) to Semantic Web representations (Figure 17). Hence, many intelligent IoT applications can be built on SenML-enabled devices.

Different kinds of statistics can be derived from the moving object data. The dangerous/safe spots, congestion areas, areas of high deceleration, etc. can be found when vehicle data is collected. It is also interesting to try to find how this information can be used in taxation, as well. When social network data is fused to physical data, the possibilities are extended.

We extended our previous research on the UBI-AMI v2 wireless sensor network-based home energy consumption monitoring application, where the benefit is offering a holistic real-time view of the energy consumption of a building and, on the other hand, of the individual household appliances. The holistic view presents real-time and historical energy consumption apartment-wide, as often...
the infrastructure elements, such as heating or saunas, are the most energy consuming elements in comparison to the individual everyday appliances. This architecture is based on ideas of dynamically configuring the wireless sensor network for particular applications, and dynamically composing sensor-based services from the sensor data. Users can monitor their individual energy usage and inject user-defined computational tasks into the system in runtime from a Web service. The tasks are represented by mobile agents, migrating in the system devices based on their resource utilization, and are capable of both sensing and actuation. The agents inherently distribute the computational load in the participating devices in the system, which additionally contributes to the energy saving in the wireless sensor network infrastructure.

In the MAMMOTH project, we continued research on distributed system architectures for the M2M systems and the Internet of Things. This architecture is based on the above idea of a generic software framework, enabling the use of mobile agents as the user or application defined computational task representation. We extended the software framework with mobile sensing platforms, such as smartphones, towards generic IoT devices. The framework enables utilization of heterogeneous data sources, including low-power resource constrained wireless sensor platforms, as data producers for the IoT ecosystem. This sensor-based or refined data can be utilized by data producers in their applications, or by the dynamically injected mobile agents in their computations locally in the IoT devices (Figure 18). Additionally, we studied mobile agents-based smart objects in the IoT environment and demonstrated an evaluation method for the assessment of energy efficient resource utilization in the smart spaces on top of the IoT ecosystem. The work with the UBI-AMI v2 system, and the activities in the MAMMOTH project were conducted in co-operation with MediaTeam.

![Figure 18. The developed software framework for IoT applications.](image)

During the year 2013, we started co-operation with the University of Tokyo and Aoyama Gakuin University, and continued our previous co-operation with the Tokyo Denki University in Japan, as one of our doctoral students, Teemu Leppänen, was a visiting research associate with the Institute of Industrial Science at the University of Tokyo. This work included studying energy efficient participatory sensing applications with the mobile sensing platforms and mobile agents, furthermore extending the above mentioned software framework.

**Research on data mining**

**GlobalRF:** In 2013, the Global Spectrum Opportunity Assessment (GlobalRF) project has started. GlobalRF is a collaborative research project with a joint effort undertaken by WiFiUS (Wireless Innovation between Finland and U.S.), leveraging research and education sources in Finland and the U.S. in the area of wireless communications. The collaborating institutions are the Illinois Institute of Technology (IIT) and the Virginia Polytechnic Institute and State University (Virginia Tech) in the U.S., and the VTT Technical Research Centre, Turku University of Applied Sciences, and the University of Oulu in Finland. All these institutions have ongoing research and education programs in wireless communications, and bring significant expertise and resources to the proposed project.

Currently the data analysis and inference group is working with large-scale statistical analysis in the GlobalRF project where a fundamental radio frequency (RF) spectrum shortage problem is tackled by developing methods for understanding the current and evolving use of the spectrum in various environments. The study consists of a combination of the RF spectrum data with open data, such as human behaviour (e.g., mass events) and weather (e.g., extreme weather conditions), to discover different correlations, possible anomalies and variables explaining frequency band usage in both the frequency and temporal domains (e.g., multi-dimensional time-series). Moreover, the research in the area includes the development of big data management, processing, and visualization tools, as well as building predictive models to realize novel ways and guidance for dynamic sharing of spectrum usage. Conversely, RF spectrum measurement (and open datasets), intelligent data analysis and machine learning algorithms could provide novel ways to model environmental and human related contextual variables in urban city areas. At the moment, RF measurement units are installed in downtown Chicago and Turku, producing ongoing data for analysis.

**New methods for activation of young men:** the multi-disciplinary MOPO project combines traditional health promotion, modern technology and the measurement of physical activity. The aim of the study is to provide knowledge about physical activity, the attitude towards physical activity, information behaviour, fitness, health, nutrition, life habits and cultures of young men. A novel wellness coaching service for preventing marginalization and promoting physical activity and health in young men is being developed in the project. The information obtained in the study can be used to promote the wellness of young adults in education, and in the study and decision-making of professionals in social and health services.

Altogether about 6000 conscription aged men (five call-up age classes) have been/will be invited to participate in the MOPO study. The condition, wellbeing, health, relationship towards physical activity, information behaviour and the use of media and technology will be clarified during the years 2009–2014 with questionnaires, measure-
ments and interviews. The contents of the service network were developed together with the city of Oulu, conscription aged men and several companies.

The data mining group has been responsible for the development of a gamified webportal for mobile phones (Figure 19). Young men collect data about their daily activity using a wrist worn Polar Active, or a mobile application developed by ISG. The mobile application recognizes the user’s daily activities (walking, running, biking, riding a car and idling) using mobile phone accelerometers. The algorithms used in the recognition process are independent of the user, phone location and the mobile phone’s operating system. Information about daily activity is uploaded to the portal, and based on the data, tailored feedback is given to the user. In addition, through the mobile webportal, tailored information, for instance about health, and nutrition, is given to the user. As mentioned, the portal is gamified: based on physical activity and activity in the portal, points are given to the user. These points can be used in a mobile game called “Clans of Oulu” where different clans are trying to conquer the city of Oulu, Figure 20. The game has been developed by LudoCraft.

For several years now, one of the interests of ISG in data mining research has been the study of ethical issues associated with data mining. These include the well-established issue of protecting the privacy of data subjects, and also a number of previously overlooked issues such as fairness and trust. The ethics research of ISG also emphasizes the potential of data mining as an instrument for pursuing things of value rather than just a threat to values that needs to be controlled. All these perspectives are combined in the MOPO projects: the outcome of the project, a persuasive video game, may help the study subjects adopt healthier lifestyles, but its development involves potential ethical problems that must be actively identified and worked against. An ethical analysis of the technical work in the project is being carried out and will be published alongside the work itself.

Operators of the study are the Oulu Deaconess Institute’s Department of Sports and Exercise Medicine, the University of Oulu, the City of Oulu, the Virpiniemi Sports Institute, the Finnish Defence Forces and wellness technology companies from Northern Finland. The project website can be found from www.tuunaamopo.fi.

Data mining methods for steel industry applications: the Intelligent Systems Group is a member of the Centre for Advanced Steels Research - CASR, which is one of the interdisciplinary umbrella organizations of the University of Oulu. In 2013, together with other groups in CASR, an application for a large national research programme System Integrated Metal Production – SIMP was prepared. SIMP focuses on metal processes, and related model and algorithms creation, which requires advanced mathematics and chemistry research. The actual quantum jump in the industry’s competitiveness requires resolution of ICT technology related challenges i.e. real time adaptation of process simulation and multi-physics models, multidimensional sensor data analysis and handling over the production systems, big data reduction methods, multivariate
analysis tools, prediction of product quality solutions, etc. The programme budget is 43.8 M€ and its duration is 5 years from the beginning of 2014. There are 19 companies and SMEs participating, 7 Finnish academic and research institutions and 31 international participants that will improve the profitability of the industry (Figure 21).

There were two PhD studies that developed data analysis solutions for the needs of the steel industry. In the first of the two PhD studies, the topic is the modelling of the quality of steel products in extreme conditions of a rolling mill. The goals of the study lie in the development of new data analysis methods in the steel manufacturing processes, such as modelling of hot steel plate rolling schedules and the flatness of the steel plate or strip. So far, the temperature model for the steel plate during the rolling process has been made, and it has achieved a prediction accuracy of about 20 degrees for the whole pass schedule, and 16 degrees for the last rolling passes. This is a major improvement in comparison to earlier attempts. Additionally, significant efforts have been made to find features that describe the rolling process and enable the prediction of the temperature at different stages of the rolling. The compression of the history of the pass schedule has been one of the most challenging feature extraction tasks. The results show that the features that sum over the whole pass schedule are most important.

During the study, the problem of missing data has been considered. The measurements of rolling temperature contain a large amount of missing values due to the hot and moist conditions of the rolling process. By employing semi-supervised learning, the information contained in the observations with missing response measurements was utilized to improve the learning process by employing the COREG-algorithm. Such learning methods utilize both the labelled and the unlabelled data to produce better learners than those using only the labelled data. As a result, a slight increase in the prediction accuracy was observed. The lack of reliable measurements is a relevant issue in many rolling mills.

The future research will concentrate on two-dimensional quality properties like shape and flatness as a part of the SIMP-programme. The industrial partners for the research are Ruukki Metals, Raahe Works and Outokumpu Stainless Oy, Tornio.

The other PhD study concerns methods for exceedance probability estimation in the case of multiple measurement test sets. The situation may occur when the variability of the quality within the product is high, and thus, traditional point prediction based modelling methods are not sufficient. Density forecasting methods are needed when not only the mean, but also the deviance and the distribution shape of the response depend on the explanatory variables.

In the research, the impact toughness of the steel products has been modelled. The rejection probability in the Charpy-V quality test has been predicted with mean and deviation models, a distribution shape model and a quantile regression model. The proposed methods have been employed in two steel manufacturing applications with different distributional properties, and it has been shown that especially the case with diverse product assortment benefits from the distribution modelling. The industrial partners of the research are Ruukki Metals, Raahe Works and Ovako, Imatra. The thesis was sent to pre-examination in September.

Cognitive load study: Eija Ferreira is collaborating with Prof. Anind K. Dey from the Human-Computer Interaction Institute of Carnegie Mellon University (USA) to study how to assess the cognitive load of a person in real-time, based on psycho-physiological measurements. Task interruption, divided attention and multitasking cause split attention that increases our cognitive demands. This is a problem, especially while performing tasks during which momentary meandering can have serious consequences (e.g. driving, manoeuvring heavy machinery, controlling air traffic, walking in traffic, performing surgery, etc.). The ability to measure real-time changes in the cognitive load of individuals provides a key tool to help mediate our attention resources while performing cognitive intensive tasks (Figure 22). In addition, our cognitive abilities change as we age. Therefore, understanding issues of attention demand is particularly essential for the elderly. Our research has shown that it is possible to build systems that respond to changes in a person’s cognitive load at a time granularity of 10 seconds, and that the same tools and sensors can be used to assess cognitive load for both younger and older adults.

Figure 21. A steel plate during manufacturing.

Figure 22. Real-time cognitive load assessment has wide applications in predicting drivers' ability to maintain vehicle control.
Management of semantic data in virtual environments: In the Reaxity (Future City as Open Mixed Reality Space) project, ISG is working as part of a multi-disciplinary consortium to create concepts and enabling technologies for mixed reality-based services in future urban spaces. The project is funded by Tekes as a small strategic opening, and it focuses initially on developing demonstrations of innovative service concepts and roadmaps for future work. In the next phase, the goal is to secure funding for a large strategic opening, and then proceed to pursue the long-term vision of the project by following the roadmaps.

The role of ISG’s data mining researchers in Reaxity is to study questions related to the management of semantic metadata in mixed reality (MR) spaces. Semantic metadata is used to encode the meaning of MR objects in a machine-readable format, making it easier, for instance, for a user to discover relevant services and content. The principal questions to be answered are: how the metadata is authored, how it is represented, and how it is incorporated in MR objects. By designing and prototyping a metadata management solution that addresses these questions, ISG is participating in the development of an open technology platform for MR applications in future cities.

Research on software security

Within the Intelligent Systems Group, the Oulu University Secure Programming Group (OUSPG) has continued research on security and safety in intelligent systems. Security and safety challenges in intelligent systems are threefold: increasing complexity leads to unforeseeable failure modes, quality is not the priority and awareness is lacking. We have approached the challenges from these three directions in our research.

Complexity - Model Inference and Pattern Recognition: we work under the premises of unmanageable growth in software and system complexity and emergent behaviour (unanticipated, not designed) having a major role in any modern non-trivial system. We have worked on natural science approaches to understanding artificial information processing systems. We have developed and applied model inference and pattern recognition to both content and causality of signalling between different parts of systems.

Quality - Building Security In: software quality problems, wide impact vulnerabilities, phishing, botnets, and criminal enterprise have proven that software and system security is not just an add-on, despite the past focus of the security industry. Instead, security, trust, dependability and privacy have to be considered over the whole life-cycle of the system and software development, from requirements all the way to operations and maintenance. This is furthermore emphasized by the fact that large intelligent systems are emergent and do not follow a traditional development life-cycle. Building security in not only makes us safer and secure, but also improves overall system quality and development efficiency. Security and safety are transformed from inhibitors to enablers. We have developed and applied black-box testing methods to set quantitative robustness criteria. International recognition of the Secure Development Life Cycle has provided us with a way to map our research on different security issues.

Awareness - Vulnerability Life Cycle: Intelligent systems are born with security flaws and vulnerabilities, new ones are introduced, old ones are eliminated. Any deployment of system components comes in generations that have different sets of vulnerabilities. Technical, social, political and economic factors all affect this process. We have developed and applied processes for handling the vulnerability life-cycle. This work has been adopted in critical infrastructure protection. Awareness of vulnerabilities and the processes to handle them all increase the survivability of emergent intelligent systems for developers, users and society.

These research goals are reached through a number of research activities.

Secure Software Development Lifecycle in Cloud Computing as part of the Cloud Software project - we approach all three goals by researching practical ways of building security into complex Cloud Computing services, from the design phase to actual operational use (Figure 23). This work culminated in a practical handbook of the Secure Agile Software Development Cycle.

Figure 23. Dependencies of a single cloud based web service visualized by technology and location.

Development and Industrial Application of Multi-Domain Security Testing Technologies (DIAMONDS) enabled efficient and automated security testing methods of industrial relevance for highly secure systems in multiple domains (including for example banking, transport or telecommunication). In particular, over 90% of software security incidents are caused by attackers exploiting known software defects. DIAMONDS addressed this increasing need for systematic security testing methods by developing techniques and tools that can efficiently be used to secure networked applications in different domains. DIAMONDS leveraged systematic, model-based testing and monitoring approaches for security testing to enable highly secure systems by early testing and test automation. Advanced model-based security testing and visualization methods allowed for the early identification of design vulnerabilities and efficient system/test design targeting security aspects (Figure 24).
Identification of a protocol gene: this research, PROTOS-GENOME, approaches the problems of complexity and quality by developing tools and techniques for reverse-engineering, and identification of protocols based on using protocol genes - the basic building blocks of protocols. The approach is to use techniques developed for bioinformatics and artificial intelligence. Samples of protocols and file formats are used to infer structure from the data. This structural information can then be used to effectively create large numbers of test cases for this protocol. In 2013, the project further developed the existing methodology, resulting in improvements in efficacy and discovering a number of vulnerabilities in web browsers.

Economic Models for Collaborative Access Network Provisioning (EMCANP) was launched in 2012 in cooperation with the Centre for Wireless Communications and the Virginia Polytechnic Institute and State University. The project explores the potential for capacity increase in heterogeneous wireless networks through increased collaboration, both among network operators and among end users. The task of OUSPG is to create a socio-technical security model for the purpose of identifying the information security threats involved in such collaboration and the appropriate responses to those threats. The chosen modelling approach is to adapt and apply the PROTOS-MATINE methodology, characterized by its ability to synthesize data collected from diverse sources, and it has previously proven effective when used to evaluate targets such as antivirus software and voice-over-IP systems. We are thus pursuing two objectives in parallel: to develop a new version of the methodology, and to use it to analyse the EMCANP case. We made progress toward both objectives in 2013.

Internet of Things studies security and privacy issues in large-scale sensor networks. Topics of interest are alternative ways of authentication, such as proof of work and cryptocurrencies, secure update mechanisms, software defined networking and related service-level agreements for data centres. The work brings together our research themes of Quality, Complexity and Awareness to an application area where resource limits are combined with global connectivity.

The Electric Vehicle ecosystem studies security and privacy issues involved in future infrastructures for charging and testing electric vehicles in northern environments, as well as associated end-user services. The work aims to bring our research themes into new application areas, where connectivity to a global infrastructure is applied to traditionally isolated systems.

Exploitation of Results

The results of our research were applied to real-world problems in many projects, often in collaboration with industrial and other partners. Efficient exploitation of results is one of the core objectives of the national Tivit ICT SHOK projects like Cloud Software, D2I and IoT; in these projects we work in close collaboration with companies throughout the projects.

The Intelligent Systems Group utilizes a robotics laboratory and a pressure-sensitive floor (EMFi material) installed in our laboratory as part of a smart living room. Other equipment includes a home theatre, two degree-of-freedom active cameras, four mobile robots and one manipulator, a WLAN network, and various mobile devices. Our aim is to gradually build a versatile infrastructure that offers various generic services for pervasive applications. Naturally, this kind of environment enables realistic experiments that lead to a better understanding of such applications.

We are also building an immersive space into our laboratory. This affordable cave is built from six white screens covering 360 degrees and six projectors, one for each white screen. We are currently adapting the realXtend 3D virtual environment platform for this setting.

During the reporting year, the group continued utilizing outdoor robotic systems. Development and utilization of Mörr, a multipurpose, high performance robot platform continued. More focus was put on perception in natural conditions, representation of detections, knowledge, and an environment model of the operating environment. The software architecture further developed the earlier work on Property Service Architecture, and the Marker concept as general purpose representation was further developed.

Future Goals

The partnership in the SIMP programme that belongs to the SHOK concept of Tekes enables us to continue our steel research into new areas. The new goals are in quality prediction at different process stages and for more challenging properties. As a result more advanced expert systems can be developed to aid the operators with different roles in steel making.

We will continue to strengthen our long term research and researcher training. We will also continuously seek opportunities for the exploitation of our research results by collaborating with partners from industry and other research institutions on national and international research programs and projects. The University of Oulu is a founding member of euRobotics. Juha Röning is a member of the Board of Directors of euRobotics.

We will strengthen our international research co-operation. Over recent years, the group has created collaborative projects with Japanese researchers. Two doctoral students have funding for one-year visits to Japanese universities. We will continue the collaboration with Sonic Studio from
Sweden and the Shanghai Jiao-Tong University from China. With the University of Tianjin in China, we have a joint project in which methods and a system will be developed for vision-based navigation of Autonomous Ground Vehicles, which utilize an omni-directional camera system as the vision sensor. The aim is to provide a robust platform that can be utilized in both indoor and outdoor AGV (Autonomous Ground Vehicles) applications. This co-operation will continue.

In the USA, we will continue to co-operate with the Human-Computer Interaction Institute in Carnegie Mellon University with Assistant Professor Anind K. Dey. The research is on human modelling in the area of human-machine interaction. We continue and strengthen US-Finland co-operation through an NSF grants. With Virginia Polytechnic Institute and State University we have our collaborative research project on Techno Economic Models for Collaborative Access Network Provisioning. In 2013, we started another US-Finland project: NSF EAGER: Global RF Spectrum Opportunity Assessment.

Shorter research visits to European partners in EU-funded projects are also planned.

In 2014, the aim is to utilize more widely the know-how from sensor technology and data mining. New application areas will be studied, including rehabilitation, exercise motivation and energy efficiency in households, and the benefits of our expertise will be highlighted to actors in the areas.

In human-environment interaction and sensor networks, our research will continue mainly in Tekes and ICT SHOK projects. Our main goals are to develop analysis methods for sensor network data and to develop applications utilizing physical user interfaces. Research on novel software architectures, reasoning and knowledge representations will continue as well. Field trials in realistic settings, and close collaboration with research groups (national and international) and companies will be emphasized.

**Personnel**

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**Doctoral Theses**


**Selected Publications**


Background and Mission

The Center for Machine Vision Research (CMV) is a creative, open and internationally attractive research unit. It is renowned world-wide for its expertise in computer vision.

The center has a strong record, which now spans for over 32 years, of scientific merits on both basic and applied research on computer vision. It has achieved ground-breaking research results in many areas of its activity, including texture analysis, facial image analysis, geometric computer vision, and energy-efficient architectures for embedded systems. The mission of the center is to develop novel computer vision methods and technologies that create the basis for emerging innovative applications.

In February 2014, the CMV had three professors, one Associate Professor and one FiDiPro Professor, 16 senior or postdoctoral researchers, and 25 doctoral students or research assistants. The unit is highly international: 50% of our researchers (doctors, PhD students) are from abroad. CMV has an extensive international collaboration network in Europe, the USA, and China. The mobility of the researchers between leading research groups abroad, and vice versa, is intense. Within the Seventh Framework Programme FP7, the CMV currently participates in the project consortium of Trusted Biometrics under Spoofing Attacks (TABULA RASA). It also participates in two European COST actions.

The main areas of our research are computer vision methods, human-centered vision systems and vision systems engineering. The results of the research have been widely exploited in industry, and contract research forms a part of our activities.

Highlights and Events in 2013

In September, the Center for Machine Vision Research (CMV) was re-selected to Infotech Oulu for the period of 2014-2017, attaining the highest score among all applicant groups. In January 2014, the results of the Research Assessment Exercise (RAE 2013) of the University were released. An international panel, aided with a bibliometric analysis made by Leiden University, ranked CMV with the highest score 6 (outstanding), representing the international cutting edge in its field.

CMV played a significant role in the ninth Conferment Ceremony of the University of Oulu in May. Professor Matti Pietikäinen acted as the Conferer of Degrees for the Faculty of Technology. Dr. Juho Kannala was chosen as Primus Young Doctor - the first young doctor whose degree was conferred in the ceremony - chosen according to his excellent merits. The University honored distinguished scientists or influential members of society with the award of an Honorary Doctorate. CMV core partner, Prof. Stan Z. Li (Chinese Academy of Sciences), received this award for his contributions to image pattern recognition and biometrics.

Two of the CMV senior researchers strengthened their role as independent team leaders. Dr. Guoying Zhao received a tenure track position as Associate Professor at the University of Oulu from January 2014 until the end of 2018. Dr. Abdenour Hadid received five-year Academy of Finland Research Fellow funding from September 2013 onwards. Both positions were highly competitive.

The IET Biometrics Premium Award 2013 was given to CMV. The Institution of Engineering and Technology (IET) presents one Premium Award per each for its journal to recognize the best research papers published during the previous year. CMV’s winning paper “Face spoofing detection from single images using texture and local shape analysis” is authored by Jukka Komulainen (né Määttä), Abdenour Hadid and Matti Pietikäinen. It was published in 2012 in the IET Biometrics journal, volume 1, issue 1. The winners were given a certificate at the 2013 IET Achievement Awards in London in November.

CMV has had a significant role in the TABULA RASA project, appraised as a success story by the European Commission and followed by a large media campaign. The consortium comprises 12 different organizations across seven countries that have worked together over a period of three years in improving the security of biometric systems.

CMV has provided expertise in both face and gait recog-
nition using Local Binary Patterns in developing ways to
detect the spoofing attacks. The same LBP methodology
has also been utilized by other TABULA RASA partners.
In addition, CMV has led the work package in evaluating
the vulnerabilities in current biometric systems.

CMV contributed significantly to the 18th Scandinavian
Conference on Image Analysis (SCIA 2013), organized in
June in Espoo, Finland. The CMV Leader, Prof. Matti Pieti-
käinen co-chaired the SCIA conference with Prof. Erkki
Oja. CMV Vice Leader, Prof. Janne Heikkilä acted as one
of the area chairs. Prof. Pietikäinen and Dr. Guoying Zhao
lectured in a tutorial “Image and video analysis with local
binary patterns”. CMV researchers presented altogether as
many as ten papers.

Scientific Progress

The current main areas of research are: 1) Computer vision
methods, 2) Human-centered vision systems, and 3) Vi-
sion systems engineering. In addition to these main areas,
our research activities include biomedical image analysis
where we collaborate with Biocenter Oulu.

Computer vision methods

The group has a long and highly successful research tradition
in two important generic areas of computer vision: texture
analysis and geometric computer vision. In the last few
years, the research in computer vision methods has broadened to cover also two other areas: computa-
tional photography, and object detection and recognition.
The aim in all these areas is to create a methodological
foundation for the development of new vision-based tech-
nologies and innovations.

Texture analysis

Texture is an important characteristic of many types of im-
esages and can play a key role in a wide variety of applica-
tions of computer vision and image analysis. The CMV
has long traditions in texture analysis research, and ranks
among the world leaders in this area. The Local Binary
Pattern (LBP) texture operator has been highly successful
in numerous applications around the world, and has in-
spired plenty of new research on related methods, includ-
ing the blur-insensitive Local Phase Quantization (LPQ)
method, also developed at CMV.

We proposed a simple and robust local descriptor, called
the robust local binary pattern (RLBP). The basic LBP
works successfully in many domains, such as texture clas-
sification, human detection and face recognition. How-
ever, an issue of LBP is that it is not so robust to the noise
present in the image. We improved the robustness of LBP
by changing the coding bit of LBP. Experimental results
on the Brodatz and UIUC texture databases show that
RLBP outperforms other widely used descriptors (e.g.,
SIFT, Gabor, MR8 and LBP) and other variants of LBP
(i.e., completed LBP), especially when we add the noise
in the images. In addition, experimental results on human
face recognition also show a promising performance, com-
parable to the best known results on the Face Recognition
Grand Challenge (FRGC) dataset.

Recently, local quantized patterns (LQP) was proposed
for using vector quantization to code complicated patterns
with a large number of neighbors and several quantization
levels. It uses a lookup table technique to map patterns into
the corresponding indices. Since LQP only considers the
sign-based difference, it misses some discriminative infor-
mation. We proposed completed local quantized patterns
(CLQP) for texture classification. The magnitude and ori-
entation-based differences are utilized to complement the
sign-based difference for LQP. In addition, vector quanti-
ization is exploited to learn three respective codebooks for
local sign, magnitude and orientation patterns. For reducing
the unnecessary computational time of initialization,
we used preselected dominant patterns as the initialization
in vector quantization. Our experimental results show that
CLQP outperforms well-established features, including
LBP, LTP, CLBP and LQP on a range of challenging tex-
ture classification problems and an infant pain detection
problem.

For improving the accuracy of LBP-based operators by
including texture image intensity characteristics in the op-
erator, we proposed the utilization of a shifted step func-
tion to minimize the quantization error of the step function
to obtain more discriminative operators. Features obtained
from the shifted step function are simply fused together
to form the final histogram. This model is generalized,
and can be integrated with other existing LBP variants to
reduce quantization error of the step function for texture
classification. The proposed method is integrated with
multiple LBP-based feature descriptors, and evaluated on
publicly available texture databases (Outex_TC 00012
and KTH-TIPS2b) for texture classification. Experimental
results demonstrate that it not only improves the perform-
ance of operators with which it is integrated, but it also
compares favorably to the state of the art in texture clas-
sification.
Dynamic texture (DT) is an extension of texture to the temporal domain. How to segment DTs is a challenging problem. We addressed the problem of segmenting DT into disjoint regions. DTs might be different from their spatial mode (i.e., appearance) and/or temporal mode (i.e., motion field). To this end, we developed a framework based on the appearance and motion modes. For the appearance mode, we use a new local spatial texture descriptor to describe the spatial mode of DT; for the motion mode, we use the optical flow and the local temporal texture descriptor to represent the temporal variations of DT. In addition, for the optical flow, we use the Histogram of Oriented Optical Flow (HOOF) to organize them. To compute the distance between two HOOFs, we developed a simple, effective and efficient distance measure based on Weber Law. Furthermore, we also addressed the problem of threshold selection by proposing a method for determining thresholds for the segmentation method by offline supervised statistical learning. Experimental results show that our method provides very good segmentation results compared to the state-of-the-art methods in segmenting regions that differ in their dynamics.

Illustration of DTs; (a) DTs are different in their spatial mode (i.e., appearance) but show a similar temporal mode (i.e., motion), (b) DTs are different in their temporal mode but show a similar spatial mode, and (c) the similar temporal/spatial mode of DTs are cluttered.

Video texture synthesis is the process of providing a continuous and infinitely varying stream of frames, which plays an important role in computer vision and graphics. However, a challenging problem remains in generating high quality synthesis results. Considering the two key factors that affect the synthesis performance - frame representation and blending artifacts, we improved the synthesis performance from two perspectives: first, effective frame representation is designed to capture both the image appearance information in the spatial domain and the longitudinal information in the temporal domain. Second, artifacts that degrade the synthesis quality are significantly suppressed based on a diffeomorphic growth model. The proposed video texture synthesis approach has two major stages: the video stitching stage and the transition smoothing stage. In the first stage, a video texture synthesis model is proposed to generate an infinite video flow. To find similar frames for stitching video clips, we presented a new spatial-temporal descriptor to provide effective representation for different types of dynamic textures. In the second stage, a smoothing method is proposed to improve synthesis quality, especially from the point of view of temporal continuity. It aims to establish a diffeomorphic growth model to emulate local dynamics around stitched frames. The proposed approach is thoroughly tested on public databases and videos from Internet, and is evaluated in both qualitative and quantitative ways.

Overview diagram of the whole DT synthesis method, which consists of two main steps: video stitching using a Multiframe LBP-TOP signature (left), and transition smoothing using deformable image registration and growth model estimation (right).

Computational photography

In computational photography, the aim is to develop techniques for computational cameras that give more flexibility to image acquisition and enable more advanced features to be employed, going beyond the capabilities of traditional photography. These techniques often involve use of special optics and digital image processing algorithms that are designed to eliminate the degradations caused by the optical system and viewing conditions. In our recent work, new imaging solutions such as microlens array based sensing technology, and novel algorithms for facilitating image acquisition, coding and reconstruction have been the key areas of interest.

In our research related to light field imaging, we have investigated techniques for compression of light field images. In particular, our work has addressed an asymmetric scenario where the encoder should have low computational complexity, allowing its implementation on resource-limited devices. In the first phase, we have surveyed potential techniques, such as sampling approaches, image transforms, distributed source coding and compressed sensing techniques for the purpose.

In addition to the further development of microlens array based detection of parasites on a mobile platform, the
automatic parasite detection was studied in collaboration with the Institute for Molecular Medicine Finland and the Karolinska Institute. The on-chip imaging was successfully used to detect Schistosoma haematobium eggs. The future studies will be focused on improving the result image quality for data captured with the microlens array cameras and data captured with in-line holography.

Image registration is one of the most important and most frequently discussed image processing topics in the literature, and it is a crucial pre-processing step in all image analysis tasks in which the final information is obtained from a combination of various data sources, like image fusion, change detection, multichannel image restoration, superresolution, etc. In many cases, the images to be registered are inevitably blurred. The blur may originate from camera shake, scene motion, inaccurate focus, atmospheric turbulence, sensor imperfection, low sampling density and other factors. We developed an original registration method designed particularly for registering blurred images. Our method works for unknown blurs, assuming the PSF’s exhibit N-fold rotational symmetry. We proved experimentally its good performance which is not dependent on the amount of blur.

Two images blurred by two different symmetric PSF’s (left and middle). The result of multichannel blind deconvolution after registering the two images with our method (right).

Object detection and recognition

Just by glancing at an object, for example an apple or a building, a human is immediately aware of many of the object qualities. For instance, the apple may be red or green, and the building may be made of concrete or wood. These properties can be used to describe the objects and further qualify them. Currently, even the best systems for artificial vision have a very limited understanding of objects and scenes. For instance, state-of-the-art object detectors model objects as distributions of simple features (e.g., HOG or SIFT), which capture a blurred statistics of the two-dimensional shape of the objects. Color, material, texture, and most of the other object attributes are likely ignored in the process. Fine grained object classification and attributes have recently gained a lot of attention in computer vision, but the field is still in its infancy. For instance, currently there are only a few small databases.

Our research objective is to develop novel methods to reliably extract a diverse set of attributes from images, and to use them to improve the accuracy, informativeness, and interpretability of the object models. The goal is to combine advances in discrete-continuous optimization, machine learning, and computer vision, to significantly advance our understanding of visual attributes and produce new state-of-the-art methods for their extraction. We do this in three ways: by developing learning approaches, which utilize mid-level image segments to automatically find the combination of object parts that correspond to, possibly small, differences between two object classes (e.g. two bicycle models); by utilizing dependencies for learning complex attribute combinations using structured output models; by using crowd sourcing tools to discover a comprehensive vocabulary that is used by humans to describe objects when performing a particular task (e.g. browsing bicycle catalogue).

In 2012, CMV researchers participated in a workshop led by Prof. A. Vedaldi at Johns Hopkins University. As a part of the workshop, we began to collect a new extensive dataset that is intended to serve as a benchmark for detailed object attribute and part recognition. Part of this data was published in the Fine-Grained Visual Categorization workshop, organized in conjunction with the Conference on Computer Vision and Pattern Recognition (CVPR) 2013. This data also became a part of the ImageNet FGVC challenge, which was in conjunction with the International Conference on Computer Vision (ICCV) 2013.

Efficiency is one of the key issues for real-time object detection. Although nonlinear classifiers are more powerful than the linear ones, few existing methods integrate them as the weak classifiers into the commonly used boosting framework. The reason mainly lies in that the conventional nonlinear classifiers usually have high computational costs. To address this problem, we proposed an efficient nonlinear weak classifier, named the Partition Vector weak Classifier (PVC). PVC is a weighted combination of a series of additive kernel functions of the (input) feature vector with respect to a set of pre-defined vectors, namely the Partition Vectors (PVs). The PVC’s learning includes three key steps: encoding, hyper-plane learning, and decoding. The obtained classifiers can be further accelerated using piecewise constant functions, such that it ensures a computational cost proportional to the dimension of the features during evaluation, as do the conventional linear classifiers.

PVC learning. (a) Encoding maps samples in the original space to the implicit space. (b) Learning the hyper-plane using the encoded samples in the implicit space. (c) Decoding transforms the learnt hyper-plane to the original space.

We demonstrated our algorithm in detection tasks for multiple classes of objects, including pedestrians, cars, bicycles, and cows, as illustrated below. Experimental results show that the boosted PVC significantly improves both the learning and evaluation efficiency of nonlinear SVMs to the level of boosted linear classifiers, without losing any of the high discriminative power.
Geometric computer vision

Images are 2D projections of the 3D world, which makes inferring 3D information an ill-posed problem from a single viewpoint, and a challenging problem from multiple views. Geometric computer vision provides the tools for establishing the relationship between the image and the 3D scene. While the fundamental theory of geometric computer vision has been developed already in the previous century, still for example, automatic construction of 3D scene models from multiple photographs is a relevant problem, and is subject to active research. Furthermore, new depth cameras, such as the Kinect sensor, have boosted rapid progress in scene modeling. Intelligent machines that require 3D information from the environment are a natural application area for geometric computer vision. Another application area that has gained much attention in the last few years is mixed reality, where real and virtual objects co-exist in the same environment. Wearable computers such as Google Glass have created a strong demand for such technology. Mixed reality has been also the key driver in our recent work on geometric computer vision.

During the last year, we have been developing a method for creating reconstructions from multiple photographs. Our previous method published in ICPR 2012, which basically takes a set of images as input, and outputs a point cloud in three-dimensional space, was extended with a couple of improvements. The improvements make the point clouds both denser and more accurate, without notable loss in computational efficiency. Hence, compared with the state of the art, our method produces reconstructions of similar or better quality, and is significantly faster. During the year, we also studied methods for generating triangular meshes from point clouds. The goal in this part is to turn a point cloud into a compact and watertight mesh of connected triangles so that it could be used, for example, to create virtual reality models. The pipeline from a set of images to a triangular mesh is illustrated in the figure below.

Establishing point-to-point correspondence between images is a fundamental problem in many applications such as augmented reality. In the past decade, many local image detection/description techniques have been developed to detect locations in images that are suitable for matching and to describe the visual properties of those points using the local image region around them. Robustness and computational efficiency are the two main criteria for choosing a particular local descriptor for an application. The need for real-time speed on video stream data has led to the emergence of many fast descriptors (Random Ferns, ORB etc) using simple pixel level comparisons which can be computed and matched efficiently. But they are not robust against camera pose variation. Robust features like SIFT/SURF have been successfully used under many challenging conditions. These robust features are computationally expensive. Our recent study aims at exploring different ways of accelerating the point-to-point correspondence of a matching process involving robust descriptors. Our initial experiments with SIFT vs. ORB have provided some hope of achieving fast point matching using SIFT descriptors while maintaining a superior accuracy over ORB descriptors. We are in the process of expanding the scope of the experiments to larger datasets involving widely varying scenarios.
Human-centered vision systems

In future ubiquitous environments, computing will move into the background, being omnipresent and invisible to the user. This will also lead to a paradigm shift in human-computer interaction (HCI) from traditional computer-centered to human-centered systems. We expect that computer vision will play a key role in such intelligent systems, enabling, for example, natural human-computer interaction, or identifying humans and their behavior in smart environments.

Face recognition and biometrics

CMV continued playing a key role in the FP7 EU project TABULA RASA which has recently been selected as a success story by the European commission. TABULA RASA aims at researching, developing and evaluating countermeasures for spoofing attacks against biometric systems. In this context, we have proposed and evaluated advanced countermeasures for face and gait biometric modalities. We also co-organized, jointly with UNICA from the University of Cagliari (Italy), a spoofing challenge at the International Conference on Biometrics (ICB 2013) which was held in Madrid in June 2013. The aim of the challenge was to demonstrate the effects of spoofing and anti-spoofing in fingerprint biometrics and to raise awareness of the spoofing threats to biometric systems.

An example of a mask that can be used to attack (spoof) a biometric system.

We hence continued exploring promising directions for face spoofing detection within the context of the TABULA RASA project, in addition to analysis of facial texture and motion patterns that have shown to be effective in our previous studies. As we humans rely mainly on scene and context information when performing spoofing detection, we have been investigating approaches for exploiting contextual information in face anti-spoofing. In our initial studies, histogram of oriented gradients (HOG) descriptors were used for describing distinctive discontinuities around the detected face and determining whether a natural upper-body profile or the boundaries of the spoofing medium is detected in the scene. The proposed countermeasure improved the state of the art and showed promising generalization capabilities also in cross-database evaluation. Moreover, it is reasonable to assume that no single superior technique is able to detect all known, let alone unseen, spoofing attacks. Therefore, we have been studying how different countermeasures could be combined in order to construct a flexible network of attack-specific spoofing detectors in which new techniques can be easily integrated to patch the existing vulnerabilities in no time when new countermeasures appear. Together with the ID-IAP Research Institute in Switzerland, we developed and published an open-source face anti-spoofing framework that includes several countermeasures and strategies for combining them. The same software framework was also successfully utilized in the 2nd Competition on Counter Measures to 2D Face Spoofing Attacks organized within the context of ICB 2013.

We also continued our research on recognizing human demographics (e.g. age and gender) from facial images with emphasis on local binary patterns (LBP). The most significant achievement in this domain is a method called the LBP kernel density estimate. Our extensive experiments showed very promising results especially in human age estimation, but also in texture classification and face recognition. The proposed method can be seen as an alternative to the widely used histogram representation, and it has potential in situations where the number of all possible local binary patterns producible by any given LBP operator exceeds the number of pixels in the image. The method provides an efficient way for preventing sparsity, which is a common problem with LBP histograms. The method also turned out to perform well with other LBP variants, for example, with CLBP, which is among the most powerful LBP variants.

Examples of automatically estimated age categories (ground truth in parantheses).

Recognition of facial expressions and emotions

The face is the key component in understanding the emotions, and this plays significant roles in many areas, from security and entertainment to psychology and education.

We proposed a method to detect facial action units in 3D face data by combining novel geometric properties and a new descriptor based on the Local Binary Pattern (LBP) methodology. The proposed method enables person and
gender independent facial action unit detection. The decision level fusion is used by employing the Random Forests classifiers to combine geometric and LBP based features. Unlike the previous methods, which suffer from the diversity among different persons and normalize features utilizing neutral faces, our method extracts features on a single 3D face data. Besides, we show that an orientation based 3D LBP descriptor can be implemented efficiently in terms of size and time without degrading the performance. We tested our method on the Bosphorus database, and presented comparative results with the existing methods. Our approach outperformed existing methods, achieving a mean receiver operating characteristic area under curve (ROC AuC) of 97.7%.

It is commonly agreed that emotions are a multimodal procedure. Combining complementary information from different modalities may increase the accuracy of emotion recognition. In the AFFECT project, funded by TEKES, we have been investigating the fusion of different modalities e.g., spontaneous facial expressions as an external channel and electroencephalogram (EEG) as an internal channel, supplementing facial expressions for more reliable emotion detection in long continuous videos.

Analysis of visual speech

Human speech perception is a bi-modal process which makes use of information not only from what we hear (acoustic) but from what we see (visual). In machine vision, visual speech recognition (VSR) is the task of recognizing the utterances through analyzing the visual recordings of a speaker’s talking mouth without any acoustic input. Although visual information cannot in itself provide normal speech intelligibility, it may be sufficient within a particular context when the utterances to be recognized are limited. In such a case, VSR can be used to enhance natural human-computer interactions through speech, especially when audio is not accessible or is severely corrupted.

Our research is focused on the extraction of a set of compact and informative visual features for VSR. To do that, the generative latent variable model is adopted to model the inter-speaker variations of visual appearances and those caused by uttering. Moreover, we propose to use a path graph to capture the temporal relationships of video frames. The low-dimensional continuous curve embedded within the graph is used as prior knowledge when constructing prior distributions of latent variables. Our method has been compared with the state-of-the-art visual features and has achieved superior results.
Visual speech can also be used for determining the identity of a person. A novel local spatiotemporal directional descriptor was proposed for speaker identification by analyzing mouth movements. For this new descriptor, the directional local binary pattern features in three orthogonal planes are coded. In addition, besides sign features, magnitude information encoded as weight for the bins with the same sign value is developed to improve the discriminative ability. Moreover, decorrelation is exploited to remove the redundancy of features. Experimental results on the challenging XM2VTS database show the effectiveness of the proposed representation for this problem.

As a part of the Future School Research Second Wave project, we have been developing a mobile multimodal recording system, called MORE. The MORE system is designed for observation and analysis of social interactions in real life situations, for example, to support pedagogic purposes. The MORE system provides a unique way of recording and analyzing information that consists of a 360 degree panoramic video and multiple audio channels. Furthermore, the software developed allows previewing, editing, and exporting of interesting events from the collected data. The system also provides a server backend and web interface for collaborative work. It gives the possibility to annotate both video and audio, and to store comments to be viewed by other experts. From the analysis point of view, the solution is designed to combine advanced signal analysis techniques, such as speech processing, motion activity detection, as well as face detection, tracking and recognition. The aim of these approaches is to speed up the exploration and analysis of a large material base with (semi-)automatic methods. Finally, one of the main advantages of the MORE is the ease of setup, as well as the mobile configuration when used as a carry-along device.

Human tracking and action analysis

Even though much work has been done for action recognition, minor efforts have been dedicated to understanding emotion from analyzing action, e.g. people’s walking. We have collected an affective gait database and designed descriptors to be robust against rotation and scale variations that occur during recording gait data in the real world while individuals are truly affected emotionally.

In order to improve the user experience with a large touchscreen, we introduced gesture interaction based on a Kinect sensor in a wall-sized touchscreen. According to the distance between the user and the display, we created two interaction modes: ‘Near-Mode’ for touch interaction; ‘Far-Mode’ for gesture interaction. With this solution, the interaction is more user-friendly and young users or users in wheelchairs are also able to interact with the large touchscreen applications.

Affective human-robot interaction

Development of our experimental HRI platform, Minotaurus, was continued with the support of the European Regional Development Fund (2010-2014) in collaboration with the Intelligent Systems Group. Minotaurus consists of a Segway Robotic Mobility Platform (RMP 200) and a set of laptops, Kinect sensors, video cameras, laser scanners, microphones, magnetic field sensors, a robot arm, an avatar display and a ubiquitous multi-camera environment.

During the last year of the project, the work continued to integrate various components to function together. We also developed methods of controlling the robotic arm using observations from Kinect sensor. We have successfully demonstrated that Minotaurus can recognize various objects from a table surface, has the capability to plan how to pick up the detected object, and can execute the plan by controlling the robotic arm.
Minotaurus is also capable of detecting people from a distance and can understand some of their gestures. From a closer distance, it can detect and recognize familiar faces, analyze faces to detect facial expressions and the gender of the person. It can also understand both Finnish and English voice commands, and reply using spoken sentences with the same language. While the robot speaks, the mouth movements of the avatar are synthesized to match the generated speech. Minotaurus can also understand the environment and navigate to its target while avoiding obstacles by using a combined environment model generated from all the sensors.

Minotaurus and its capabilities have been successfully demonstrated at various private and public events like, for example, during the University Science Day and a robot-themed event at the science center Tietomaa. This way, the demonstrations have been arranged not only in our robotic lab, but in real environments, and the reactions of the audiences have been entirely positive and enthusiastic.

Our work on motion-based object detection and tracking has also continued. The aim in this work is to integrate feature based sparse motion segmentation with a sampling based motion detection and tracking framework, which would lead to efficient solutions applicable in online dynamic scene analysis tasks. The method is designed for mobile platforms and can be utilized, for example, in gesture controlled user interfaces.

In the field of energy-efficient embedded computer vision, we have implemented several variants of the LBP operator in multiple mobile and custom processors. The embedded platforms used range from multicore-ARM and mobile GPUs to TTA processors and a hybrid SIMD/MIMD image co-processor. We have compared the different implementations in terms of computational performance and energy efficiency, while analyzing the different optimizations that can be made on each platform and its different available computing resources. In addition, we have released a software package providing a valuable tool for other researchers and developers.

Two computationally intensive multimedia applications - face detection and depth estimation - were implemented and optimized for parallel processing using the Portable computing language (PoCL) implementation of Open Computing Language (OpenCL). So far, the benchmarks have been implemented on desktop CPU and GPU. An ini-
tial design of an energy efficient multicore transport trig-
gerred processor that could achieve the same performance with significantly lower energy con-
sumption has also been implemented, but not yet bench-
marked.

The Energy Efficient Architectures and Signal Process-
ing team of CMV has been working on design automation and energy efficient computing for signal processing ap-
lications. A remarkable new opening was the initiation of a joint US-Finnish research project CREAM, together 
with the Centre for Wireless Communications. During the 
first project year, the research focus has been on dataflow modeling and energy-efficient implementation of a digital 
pre-distortion filter for wireless mobile transmitters. One 
of our doctoral students, Amanullah Ghazi, also conducted 
a 2-month research visit to the University of Maryland on 
the basis of this project with Infotech financial support. 
Another 2-month research visit was made by Dr. Jani 
Boutellier to EPFL, Switzerland focusing on the topic of 
dataflow programming.

In the context of video processing, a programmable, 
energy-efficient processor for HEVC/H.265 adaptive loop 
filtering was developed. This work is also to be extend-
ed to further parts of the latest H.265 video compression 
standard. This research topic has been carried out, heavily 
supported by the Academy of Finland. In general, the proj-
ect creates tools for generating efficient embedded soft-
ware/hardware solutions. Platform independent high-level 
specifications are used to describe parallelism at data, in-
struction, task and memory levels. The target is many-core 
systems that are becoming the key approach in improving 
computing throughput.

Biomedical image analysis

In recent years, increasing resolving power and automa-
tion of microscopic image acquisition systems have re-
sulted in an exponential increase in microscopic data set 
 sizes. Manual analysis of these data sets is extremely labor 
intensive and hampers the objectivity and reproducibility 
of results. There is, therefore, a growing need for auto-
matic image processing and analysis methods. Biomedical 
image analysis is an emerging application area in which 
we have collaborated with Biocenter Oulu for few years.

We have recently started a new project called “Algorithm-
based combination and analysis of multidimensional vid-
eo and open data” (ABCdata), funded by Tekes. In this 
project, the objective is to analyze 3D microscopic image 
sequences, and develop tools for cell segmentation and 
tracking, as well as for detection of cellular events such as 
itosis and apoptosis in conditions that mimic human tis-
ues, which makes this research unique from the scientific 
point of view.

One of the topics we have been investigating in the pro-
ject during the last year is analysis of cancer progress. The 
ability of a cell to sense its environment and adapt to it 
and its morphological appearance is a crucial element in 
tumor progression. Therefore, analysis of these morphol-
ogy changes and cell dynamic behavior in long term liv-
ing cell imaging is a critical investigation in cell biology 
and drug development research. To monitor and quantify 
the cell dynamics in cancer biology in live cell micros-
copy, which is comprised of long image sequences, auto-
ated image analysis solutions are needed. Therefore we 
have been developing computer vision/machine learning 
methods to address these needs. In this project, we em-
ploy phase contrast and fluorescent images taken from 3D 
models in which tumors reside and interact dynamically 
with the surrounding matrix and fibroblast cells. Recently, 
we proposed an automated method, based on a learn-
ing framework, for detecting tumor cells. The proposed 
method, which can be employed in different applications 
in biomedical image analysis, is able to distinguish differ-
ent cell types in cell co-cultures and does not suffer from 
parameter tuning.

Sample images from our database. (Upper Left) Phase 
contrast image of a 3D culture containing tumor (round-
ish) and fibroblast cells (elongated). (Upper Right) Fluores-
cent image of the same culture. Green Fluorescent Protein 
(GFP) is used to label fibroblast cells. (Lower Left) Phase 
contrast and fluorescent images are superimposed and in-
terpretation of the phase contrast image is easier. (Lower 
Right) Our learning based probabilistic tumor detection re-
sult. The colormap indicates confidence level.

Accurate cell segmentation is a prerequisite of any de-
tailed analysis of microscopic images. Good segmentation 
results can greatly simplify many analysis tasks. During 
the previous year we have been working with GFP labelled 
squamous carcinoma cells (HSC-3) embedded in the 3D 
collagen matrix, and image stacks have been captured 
with a spinning disk confocal microscope. One of the 
major challenges with our data is separating cells that touch. 
Most approaches make some assumptions about the shape 
of the cells (usually cells are assumed to be round and their 
size to be within a narrow range). These approaches do not 
work well when cells have very flexible shapes and can 
have intensity variation within their body.

We have attempted to separate touching cells using a cas-
cade of segmentation methods. Our method works better 
than basic segmentation methods alone, but it is still far 
from solving the difficult case of a dense cell sample with 
non-uniform intensity within the cell and very flexible cell 
shapes.
Phase-contrast illumination is simple and is the most commonly used microscopic method to observe non-stained living cells. Together with automatic cell segmentation and motion analysis tools, even single cell motility in large cell populations can be analyzed. To develop better automatic tools for analysis of low magnification phase-contrast images in time-lapse cell migration sequences, we have developed a segmentation method that relies on the intrinsic properties of maximally stable extremal regions (MSERs). In order to analyze cell migration characteristics in time-lapse movies, MSER-based automatic cell detection was combined with our own Kalman filter based multi-object tracker that efficiently tracked individual cells even in confluent cell populations. The research was conducted in cooperation with Biocenter Oulu and the University of Jyväskylä. The results have been reported in a joint article recently published in the Journal of Microscopy.

### Exploitation of Results

Many researchers have adopted and further developed our methodologies. Our research results are used in a wide variety of different applications around the world. For example, the Local Binary Pattern methodology and its variants are used in numerous image analysis tasks and applications, such as biomedical image analysis, biometrics, industrial inspection, remote sensing and video analysis. The researchers in CMV have actively published the source codes of their algorithms for the research community, and this has increased the exploitation of the results.

The results have also been utilized in our own projects. For example, we have collaborated with Prof. Tapio Seppänen’s Biomedical Engineering Group in the area of multimodal emotion recognition for affective computing, combining vision with physiological biosignals. Together with Prof. Seppänen and Dr. Seppo Laukka (Department of Educational Sciences and Teacher Education) and Prof. Matti Lehtihalmes (Faculty of Humanities) we have participated in the FSR Second Wave project where we have developed a Mobile Multimodal Recording System (MORE) that is now actively used in classroom research in various schools.

Most of our funding for both basic and applied research comes from public sources such as the Academy of Finland and Tekes, but besides these sources, CMV also conducts research by contract which is funded by companies. In this way, our expertise is being utilized by industry for commercial purposes, and even in consumer products, like mobile devices.

The CMV has actively encouraged and supported the birth of research group spin-outs. This gives an opportunity for young researchers to start their own teams and groups. Side results are the spin-out enterprises. According to our experience, their roots are especially in the strands of “free academic research”. There are currently altogether five research based spin-outs founded directly on the machine vision area. The number of spin-outs could be extended up to sixteen when taking into account the influence of the CMV’s thirty-year old history and the spin-out companies from the spin-out research groups in the area of computer science and engineering in total.

### Future Goals

The very positive results obtained from the RAE 2013 and Infotech Oulu evaluations show that we are on the right track. We plan to carry out well focused cutting-edge research, for example, on novel image and video descriptors, perceptual interfaces for face to face interaction, multimodal analysis of emotions, 3D computer vision, and energy-efficient architectures for embedded vision systems. We also have plans to further deepen our collaboration with international and domestic partners. For this purpose, we are participating in new European project proposals. Close interaction between basic and applied research has always been a major strength of our research unit. The scientific output of the CMV has been increasing significantly in recent years. With this we expect to have much new potential for producing novel innovations and exploitation of research results in collaboration with companies and other partners.

### Personnel

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Doctoral Theses


Selected Publications


Li X, Chen J, Zhao G & Pietikäinen M (2014) Remote heart rate measurement from face videos under realistic situations. Proc. IEEE Conf. on Computer Vision and Pattern Recognition (CVPR), Columbus, in press.


Background and Mission

MediaTeam Oulu (MediaTeam), founded in 1997, was a research group at the Department of Computer Science and Engineering at the University of Oulu. MediaTeam conducted leading edge research on urban computing, multimedia computing and Internet of Things with the objective of making a visible and lasting impact on society. MediaTeam was dissolved in 2014.

Scientific Progress

MediaTeam’s main research areas in 2013 were urban computing, community imaging, multimedia computing, and Internet of Things (IoT).

Urban computing

Urban computing is an emerging interdisciplinary research field which considers public spaces as potential sites for the development of ubiquitous computing. Urban computing is driven by two important and related trends, urbanization and rapid deployment of computing infrastructure in urban spaces. However, while urban spaces offer the greatest opportunities and strongest demands for ubiquitous computing, there is no fundamental theory, knowledge base, principled methods nor tools for designing and building ubiquitous systems as integral elements of the urban landscape.

MediaTeam coordinates the UBI (Urban Interactions) research program that aims at introducing a visible and lasting change to society by building a functional prototype of an open ubiquitous city in Oulu in the form of the Open UBI Oulu test-bed. From the user community’s point of view, such a city appears as a smart urban space providing rich interaction between physical, virtual and social spaces. From the R&D community’s point of view, the city appears as an open community test-bed stimulating research, innovation and development of new services and applications. The test-bed enables urban computing research in an authentic urban setting with real users and with sufficient scale and time span. Such studies are important, because real world systems are culturally situated, and cannot be reliably evaluated with lab studies that are detached from the real world context. By deploying a system for a sufficiently long time “in the wild”, we can establish the technical and cultural readiness and the critical mass of real users that are needed for determining whether the system can be deemed ‘successful’ or not.

The UBI program is executed by a portfolio of projects funded by various sources. 2013 saw the conclusion of the UBI Anthros and the Adaptive Urban Lighting projects funded by the Academy of Finland, and the Urban Flows and Networks project funded by Tekes under the Finland Distinguished Professor Programme. In 2013 the UBI Metrics and UBI Mingle projects continued, funded by the Academy of Finland; the NIMO project funded by the INTERREG IV A North programme, the City of Oulu and industry; and the MAINIO project sponsored by the ERDF and the City of Oulu. New projects starting in 2013 were the UBI HIIB project funded by the Academy of Finland, the reaxity project funded by Tekes, and the Open 3D Internet City Laboratory project funded by the University of Oulu.

The UBI program brings together a multidisciplinary research consortium. In 2013, it comprised of MediaTeam Oulu (Professor Timo Ojala and Professor Vassilis Kostakos), Interactive Spaces (Professor Jukka Riekki), the Department of Architecture (Dr. Aulikki Herneoja) and the Department of Economics (Professor Rauli Svento) from the University of Oulu.

To realize the open ubiquitous city, the UBI program engages an iterative cycle of technology-led and application-led research, together with the deployment of an open pervasive computing infrastructure at downtown Oulu. This is the unique dimension of our research strategy. The technology-led research produces new technology and knowledge, which, together with the new computing infrastructure, creates novel opportunities for application-led research. It is driven by domain-specific problems, which the UBI program addresses by developing two types of “proof of concept” prototypes, small-scale short-term demos and longitudinal large-scale pilots. Their empirical evaluation with real users in an authentic urban setting provides valuable feedback and creates new requirements on the technology-led research and the computing infrastructure.

The most visible piece of the pervasive computing infrastructure deployed by us is the UBI-hotspots, a network of large interactive public displays installed at pivotal outdoor and indoor locations around Oulu (Figure 1). Studies of interactive public displays are often criticized because their evaluation typically takes place in unrealistic lab environments, for short periods, with handpicked test users, predefined tasks, and limited content or services through a single prototype. Such focused usability evaluations provide excellent material for research papers, but whether they test anything of much practical interest is debatable. To gain more in-depth knowledge about the real-world use of interactive public displays, we have since 2009 de-
ployed 18 multipurpose interactive displays around Oulu, Finland. They represent the world's largest deployment of interactive public displays in a city center for research purposes. Our objective in deploying these displays was to understand how users derive value from interactive public displays that provide real services based on real content over an extended period. The hotspots offer typically 25-30 distinct interactive services, provided by us, the City of Oulu, private businesses, nongovernment organizations, and creative communities. We believe that this type of longitudinal real-world deployment gauges the value of any system for real users in a much more concrete way than short-term studies with predefined tasks and handpicked test participants. By deploying this many UBI-hotspots for this long, we can establish technical and cultural readiness and a critical mass of users needed to reliably evaluate the degree to which our hotspots succeeded as an interactive public display system. For example, our deployment has crystallized several design challenges, such as interaction blindness, i.e. people failing to interact with a display simply because they do not realize that they can.

One of the most valuable lessons that we have learned from our deployment of the UBI-hotspots is the degree of difference between laboratory and real-world settings. What works with recruited test users in a controlled laboratory setting is not necessarily representative of what works with a large population of real users accessing the displays on their own in a real-world setting. This was highlighted for example in the 2013 study involving the Wordster game. Wordster is derivative of Boggle, where the goal is to find as many words as possible from a grid of random characters within a limited time. In a multiplayer mode Wordster is played with mobile phones that are coupled with the UBI-hotspot using QR codes (Figure 2). Using the Wordster game as a probe, among other things, we compared the findings of controlled user evaluations and uncontrolled long-term deployment “in the wild”. First, we conducted controlled user evaluations on our university campus, where the usability and playability of the game was found to be very good, including the coupling of the phones with the UBI-hotspot using QR codes. Then we deployed the game on all UBI-hotspots where it soon became the most popular service. However, the general public did not adopt the multiplayer mode that required scanning the QR code with a mobile phone. Within a particular observation period, only five of the first 1676 completed games were multiplayer games played with mobile phones. 572 multiplayer games were selected to be played, but the actual gameplay never commenced. This poor adoption of the distributed user interface requiring the scanning of the QR code by the general public is in stark contrast with the promising findings of the controlled user evaluation.

In terms of longitudinal studies, in 2013 we published a paper on the discrepancies between citizens’ a priori and a posteriori information seeking strategies extracted from self-proclaimed information needs and the actual usage of the UBI-hotspots. In the design phase of the UBI-hotspots, we employed various methods such as contextual inquiry with lo-fi prototypes and card sorting to identify the types of information services that citizens believed to be useful in the upcoming interactive public displays. We then implemented most of the desired services in the UBI-hotspots, and logged the quantitative usage of the services over a long period of time. When we compared the usage data to the prediction we had made based on citizens’ opinions, we found that there were multiple services that people thought would be useful, but it turned out were not. For example, most people said they would love to have a service to find bus and transport schedules, or events happening in the city, or places to eat. It turns out these services (bottom-right in Figure 3) were some of the least used. On the other hand, news and games (top-left in Figure 3) turned out to be some of the most popular services on our displays, although initially they were not desired by citizens. This data shows that it can be really hard to identify beforehand popular services to be deployed on public displays, and most likely a trial-and-error approach should be expected.

Figure 1. UBI-hotspot at Oulu airport (left) and downtown Oulu (right).

Figure 2. Multiplayer Wordster is played with a distributed user interface coupling mobile phones and an UBI-hotspot.
Figure 3. Lack of correlation between self-proclaimed (x-axis) and actual (y-axis) usefulness of services on the UBI-hotspots.

Our anthropologic research of the ubiquitous Oulu continued with the collection of rich qualitative data on elderly and young adult citizens’ experiences and conceptions of ubiquitous technology in Oulu. The spatial dimension was taken into account both in the collection and analysis of the material to scrutinize people’s accounts of the urban space. Semi-structured theme interviews were employed together with more experimental methods borrowed from human-centered design. The analysis of the data supports our hypothesis: different people experience the ubiquitous Oulu in differing ways and have distinct technological needs and skills. However, these differences are not solely explained by age, but we have to take into account also people’s backgrounds and demography to better understand citizens’ technology-related experiences. Generally speaking, the results indicate that social aspects connected to technology are highly valued and that ubiquitous computing technologies could also be developed to be more experimental and co-creative. In 2013, we published a study that through a conceptual technology appropriation model (Figure 4) identified factors affecting the (dis)appropriation of two particular ICT infrastructures – a municipal WiFi network (panOULU WLAN) and the interactive public displays (UBI-hotspots) - in people’s daily ICT practices.

An emerging research direction has been community imaging that studies communities of users through the lens of technology. Increasingly, the use of technology is resulting in usage data being recorded, most often as a byproduct. Our community imaging research focuses mostly on analyzing such usage data, and deriving models and understandings of how groups of people behave, both in terms of interacting with each other, but also in terms of individual behavior. This work involves three main axes: understanding, tools, and applications. The first focus in our work has been an analysis of the panOULU WLAN traces in order to model the movement of the population across the City of Oulu. Using heuristics, we have been able to identify tourists visiting our city and using the panOULU WLAN

Figure 4. Our technology appropriation model.
network, and we have been able to contrast tourists’ mobility patterns to those of local residents. This analysis has helped us understand better how various parts of the city, or indeed our university campus, are used differently by visitors and locals, and which parts are more likely to act as “attractors” for visitors. An orthogonal set of activities involves developing instrumentation and analysis tools for capturing and treating community-level data. For instance, we have developed web-based tools that let us conduct an historic analysis of the WLAN mobility traces, and provides visualization and animation tools such as heat maps, firefly effects and catchment area analysis to further investigate city-level mobility. In addition, we have been actively developing a pioneering Android platform instrumentation tool that lets us investigate in extreme detail what happens on smartphones, how they are used, and in what circumstances. Using this tool, we have been able to identify particular peculiarities in how smartphones are used. For instance, we have identified a phenomenon that we call “micro-usage”: about half of our use of smartphones every day takes place in short bursts of interactions that last less than 15 seconds. Finally, our work seeks to develop interesting applications that communities of users can interact with. For instance, in our work we have used appstores to deploy our software on thousands of smartphones and collect data in real-time about their usage. Furthermore, we were the first group to systematically study the potential of public displays for crowdsourcing. Our work has demonstrated that the expertise and skills of a community may be reachable by developing interactive applications on public displays, and we have found that communities are willing to donate time to interact with public displays in order to contribute to a worthy cause or charity.

With invaluable support from the City of Oulu, industry and public funding bodies, the UBI program has established the Open UBI Oulu test-bed at downtown Oulu for studying ubiquitous computing in an authentic urban setting. We have engaged in various outreach activities to make the globally unique test-bed available to the R&D community at large, and to stimulate the innovation of new services. The UBI RIR (Researcher in Residence) program invites researchers to residency in Oulu, to work in our city laboratory together with our researchers. The annual international UBI Summer Schools provide young researchers with an opportunity to gain hands on experience and insight into selected topics in the multidisciplinary fields of ubiquitous computing and urban informatics under the tutelage of distinguished experts. We have also hosted two international UBI Challenges in 2011 and 2013 that invited the global R&D community to design, implement, deploy end evaluate novel applications and services in the real-world setting at downtown Oulu, Finland. This way we hope to stimulate international research collaboration on ubiquitous computing and on urban informatics in a very concrete manner. (http://www.ubioulu.fi/en)

Multimedia computing

Our research on multimedia computing focused on content-based video technologies, digital watermarking and speech processing. These research themes have emerged to be highly essential for enabling large-scale and interconnected multimedia systems and services, and have attracted industrial collaboration on several joint research projects.

Our research on content-based video technologies ended with the conclusion of the Next Media research program of the ICT SHOK in 2013. It aimed to meet people’s insatiable need for engaging and activating media experiences by means of new business models, concepts and technology. Production and consumption of media is under radical transformation. Digitalization of production, distribution and consumption of media, as well as the growing penetration of broadband access and mobile internet allow increasingly rich media content to be distributed to a variety of terminals. This endeavor takes advantage of the current transition towards co-creation, interactivity and independence of time and place. The diversity of terminals and devices in consumers’ everyday life is increasing, and the significance of mobility is emphasized. The company led program consisted of four work packages whose research themes cover all aspects of media production, from media content access to working processes and business models, as well as user experience. All major Finnish research organizations and universities are participating in the program. MediaTeam participated in the Affective Facets of Multimedia Content research topic, creating novel methodology for analyzing sentiments in video broadcasts of news, drama and movies. Our latest research findings on online TV content discovery services and automatic content analysis relate to long-term user studies on time-shifting behavior in web-based TV archive systems, unsupervised detection of novelty concepts from unstructured TV content data stream, online end-user systems for TV discovery, a mobile EPG application for TV content recommendations, non-linear skimming of archived TV programs and distributed multimedia data processing using Hadoop. We also published a consumer video dataset with annotated head trajectory ground truth data created with an in-house ground truth editor (Figure 5). The dataset can be utilized in benchmarking new person tracking methodologies with handheld camera recordings.

Figure 5. A screenshot of the ground truth editor used for annotating head trajectories in videos.
We continued research on digital watermarking in 2013. Digital watermarking is a method of embedding a secret sequence of bits in the host media such that it is hard to perceive or remove. This message can be then extracted from the host signal when the necessary algorithms are available. The essential technical challenges in watermarking include invisibility, robustness and capacity. A wide range of watermarking algorithms has been proposed, especially for watermarking of digital images. Generally, however, the resilience of this information in a physical printout, like binary images, holograms or color images has been less studied. This hardcopy watermarking, print-scan resilient and print-cam resilient watermarking, differs greatly from traditional watermarking. The detection, extraction and interpretation of the watermark are realized after a conversion of image information back to digital format using a scanner or mobile phone camera. The extraction algorithms have to handle both geometrical distortion, and pixel value distortions. Very specialized techniques compared to traditional watermarking are required. In 2013, we focused on inspecting applications and use cases (Figure 6) of print-cam robust watermarking and continued the work begun in 2012. A demo program was implemented on different platforms, and the results of these studies will be later published. The aim is to gain new insight into the print-cam robust watermarking by studying it in practice and through implementation in real life instead of simulated environments provided by Matlab etc. In addition, the current work gains benefit from other fields such as computer vision and software engineering. In 2013, first steps were also taken in the field of medical watermarking and its applications on healthcare systems, in parallel with other security measures.

In speech processing research, a novel method for the construction of low dimensional visualizations of emotional speech was developed, based on prosodic speech features. Class labels assigned to data samples are utilized in nonlinear manifold learning in order to generate manifold structures that differentiate emotions. A supervised classifier based method is used to emphasize the relevant emotional structures. The developed method was used to present the MediaTeam Speech Corpus emotional speech data in a way that resembles closely to the current knowledge of dimensional model of emotion. The method was shown to be capable of robust emotional content discrimination, achieving the performance level of the human reference. The created visualization was further shown to be capable of mapping the perceived emotional intensity of the emotional speech data samples, even though intensity data was not used in the training of the model.

Internet of Things (IoT)

The Internet of Things (IoT) paradigm refers to uniquely identifiable objects (things) and their virtual representations in an Internet-like structure. The future IoT is likely to contain tens of billions of nodes providing universal control of electricity and water utilities, medical ICT and industry automation. Sensor networks on a scale of a million nodes are possible already today, and M2M (machine-to-machine) automatic metering systems of tens of millions of nodes have already been deployed.

MediaTeam’s key research project in this area was the Massive Scale Machine-to-Machine Service (MAM-MOTH) project funded by Tekes and industry. The MAM-MOTH project focused on three complementary aspects in M2M communications: scalability of architectures and protocols, security and congestion aspects of embedded web services on sensor nodes, and platform application interfaces. In 2013, the focus was on developing fully decentralized service architecture for M2M communications and integrating the components to enable large-scale evaluation scenarios. The architecture comprises of Dynamic Task and Service Composition (DTSC), Execution Environments (EE) for different sensor and actuator devices, and a Distributed Resource Database (DRD). Together, the components provide a scalable, cost efficient and failure tolerant alternative to the current M2M network architectures. Implementing the evaluation scenarios provided practical understanding of the requirements for M2M application interfaces.

International collaboration and events

MediaTeam is highly multidisciplinary and international in its activities, collaborating with domestic and international research partners from different disciplines, and contributing to the international academic community. Collaboration takes mainly place in form of research visits and organizing international events.

Dr. Hannu Kukka made an 11-month visit to Carnegie Mellon University, hosted by Professor Anind Dey, Jorge Goncalves made a 3-month visit to PKNU and KAIST in Busan and Daejeong in Korea, and Marko Jurmu complet-

Figure 6. An interactive poster using digital watermarking and a mobile phone camera.
ed his 12-month visit to Keio University, hosted by Professor Hideyuki Tokuda in April 2013. We hosted Professor Marcus Foth from Queensland University of Technology for two weeks and Javier Gomez Escribano from Universidad Autónoma de Madrid for six months under the UBI Researcher in Residence (RIR) program.

We organized the UBISS 2013 (4th International UBI Summer School 2013) in Oulu on June 10–15. It comprised of four parallel workshops instructed by leading international experts (Figure 7): “Experience-driven Design of Ubiquitous Interactions in Urban Spaces” by Professor Kaisa Väänänen-Vainio-Mattila from Tampere University of Technology and Dr. Jonna Hääkkilä from the University of Oulu; “Designing Mobile Augmented Reality Interfaces” by Professor Mark Billinghurst from the University of Canterbury, New Zealand; “Developing Ubiquitous Computing Devices” by Professor Albrecht Schmidt from the University of Stuttgart, Germany; and “Urban Resource Networks” by Professor Malcolm McCullough from the University of Michigan, USA. 76 students from 18 countries enrolled in the summer school via an open international call, making it the largest UBI summer school so far. All students attended a number of joint events, including a madness session where students presented their background and ongoing research, an opening plenary where each workshop was introduced and a closing plenary where each workshop presented their results. Each workshop had its own curriculum and activities, which included theoretical presentations by the instructor and practical projects conducted in groups of 3-5 students. (http://www.ubioulu.fi/en/UBI-summer-school-2013)

We organized the 2nd International UBI Challenge 2013 that again invited the global R&D community to design, implement, deploy and evaluate novel applications and services in the real-world setting at downtown Oulu, Finland, atop the Open UBI Oulu test-bed. In comparison to the 2011 UBI Challenge, the most important change in the setup was that the finalists were no longer required to stay up to three months on site in Oulu to deploy and evaluate their applications in person. Some jury members felt that this requirement limited the people that could participate. So, instead, remote participation was allowed so that the finalists could submit their working applications for deployment and data collection by the organizers. Only four proposals were submitted, three from European universities and one from a local researcher at the University of Oulu. One of the four proposals was deemed infeasible by the organizers. The remaining three proposals were invited to the final, all three involving the UBI-hotspots. Eventually, two of the three finalists completed the deployment of their applications in Oulu. HotCity had originally been developed for the City of Patras in Greece, and the contributors adapted it for the City of Oulu in the Challenge. Martians from Outer Space was being developed independently by a local researcher as a free time hobby, and he then submitted it as a proposal to the Challenge that just happened to conveniently take place. The collection of the field data commenced on July 1, 2013, and continued till August 31, 2013. The finalists reported their studies to the jury in the form of a full paper, and a video recording of a presentation structured according to a given presentation template. The jury ranked as the winner the HotCity service contributed by a team of researchers from the University of Patras, Greece that was led by Dr. Andreas Komninos. The runner-up, Martians from Outer Space contributed by Jukka Holappa from the University of Oulu can take some consolation from the fact that it has since become the most popular service on the UBI-hotspots. The award ceremony was held in the in the MUM 2013 conference in Luleå, Sweden, in December 2013 (Figure 8). (http://www.ubioulu.fi/en/UBI-challenge)

Finally, we contributed in different roles to the organization of the following international conferences and workshops: the 2nd ACM International Symposium on Pervasive Displays (PerDis 2013) held in Mountain View, CA, USA; the 2013 UbiComp Doctoral School in Zurich, Switzerland; and the 2nd International Workshop on Ubiquitous Mobile Instrumentation (UbiMI 2013) and the Human Interfaces for Civic and Urban Engagement workshop (HiCUE 2013) collocated with UbiComp 2013 in Zurich, Switzerland.

Figure 7. The instructors of the UBISS 2013 (4th International UBI Summer School 2013) posing with Timo Ojala. From left: Jonna Hääkkilä, Kaisa Väänänen-Vainio-Mattila, Mark Billinghurst, Albrecht Schmidt and Malcolm McCullough.

Figure 8. The award ceremony of the 2nd International UBI Challenge 2013 at the MUM 2013 conference in Luleå on Dec 3, 2013 (from left): Timo Ojala (Chair of Jury); Tommi Heikkinen (University of Oulu) and Jeries Besharat (University of Patras).
Farewell

All good things come to an end someday. MediaTeam was dissolved in early 2014, after 16 years of research, yielding 570 scientific publications, 16 dissertations, and a visible and lasting impact on the urban landscape of Oulu in form of the panOULU WLAN network and the UBI-hotspots. We warmly thank our public financiers, industrial and academic partners, the City of Oulu, and the citizens of Oulu for their collaboration and support over the years. Selected research activities will be continued by various existing and new research groups as follows. Research on urban computing will be conducted by the new Urban Computing and Cultures group, established by Professor Timo Ojala (http://ucc.oulu.fi). This group will also adopt MediaTeam’s responsibilities for the Open UBI Oulu testbed, most notably the maintenance duties of panOULU WLAN network and the UBI-hotspots. Research on community imaging will be conducted by the new Community Imaging Group established by Professor Vassilis Kostakos (http://comag.oulu.fi). Research on content-based multimedia analytics will be continued in Professor Tapio Seppänen’s Biosignal Processing Team in the Biomedical Engineering Research Group (http://www.oulu.fi/cse/bme). IoT research will be continued by Professor Mika Ylianttila at the Center for Internet Excellence (http://www.cie.fi) and in the Networking team (NET) at the Centre for Wireless Communications (http://www.cwc.oulu.fi).

Personnel

| teachers, doctors | 10 |
| doctoral students | 13 |
| others | 11 |
| total | 34 |
| person years | 22 |

External Funding

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Doctoral Theses


Selected Publications


Rautiainen M, Sarvanko J, Heikkinen A, Ylianttila M & Kostakos V (2013) An online system with end-user services: Mining novelty concepts from TV broadcast subtitles. Proc. 19th ACM SIGKDD Conference on Knowledge, Discovery and Data Mining (KDD 2013), Chicago, IL, USA, 1486-1489.


Background and Mission

The mission of the Wireless Communication Systems Group (WICS) is to conduct world-class research, train world-class graduates, create new technology and IPRs, and support society by transferring technology to practical usage. WICS is internationally perceived as a forerunner in its field, and a valued partner for research cooperation. Much of its success is due to the capability to react fast to the changes taking place in the operational environment, as well as to the needs expressed by its research partners. As a provider of high-quality university training, WICS aims at producing theses and dissertations, and peer-reviewed publications of the highest rank.

On the global scale, WICS possesses the extraordinary knowledge and prestige demanded for cross-layer wireless system research and optimization. WICS is one of the largest university-based groups in the field of communications engineering and networking, and has a strong focus on industry cooperation and relevance. Currently, WICS employs approximately 130 research and teaching staff members, and operates with a total budget of €9.1 million, 81% of which comes from external funding sources. In essence, WICS is an extremely international research and working environment with 48% of its staff of non-Finnish origin, including two full-time and three part-time professors. Due to its composition and wide international research networks, the group has exceptionally strong potential influence on the global development of practical systems and research trends. WICS runs Master’s level training in Wireless Communications Engineering, and currently offers possibilities for international double degrees with four countries within the CWC International Double Degree Doctoral programme.

Scientific Progress

In 2013, WICS was running 65 research projects with external research funding, including nine projects with international funding, whereas in 2012 the total number of projects was 54. The results of intensive project work produced 48 peer-reviewed international journal papers and 81 peer-reviewed international conference papers. The year was also successful from the perspective of academic degrees, as 8 doctoral students from WICS defended their theses.

Excellent scientific results were produced in 2013 in both the fundamental research areas and applied research areas of WICS. Based on the WICS mission statement and strategy, fundamental research was conducted on Signal Processing for Wireless Systems, Radio Access Networks and the Future Wireless Internet as portrayed in Figure 1. The research focus and outcome of the three research areas, functioning as research groups, is presented in the following.

Signal Processing for Wireless Systems

WICS researchers involved in “Signal Processing for Wireless Systems” focus essentially on technologies required for efficient implementation of the multitude of wireless devices or network nodes of the future connected society by facilitating improved connectivity with moderate device and system complexity. This will enable improved energy, bandwidth and cost efficiency of wireless systems and the consequent applications. The research methodology of the research group is based on fundamental theories behind the signal processing paradigm, such as statistical inference, and communications and information theory. In addition, computing and signal processing architecture technologies and electromagnetism are applied to realise the developed solutions on real wireless devices; also electromagnetism, antenna design and related optimization are studied by the group members. The focal area of the research is to develop transceiver algorithms and their realizations for dense wireless networks, in particular for communication ranges diminishing in indoor and urban areas. Extreme examples include body area networks, and nanoscale or molecular communications. Efficient interference management, resource allocation and routing algorithms is one area of system algorithm research; this implies that minimization of system level control overhead is important. The focus is on the design and realization of the algorithms, in ad-
dition to which access and networking technologies are explored in order to guarantee seamless interplay of the network nodes. This enables on-line optimization for energy efficient system operation as configurability of the devices becomes more important in the future. Application layer processing is also taken into consideration from the perspective of compression and joint-source channel coding to improve the overall system efficiency via the signal processing research paradigm. The innovative research group aims at creating radically novel solutions that enable the convergence of networks and services. All this facilitates possible major breakthroughs in signal processing technologies, and their application for wireless connectivity and services from large area coverage to molecular communications. The practical application areas of the research include wireless access networks, Internet of Things, and wireless sensor networks covering various medical and well-being services.

In 2013, the research work carried out by the signal processing experts resulted, in, for example:

- joint source-channel coding inspired multihop link and code design for ad hoc networks
- new constellation and precoder designs for channels with channel estimation errors
- distributed optimization methods for rate maximization and power minimization in cellular networks with channel uncertainty and secrecy constraints.

The year 2014 will bring yet new major challenges in externally funded projects for the group. The European RESCUE project proposes an integrated concept “links on the fly”, encompassing the key technologies of distributed joint source/channel coding in lossy wireless networks, exploitation of multi-path information transfer in wireless mesh networks, and cross-layer design for interference management and error control. The approach is portrayed in Figure 2.

The planned concept will allow successful and robust information transfer through multi-path networks, and the integration of diverse communication infrastructures (e.g., base stations, relays, satellites, and terminals) taking into account the mobility of nodes, high density cells, dynamic and opportunistic frequency management which have a major impact on the challenges of future 5G networks.

The radio engineering team, operating within the signal processing research group, will carry out extended measurements and simulations in 2014 where the integrated LTE-A (long term evolution - advanced) and EM (electromagnetic) simulation tools developed by the team will be used for verifying against signal throughput measurements in order to define the accuracy of the MIMO OTA (multiple input multiple output over the air) test method for MIMO terminal devices. One goal of the simulations is to find cost effective and sufficiently accurate measurements for different communication cases, in different radio channel environments. An important part of the project is to study the effects of user proximity, and the previously developed compensation methods for capacity, using different radio channel models and communications standards. The results are expected to be significant, for example, for standardization of the test methods of MIMO devices.

**Radio Access Technologies**

“Radio Access Technologies” - the largest fundamental research group in WICS - focuses on access solutions for the next generation wireless systems. The expertise areas of the group cover all the critical aspects for future radio access design, from the physical layer to wireless networking, with the major application areas being 5G cellular systems and wireless systems for crisis management. The potential key technologies related to 5G include massive MIMO techniques, next generation physical layer techniques, heterogeneous networking, and self-organized networking. The research on dependable wireless systems is looking at robust and self-healing wireless connectivity, utilizing both commercial and proprietary technologies. Also co-design of future smart grids and wireless infrastructure is being investigated by the research group. The group is very active in various international research projects, including METIS (www.metis2020.com), the European spearhead 5G project. The overall goal of METIS is to provide a system concept that supports 1000 times higher system spectral efficiency, as compared with current LTE deployments, but with a similar cost and energy dissipation per area as in today’s cellular systems.

In 2013, the Radio Access group developed improved algorithms to determine and predict user context/activity by combining the various approaches of system optimization in order to cater for the end-to-end context specific user requirements and direct scarce resources (spectrum, energy, etc.). The ultimate goal of the research work was to optimize the network on all levels towards where most value is created for the users in their respective contexts. Some of the key research results of 2013 were

- algorithms for decentralized massive MIMO
- full duplex underlay device-to-device transmission
- filter bank multicarrier techniques for high capacity air interface and multiple access
- novel method for joint resource and routing optimization in wireless sensor networks based on the alternating direction method of multipliers
- evaluated data from the new channel measurement campaign in 2 and 5 GHz to support large scale MIMO and
vehicle-to-vehicle communications
• the initial dependable system design prototype for LTE
type commercial communication system

In 2014 the research group will intensify its 5G activi-
ties with a large Tekes project focusing on 5G radio ac-
cess solutions to 10 GHz and beyond frequency bands.
The research focus will be on METIS use cases, support-
ing a very high data rate, very dense crowds of users and
mobility (see Figure 3). Radio channel measurements and
modelling at 10 GHz, co-primary spectrum sharing in
multi-operator small cell networks, and core 5G system
concept design are some of the key themes in 2014. The
group will also be active in preparing and finalising its
Horizon 2020 project proposals in the applicable thematic
calls, and organising the 1st International Conference on
5G for Ubiquitous Connectivity - 5GU.

Scientific problems in which group is engaged in include
network optimization on the 2.5 (MAC), 3 and 4 layers;
development of secure network architectures; develop-
ment of efficient sensor network architectures; and effi-
cient protocols on the application layer. In 2013, the group
was involved in the development of networking protocols
for cognitive networks, economic models for multi-opera-
tor spectra management, 5G network architectures, and
security solutions for advanced networks as well as efficient
sensor network architectures. The main results in the field
of cognitive network architectures were obtained within
the CoCaHaNe (WiFiUS) project, the economic models
were obtained within EcoMoCo (WiFiUS) project, 5G
network architectures (ADTECH, Mammoth and Sigmo-
a) and advanced network architectures (NEWCOM) have
been published in the most prestigious scientific journals.

The work of the NET group has an impact on raising
awareness in the research community and industry of the
importance of networking as a science in the development
of the future communication systems. The impact is ma-
terialised through both the educational programme and
research results.

In 2013, the NET group had significant international coop-
eration with the US (WiFiUS), Europe (NEWCOM) and
Asia (ADTECH), and had activities in Japan. Cooperation
within WiFiUS has given the group the opportunity
to generate top scientific results in the field of cognitive
networks, jointly with US universities. The group has also
developed a significant European network of excellence
within the NEWCOM project, providing access to the best
research resources in Europe. Furthermore, the coopera-
tion with Asia has provided additional necessary funding
for the group.

In addition to the regular project meetings, a dissemi-
nation event in Lisbon (NEWCOM), and summer school
(WiFiUS) gave group members opportunities to promote
their latest results and the overall vision on future wireless
networks.

In 2014 the group will be working on developing new
networking paradigms for future wireless networks with

**Future Wireless Internet**

The Networking group (NET) of WICS focusing mainly
on “Future Wireless Internet” consists of three teams: Net-
working, Future Wireless Internet and Sensor Network
Architectures, and Sensor Networking. The group carries
our research in the field of 5G/6G network architectures,
spectra management, networks economics and security,
as well as the future Internet applications, as portrayed in
Figure 4.
the goal of convincing the community and all the relevant players in the field of the necessity to support networking science in order to enable further progress in the wireless business.

**Selected samples of research**

Selected samples of research carried out by WICS research teams (in total 15) are presented next, including key results in 2013 as well as plans for year 2014.

**Radio Resource Management Algorithms Research Team**

The WICS research team focusing on algorithms for radio resource management, consisting of 6 members, considers the effects and requirements of the inevitable massive densification of the network infrastructure, from the point of view of area spectral efficiency and capability to support - in a controllable manner – various types of direct communications, e.g., device-to-device (D2D) and machine-to-machine (M2M) communications to realise the Internet of Things (IoT). In the complex operating environment of future heterogeneous networks, advanced interference and mobility management across different transmission/reception points with overlapping coverage becomes of utmost importance, making interference coordination especially vital for cell-edge users, who in the end dictate the dimensioning of the wireless networks.

The team has explored the effect of reliable channel state information (CSI) at the transmitter on the use of coordinated/cooperative multi-cell transmission resulting in efficient multi-user precoding techniques across distributed antenna elements or access nodes. In 2013, team members published promising results on fast converging downlink precoding algorithms for multicell systems with perfect and imperfect CSI at the transmitter. Another key research topic in 2013 was using cooperation and information exchange between base stations for joint multiuser detection and decoding in multi-cell multicarrier uplink communications. To improve the performance of the turbo receiver and reduce the intra- and intercell interference generated by the multiuser transmission, the convergence properties of the receiver were taken into account, resulting in highly efficient resource (power, bandwidth) allocation, and beamforming schemes for coordinated uplink systems. Subsequently, a decentralised framework was proposed for the coordinated multi-cell minimum power beamformer design problem which is able to guarantee feasible solutions even if the interference information is outdated or incomplete. A practical but efficient decentralised algorithm and corresponding signalling concepts of effective CSI for weighted sum rate maximization in multi-cell multi-user MIMO systems operating in the TDD mode was also proposed.

In 2014, in addition to the aforementioned research topics, the team will direct some of its research efforts towards large-scale multiple antenna wireless systems with hundreds of low-power antennas, that may be co-located at the base station site or distributed geographically, often called massive MIMO. In a special case with very large number of base station (BS) antennas, the processing can be simplified in a way that even matched filter (MF) and zero-forcing (ZF) can be used in an ideal i.i.d. channel for near optimal detection and beam-forming. However, in practical multi-cell environments with non-ideal correlated channels the use of more complicated precoder design algorithms is justified as the performance gains for simple MF or ZF based schemes are still significant. We demonstrated for the first time that the inter-cell interference (ICI) terms coupling the coordinating BSs can be approximated using the random matrix theory when the problem dimensions grow large, and the approximated ICI values depend only on the channel statistics (large-scale fading, load). This leads to a significant reduction in the required information exchange between BSs, as the approximated ICI values remain valid for several channel coherence periods.

**The Optimization Techniques for Wireless Networks and Signal Processing Research Team**

A WICS research team of half dozen researchers focuses on optimization techniques for wireless networks and signal processing. The research interests of the team include distributed optimization, large scale optimization, l1-norm methods for cardinality problems, dynamic programming and global (non-convex) optimization. Since 2013, the team’s interests have expanded to compressed sensing techniques, with special emphasis on Machine-to-Machine (M2M) communications and Internet of Things (IoT) applications. The aim is to understand the fundamental design principles, and investigate the ultimate capabilities of compressed sensing in wireless sensor networks. The main focus is on large sensor networks that rely on wireless interconnections (without the support of a pre-existing infrastructure), and are subjected to arbitrary temporal and spatial variability (caused, for example, by channel fading, addition/removal of nodes, node mobility, etc.).

During the first half of 2013, the main focus was on distributed optimization methods for cellular systems and wireless sensor networks. Specifically, the team derived a novel method for joint resource and routing optimization in wireless sensor networks, based on the alternating direction method of multipliers. As a result, the team introduced a new robust beam-forming design method for cognitive radio systems, and proposed several distributed optimization methods for rate maximization and power minimization in cellular networks. The team members also studied the effect of the spectrum sensing errors on the stability region of a cognitive radio system.

In the second half of 2013, research interests were directed to compressed sensing techniques for wireless sensor networks. Consequently, the team proposed novel signal reconstruction algorithms for streaming systems and worked on the mathematical modelling and analysis of the real-time status update systems in which the emerging concept of “age” (or freshness) of information plays a key role. In these systems, status updates arrive randomly at a source node and are transmitted through a (possibly wireless) network to an intended destination node. Since the receiver has interest in fresh information, the goal is to minimize the “age” of the received updates.
A major achievement in 2013 was the launching of the five-year Academy Research Fellow project “Optimized Compressed Sensing in Wireless Sensor Networks” (ComingNets) which started in September 2013. The essential forms of international cooperation in 2013 were multiple joint international publications, research visits and student exchanges. The team also organized the Fourth Nordic Workshop on System & Network Optimization for Wireless (SNOW) 2013 (http://www.snow2013.net).

The future goals related to optimization techniques for wireless networks and signal processing include gaining a better understanding of the fundamental design principles and performance limits of the compressed sensing techniques. A special emphasis will be on revealing the information theoretic connections between traditional distributed source coding and compress sensing. Another goal is to obtain a statistical characterization of the “age” of information in the status update systems, where the source node has the capability to manage the arriving samples and decide which packets will be transmitted to the destination. The team will also work on developing a unified optimization framework that will enable a systematic study of the spectrum sharing techniques in multi-operator cellular systems.

The Channel Modelling and Physical Layer Techniques Research Team

One of the WICS research team is focusing on channel modelling and physical layer techniques with eight researchers. The aim is to solve problems related to channel modelling in the case of massive MIMO, by creating new channel models taking into account elevation information and performing measurements in the cm region. Knowledge on channel models is utilized in the creation and evaluation of physical layer techniques, specifically: focusing on very high rate data rates with combined modulation and coding; in the creation of new signalling methods using novel waveforms and transceiver processing; in improvement of bandwidth - energy efficiency; and in reduction of transceiver complexity in design with massive MIMO.

In 2013, the team succeeded, for example: in defining filter bank techniques for access and multiple access; in creating full duplex underlay device-to-device (D2D) transmission solutions; in investigating physical layer network coding (PNC) for D2D underlay communications, and novel decentralized coordination algorithms for massive MIMO. The performed channel measurement campaigns also provided unique information in the 2.5 GHz band for large MIMO and vehicle-to-vehicle (V2V) communication.

The research efforts and results of the team are of major interest to industry, as channel models in new frequencies with additional parameters are vital for major technological development. The team also contributed to the evolution of access and novel transmission methods, together with massive MIMO. In 2013, research results were disseminated through several research projects and submitted to/published in esteemed journals, including EURASIP, EUCAP, JSAC, TCOM, as well as large in international conferences, including ICC, WCNC and PIMRC. International cooperation was also lively in 2013, especially within the European METIS project, and the internships from University of Alberta, Canada and University of California, San Diego, USA. The team also further enlarged its cooperation network in several project proposals for the European Commission as well as through proposals for joint projects with the University of Surrey, UK; and KTH, Sweden. Universities in Sri Lanka were also approached for both researcher training and joint research opportunities. Possibilities for new double degree programmes in doctoral studies were also discussed with several partners. Members of the team also gave talks to industry partners, as well as organised short courses on selected topics.

In 2014, the team aims at performing further measurements in the cm wave region and finalising channel models for massive MIMO. Considering physical layer techniques, objectives include validation of non-orthogonal waveforms for access; novel coding modulation schemes; full duplex d2d for a multiuser multi-cell; PNC for d2d and multi-cell massive MIMO BS; as well as efficient error control techniques for distributed storage and small cell integrated environment.

The Dependable Wireless Research Team

The recently established Dependable Wireless research team of WICS, consisting of 8 persons, is specialized in defining algorithms and system concepts that offer system level resilience in cases of unexpected events and disasters, and at the same time provide communication solutions for critical infrastructure protection by withstanding most sources of interference. Most commercial communication systems are based on the best effort design paradigm. For critical infrastructure and authorities’ communication systems, also robust and interference resistant designs are sought to provide “always connected” solutions.

In 2013, the Dependable Wireless team studied exploitation of MANET and ad hoc networking solutions for enhanced redundancy and resiliency. This work was supported by studying routing mechanisms, as well as MAC protocols suitable for distributed control of such systems. For authorities’ systems mechanisms for robust communication algorithms for the physical layer (PHY) were studied, including robust estimators, channel coding, and interference suppressors to name but a few. As a result, an initial dependable system design prototype for an LTE type commercial communication system was drafted. The system concept was named citizen radio – a system that can provide connectivity during communication infrastructure failures. The system can also be deployed as a critical infrastructure communication system. Also several system improvements were drafted for an authorities’ communications system. At this stage, the concept shows plenty of promise. The impact could be remarkable if the system designs, or parts thereof, is included in future standards releases of LTE. As for system design improvements for authorities’ communication system, the designs shall be included in operational devices within the next years. The team was also active in funding acquisition, as several EU project proposals were generated (security oriented maritime LTE, peer-to-peer smart grid system, authorities’ communications system) to be submitted to H2020 calls.
In 2014, the team will concentrate on finalizing the dependable LTE system design, which will be evaluated both in citizen radio and critical infrastructure configurations. Also the authorities’ communication system’s algorithmic designs will be finalized after which key results will be published in international fora.

The Medical ICT Research Team

Healthcare and the medical sector are increasing their significance as an important application area of wireless communications. Due to the requirement of highest reliability in health-related issues, extremely robust, secure and safety communication must be guaranteed. The WICS Medical ICT team is investigating the concept and the problematic resulting from this requirement focusing on short range communication (up to tens of meters), wide-band communication (in all the forms), channel modelling (crucial for system development), knowledge on antennas, and physical layer and medium access control (MAC). The wireless body area network (WBAN) is a key element of the research approach. In 2013, the central research topics included channel models for WBAN, performance evaluation of ultra wideband receivers, low-power MAC protocols for WBANs, in-body antennas, the effect of body tissues, as well as environmental challenges in medical WBANs. The team submitted a patent application on a method of improving IEEE Std 802.15.6 dependability and channel utilization. It also contributed to on-body WBAN channel modelling for static and pseudo-dynamic links, produced a Matlab simulator extension and performance comparison of different WBAN receivers using CWC’s & IEEE802.15.4-2011 and IEEE802.15.6-2012 channel models, and created novel antenna solutions designed for on-body. These results were presented in four accepted international journal papers, and 14 international conference papers. The team had also a major role in initiating and contributing to the ETSI SmatBAN standardisation work. International relations were further developed in 2013 through the advisory Board membership of the Research Centre in the area of wireless medical technologies and applications in Macquarie University (Australia), as well as through new collaborations related SmatBAN standardization work. Furthermore, new partners for Horizon2020 were identified and contacted. WICS also contributed to the scientific community by organising UWLAN 2013 (in conjunction with Bodynets 2013), serving as ISMICT2013 board members (International Steering Committee, International Advisory Board, Technical Program Committee), and co-chairing the IEEE ICUWB 2013 Technical Programme Committee. In 2014, the Medical ICT team is focusing its research essentially on solutions of dual use in homes and institutions; receiver performance evaluation and new MAC protocols; dependable WSN networks (robustness, security and secrecy); antennas; interference modelling; nanoscale communications; mobile clouds for medical ICT; and visible light communication for medical ICT.

The Small and Nanoscale Communications Research Team

Nanotechnology is an extremely diverse field with very promising research being carried out in many areas. In the future, nanotechnology will be a significant part of people’s everyday lives. Nano-machines refer to integrated devices consisting of nanoscale components. The WICS research team specialises in small and nanoscale communications concentrating on wireless communication between nanomachines with realistic channel models. The team leader has been on a 6 months research visit to the Georgia Institute of Technology, USA during 2013. One student was on a 3 month research visit to the Tokyo University of Agriculture and Technology, Japan during 2013. This research visit was very useful for establishing cooperation on nano-machines with Japanese partners. During 2014, the team will address many challenges related to wireless communication of nano-machines, including the effects based on quantum mechanical considerations. Several journal papers will be submitted during 2014.

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Doctoral Theses


Selected Publications


Scientific Progress

Cardiovascular and respiratory system research

We are studying methods of synthesizing VCG-like signals from measurements with a reduced number of leads. In this way, fewer electrodes than normal need to be used in measurements, but the signal can be reconstructed with high enough accuracy to perform vectorcardiographic or standard ECG lead based analyses. We are exploring novel non-linear systems theory based approaches. Similarly to the ECG, respiration flow yields important information on many disorders and problems such as cardiac disorders, asthma, obstructive pulmonary diseases and sleep apnea. We have developed novel ECG-derived respiration (EDR) methods. The performance is proven to surpass that of many current methods in the literature, as the new EDR signal has a strong correlation and coherence with chest band based respiration measurements.

The multiple linear regression technique with two predictor variables has been used commonly since the 1980’s for calibration of respiratory effort belts. However, this method yields only crude predictions of the waveforms in the airflow signal. We developed an improved calibration method that uses an optimally trained FIR filter bank and Multiple-Input Single-Output system model. Our FIR filters perform optimal linear transforms of the belt signal waveforms in order to match them to the spirometer signal waveform, which makes the result of the prediction much more accurate than with the standard method. The method can be used in pulmonary and critical care medicine.

Central nervous system research

Hypoxic ischemic encephalopathy (HIE) is a severe complication of cardiac arrest (CA). At the moment, no reliable technological solution for early assessment of HIE after CA exists. Even though quantitative EEG analysis has recently shown promising results as a tool for diagnostic monitoring of HIE, the effects of anaesthetics during intensive care can potentially disrupt the interpretation of the signal. We gathered a unique data set from CA patients in the early phase of recovery, in which the combined effects of HIE and anaesthetics on EEG are investigated. In the future, this data will be used in the development of a novel technology for diagnosing HIE.

Emotions are fundamental for our everyday life, affecting communication, learning, perception, and decision making. Including emotions into human-computer interaction (HCI) would be a significant step forward, offering great potential for the future in the development of novel technologies. We investigated the selection of a subject-independent feature set for EEG-based emotion recognition. Features were selected to classify a person’s arousal and valence while watching videos with emotional content. Optimization of the feature set was carried out. The best classification rate, substantially improving the rate reported in the literature, was obtained with a set containing power spectral features.

Musculoskeletal system research

Current clinical diagnostic tools have only limited ability to assess fracture risk or early osteoarthritis at an individual level. Using a biomechanical approach and advanced image analysis, we have shown that structural parameters can discriminate femoral neck fractures from controls. Assessment of the trabecular structure using texture analysis of radiographs appears to be a promising method. We showed that a homogeneity index assessed by texture analysis of conventional radiographs can explain 50% of experimental failure load and determines bones with high fracture risk with similar accuracy to bone mineral density (BMD). We have developed computational finite element (FE) models and shown that FE analysis can yield reasonable accuracy in the assessment of experimental failure load. We also showed that dual-energy digital radiography (DEDR) can be applied for bone assessment, and it correlates well with the mechanical properties of bone. We also demonstrated that the novel axial transmission ultrasound technique can discriminate fracture subjects from controls with similar accuracy to that of DXA.

In collaboration with researchers from the University of Eastern Finland and Mikkeli Hospital, we have developed multimodal technology for the detection of early degenerative changes of articular cartilage. We have demonstrated quantitative magnetic resonance imaging (MRI), ultrasound, and spectral infrared spectroscopy as potential tools for improved clinical diagnostics. Novel quantitative MRI techniques have been developed and proven to be more sensitive to osteochondral degeneration when compared to established techniques. Furthermore, biomedical imaging techniques suitable for quantitative 3D imaging of osteochondral tissue samples are actively developed within the group. Specifically, micro/nano-CT and MRI based techniques are being investigated. These 3D techniques improve our understanding of the pathogenesis of early osteoarthritis.

We have performed studies on the extra-skeletal risk factors, showing that reduced physical performance is a significant determinant of a fracture. We also presented a detailed wireless body area network (WBAN) scenario
utilizing the recent IEEE802.15.6 standard as applied to a multi-accelerometer system for monitoring Parkinson’s disease and fall detection. Additionally, we presented an interactive, gamified activation method for increasing physical activity among young people.

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Doctoral Theses


Selected Publications


ELECTRONICS MATERIALS, PACKAGING AND RELIABILITY TECHNIQUES (EMPART)

Professor Heli Jantunen, Microelectronics and Materials Physics Laboratories, Department of Electrical Engineering, University of Oulu
Research Professor Pentti Karioja, VTT Oulu
heja(at)ee.oulu.fi, pentti.karioja(at)vtt.fi
http://www.infotech.oulu.fi/empart

The EMPART research group is a multidisciplinary research unit. Its main activities lie in the electronics materials and devices, and nanotechnology focus areas of the University of Oulu. The group is a key player in the Center of Microscopy and Nanotechnology of the University of Oulu, where our overall target is to integrate nanostructures enabling novel functionality of electronic, telecommunication, bio/medical and energy/environmental devices.

The group comprises of specialists in microelectronic and nanoelectronic materials, mechanical engineering, measuring techniques, and also in chemistry and physics. The personnel consists of six professors, twelve post-doctoral researchers and 20 doctoral students.

The group was funded in 2013 by the University of Oulu, a European Research Council Advanced Grant to Professor Heli Jantunen, Tekes, the EU, the Academy of Finland, ERA.Net, and by domestic and foreign industry. Global research co-operation is a characteristic feature of the EMPART group, having key roles in several EU and other international projects.

In accordance with the long term research targets, we have continued the integration of interdisciplinary topics towards future advanced device and component implementations. In addition, a wide range of application areas utilizing the generic materials knowledge of the group have been of great importance from the application point of view. In 2013, the group leader Professor Jantunen was appointed as a Member of the World Academy of Ceramics (WAC) in recognition of her eminence in promoting progress in the field of ceramics science and technology.

The group co-operated in 2013 with other Infotech Oulu research groups as a partner in PrintoCent (Printed Electronics and Optical Measurements Innovation Center) having a printed electronics laboratory. National and international research co-operation included common projects and publications, and student, researcher and lecturer exchanges. The group also acknowledges Finnish and foreign industrial partners for their active participation in research projects.

Materials, components and technologies developed by the group are widely applied in the electronics industry, especially in wireless telecommunication, sensors/actuators and hybrid microelectronics technology. LTCC micro modules and printed electronics devices are important examples of present exploitation, together with recent scientific achievements in nanotechnology with applications. Novel materials, as well as our progress in fabrication have been utilized in antennas, sensors, ceramic/polymer integrations, filters, micro-pumps, lens and mirror positioning systems, energy harvesters etc. The number of scientific refereed journal publications was about 45.

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Doctoral Theses


Selected Publications

Kumar N, Mäki-Arvela P, Diáz SF, Aho A, Demidova Y, Linden...


Background and Mission

The research area of the INTERACT group is information technology in its various forms embedded in everyday human practices. The roots of the group are in Human-Computer Interaction, European Computer-Supported Cooperative Work, Participatory Design, and Activity Theory research communities. The research group focuses on understanding and supporting participatory design, user-centred design, user innovation and human interaction with technology in divergent everyday life contexts. Generally, the research group acknowledges that information technology has become intertwined and embedded in almost all parts of our everyday life, including leisure and civic activity, thereby establishing new forms of participation and design. Hence, “users” cannot be considered as passive consumers anymore; they are at least content producers, sometimes even (co-)designers and innovators. This calls for reconsidering the traditional understandings of the roles of users and designers, as well as for different development approaches that place emphasis on user empowerment and inclusion in designing, shaping, innovating and co-creating information technology in their everyday life.

The INTERACT research group has a strong background in multidisciplinary research, combining perspectives from both humanities and information technology oriented disciplines. The group relies mainly on qualitative, participatory, and constructive research approaches; in many cases, developing novel pilot IT applications, and then experimenting with them in the field has an important role in research.

INTERACT has close cooperation in two directions: towards humanities and social sciences within the EveLINE (everyday life in technology-rich neo-communities) group, and towards computer engineering within the iUBI (Ubiquitous Interaction) group.

Human interfaces and experience with advanced mobile services and intelligent environments will be one of the major design challenges when the systems are moved from research laboratories towards everyday use. The INTERACT research group is addressing this problem area on a number of levels which support each other. On the level of basic research, the group is modelling the use context of advanced services and intelligent environments, and correspondingly envisioning and constructing novel technology architectures needed to provide the optimal user experience in those environments, in a controlled way. The group is also developing and experimenting with novel forms of enhanced multimodal interaction for devices and environments. Additionally, the group is developing new methods and techniques for design interaction in intelligent environments, and constructing test environments where both the interaction techniques and design methods can be tested and validated. Finally, the group is developing methods for the evaluation and improvement of HCI design processes in product development organisations.

Scientific Progress

During 2013 the main scientific results were: Studies on 3D user experience (Minna Pakanen, Leena Arhippainen), studies on an interactive kiosk interface (Anna-Liisa Syrjänen and team), and the introduction of a practice-based approach to HCI research (Kari Kuutti)

Exploitation of Results

Dissemination of results - The group has been publishing actively, and additionally the members of the group have been giving talks, presentations and demonstrations on a number of occasions, both in Finland and abroad, in both academic and industry led events. Several short visits from other groups have also been hosted.

Industrial cooperation - A number of Master’s theses have been supervised in cooperation with industry.

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Selected Publications

Pakanen, Minna; Arhippainen, Leena; Hickey, Seamus (2013) Designing for 3D user experience in tablet context-design and early phase user evaluation of four 3D GUIs. International Journal on Advances in Intelligent Systems 6(3-4): 266-278.


The Infotech Oulu Doctoral Program develops and fosters doctoral education and training in the general area of information technology. It is cross-disciplinary across the faculty borders covering research groups within the Faculties of Information Technology and Electrical Engineering, Medicine, and Biochemistry and Molecular Medicine. The training covers the related main subjects of doctoral training, in particular, communications engineering, computer science and engineering, electrical engineering, and information processing science.

All the doctoral student positions granted by the Ministry of Education and Culture and the Academy of Finland will cease nationally by the end of 2015. All such positions obtained by the Infotech Oulu Doctoral Program ended at the close of 2013, like positions of other doctoral programs where the research groups of Infotech Oulu were involved. The continuation for the funding of the doctoral student positions was secured by a successful application to University of Oulu.

The Infotech Oulu Doctoral Program is one of programs of the University of Oulu Graduate School (UniOGS). During the period 2010-2013 the program operated in three areas, corresponding to the major research fields of Infotech Oulu. These are electronics, communications engineering, and computer science and information engineering.

The Electronics section consists of electronic circuit and system design, microelectronics, electronics manufacturing technology, physical electronics, electronic and optoelectronic measurement technology, and testing and disturbance techniques in electronics.

Communications engineering covers telecommunication systems from the architectures and implementations of transceivers to telecommunication networks, systems and services. The main research themes include broadband wireless access, short range communications and sensor networks.

Computer science and information engineering emphasizes information processing methods, ubiquitous systems and human-computer interaction. The topics include machine vision, bio-signal analysis, data mining, intelligent robots, software security, mobile computing, urban computing and ubiquitous internet.

The Doctoral Program Board

Each of the main research areas was represented on the Infotech Oulu Doctoral Program Board, and the Technical Research Centre of Finland, VTT, had its own representative too. Professor Markku Juntti was the Director of the program and the Chair of the Board. The representatives of the main areas on the Board were Professors Juha Kostamovaara (electronics), Matti Latva-aho (communications engineering), Juha Röning and Kari Kuutti (both computer science and information engineering). Professor Pentti Karioja was the representative of VTT.

For the years 2014–2017, the following persons were appointed to the Infotech Oulu Doctoral Program Board: Professors Timo Rahkonen, Netta Iivari, Heli Jantunen, Timo Jämsä, Matti Latva-aho, Matti Pietikäinen and Juha Röning, Adjunct Professor Antti Tölli and doctoral student representative Mikko Hintikka. Professor Timo Rahkonen is the Doctoral Program Director from the beginning of 2014. At the same time, the former Director, Professor Markku Juntti begins his position as the new Dean of the University of Oulu Graduate School.

Funding

The Academy of Finland and the Ministry of Education and Culture granted 25 doctoral student posts for the Infotech Oulu Doctoral Program for the years 2010–2013. The posts were for doctoral students working in the research groups that are full or associate members of Infotech Oulu. These doctoral student posts altogether represented EUR 750 000 in salary costs in 2013. The funding for coordination was granted by the University of Oulu to the sum of EUR 38 000. Additional funding was obtained from the Academy of Finland for arranging doctoral courses and for other costs. The Academy granted EUR 430 000 for the years 2010–2013. EUR 107 500 were designated for 2013. Together with the annual direct financial support of EUR 20 000 from Infotech Oulu, the total budget of the doctoral program was EUR 915 500. In addition, Infotech Oulu supports its doctoral program by financing international workshops and researcher visits that include doctoral education, and also through the work of the staff in the research groups.

The Infotech Oulu Doctoral Program obtained 20 four-year and 14 two-year doctoral student positions funded by the University of Oulu starting from the beginning of 2014. From these 34 positions, 25 are allocated only for research groups selected to Infotech Oulu for 2014–2017, and the rest for all in the research fields of Infotech Oulu.

Students and Doctoral Theses

The Infotech Oulu Doctoral Program had 177 students at the end of 2013. This includes all the doctoral students in our research area working in the full and associate member groups of Infotech Oulu.

The output was 21 doctoral theses. Funding from the Infotech Oulu Doctoral Program positions was used for 12 of them: Mikko Määttä, Pekka Sangi, Guo Yimo, Francesco Pantisano, Pedro Nardelli, Adrian Kotelba, Jarmo Kukkola, Guoyong Duan, Jari Hannu, Marko Sonkki, Carlos Hércules Morais de Lima and Petri Komulainen defended their theses in 2013. The last five theses were funded only for a few months through our short-term posts that are used specifically for completing doctoral theses. The theses can be found in electronic format on the web from http://www.infotech.oulu.fi/dissertations.
The annual Infotech Oulu Doctoral Program student meeting was held at VTT in June, including a poster session.

Teaching Activities

Strong research contacts with other universities and research institutes are utilized in arranging lecturers for the courses. In each of the three major areas covered by the doctoral program, several lectures (the Infotech Oulu Lecture Series) and intensive courses are held annually. These all provide a valuable extension to the other doctoral courses in information technology provided by the university. The extent of the courses below is expressed in ECTS credits.

The Infotech Oulu Lecture Series

To gain two credits, a graduate student must follow 20 hours of lectures and make a written summary of one lecture. The following lectures were held in 2013.

- Dr. Elena Volkova, Saratov State University, Saratov, Russia - Impact of environment and temperature on the luminescent properties of ZnCdS nanoparticles
- Dr. Shirish Nagaraj, Nokia Solutions and Networks (NSN) - Distributed co-operative interference cancellation and power allocation strategies for enhancing small-cell cluster capacity
- Professor Laszlo Nanai, University of Szeged, Hungary - Nanophotonics
- Professor Saikat Talapatra, Southern Illinois University Carbondale, USA - 2D layered materials and applications: graphene and beyond graphene
- Associate Professor Huseyin Sari, Ankara University, Turkey - Introduction to optoelectronics
- Professor Marcus Foth, Queensland University of Technology, Brisbane, Australia - From smart city to smart citizens
- Dr. Mark C. Reed, Australian National University, and UNSW, Canberra - Heterogeneous networks and self-organising networks: new results and future challenges
- Professor Michael L. Honig, Northwestern University, USA - Power and beam optimization in interference networks
- Professor Roberto Verdone, University of Bologna, Italy - From smart lighting to smart city applications: field trials and research trends
- Professor Hamid Sharif, University of Nebraska-Lincoln, USA - Covert communication
- Assistant Professor Zhu Han, University of Houston, USA - Bad data injection in smart grid: attack and defense mechanism
- Dr. Chathuranga Weeraddana, Royal Institute of Technology (KTH), Sweden - On the application of optimization methods for secured multiparty computations & Optimizing client association in 60 GHz wireless access networks
- Professor Stan Z. Li, Chinese Academy of Sciences, China - New advances and applications of face recognition and video analysis
- Dr. Sander L. Jansen, ADVA Optical Networking, Munich, Germany - Introduction to fiber-optic communication systems
- Dr. Ian Oppermann, Director of CSIRO Digital Productivity and Services Flagship, Australia - Advances in Wireless Backhaul - more than just plumbing
- Dr. Ilya Fine, Elfi-Tech, Israel - Assessment of the vascular age by using DLS & Non-invasive optical measurement of hemoglobin: why it’s possible?

Intensive courses and workshops

- BioNanoElectronics in ICT, biomedicine & development 1)

Electronics

- Dr. Antony George, Rice University, USA - Nanofabrication
- Dr. Akos Kukovecz, University of Szeged, Hungary - Introduction to ceramic materials and silicate technology
- Associate Professor Andrei Schukarev, Umeå University, Sweden – Electron spectroscopy
- Dr. Vassil Palankovski, Vienna University of Technology, Austria - Advanced semiconductor devices, and Photovoltaic and thermoelectric devices for renewable energy harnessing
- Infotech Oulu Workshop 2013 on Optoelectronics Devices and Instrumentation XIII; Dr. Sumeet Mahajan, University of Southampton, United Kingdom - Raman spectroscopy; Dr. Björn Kemper, Center for Biomedical Optics and Photonics, Muenster, Germany - Digital holographic microscopy and speckle interferometry
- Dr. Bilge Saruhan-Brings, German Aerospace Center - Functional materials for high temperature energy and aerospace applications
- Professor A.E. Hill, Salford University, UK - Thin film solar cells, 2 credits
- Professor José C. Pedro, University of Aveiro, Portugal - Behavioral modeling and digital pre-distortion of RF PAs and wireless transmitters, 4 credits
- Dr. Evgeny Avrutin, University of York, UK - Photonic integration and nanophotonics, 4 credits
- Professor Jana Zauweis, Friedrich-Alexander University, Erlangen-Nürnberg, Germany - Organic light emitting transistors, 2 credits

Communications engineering

- Professor Dominic O’Brien, University of Oxford, UK - Visible light communications
• Professor Geert Deconinck, KU Leuven, Belgium, Smart grids
• Dr. Murilo da Silva Baptista, University of Aberdeen, UK - Information, topology and synchronization in complex networks: Theory and applications
• Professor Ekram Hossain, University of Manitoba, Winnipeg, Canada - Modeling, analysis, and design of multi-tier and cognitive cellular wireless networks; Interference modeling in random carrier-sense multiple access wireless networks; Dynamic spectrum access in cognitive radio networks
• Professor Babak Khalaj, Sharif University of Technology, Teheran, Iran - Stochastic geometry and random graphs in wireless networks
• Professor Merouane Debbah, Supelec, France - Random matrix theory for wireless communications
• The 1st International Summer School on Nanocommunications

Computer science and information engineering
• The Seventh International Crisis Management Workshop (CrIM’13) and the Oulu Winter School: Trends in cyber security after Snowden: Is cyber security still relevant? Lecturers: Professor Juha Röning, University of Oulu - Opening session and Closing session; Professor Gerald Quirchmayr, University of Vienna, Austria - A privacy perspective on social media analysis; Greg Soukiassian, IBM, Paris, France - Are your data safe and operations resilient in the clouds?; Assistant Professor Tiago Cruz, University of Coimbra, Portugal - CockpitCI cyber analysis and detection layer; Assistant Professor Filipe Caldeira, University of Coimbra, Portugal - Trust and reputation for critical infrastructure protection; Kari Jussila, Aalto University - Trade-off between privacy and security; Juhani Anttila, independent international expert - Pitfalls in the management system standardization for information security; Simona Samardjiska, Norwegian University of Science and Technology (NTNU), Norway - McEliece in the world of Escher; Professor Christos Xenakis, University of Piraeus, Greece - Compromising users’ privacy from stolen/lost mobile devices: the Android case; Antti Evesti, VTT Oulu - Case report on the NSA PRISM program
• Professor Iasonas Kokkinos, Ecole Centrale Paris, France - From motion analysis to deformable part models: representations and algorithms for shape analysis, registration, and detection
• Professor Alan FT Winfield, University of the West of England, Bristol, UK - Future directions in intelligent mobile robots
• Dr. Andrea Vedaldi, University of Oxford, UK - Large scale visual recognition of object instances and categories
• Dr. Jacques Richalet, independent consultant, Louveciennes, France - Algorithms with focus on PFC (Predictive Functional Control), tutorial, 18th Nordic process Control Workshop
• Associate Professor Magnus Bergquist, University of Gothenburg, Sweden - Open source and mobile phones: perspectives on open innovation and generativity, 4 credits
• 4th International UBI Summer School 2013 (2, 5 credits; Professor Albrecht Schmidt, University of Stuttgart, Germany - Developing ubiquitous computing devices; Professor Kaisa Välimäen-Vainio-Mattila, Tampere University of Technology, Finland - Experience-driven design of ubiquitous interactions in urban spaces; Professor Malcolm McCullough, University of Michigan, USA - Urban resource networks; Professor Mark Billinghurst, University of Canterbury, New Zealand - Augmented reality technologies in ubicomp

Co-operation
The following external organizations have provided co-financing or other support for the courses and workshops:
• Biocenter Oulu 1)
• UrBan Interactions program, Center for Internet Excellence (CIE) 2)

Course Information
Information about the courses is distributed through our web-pages and by email. The web address for the doctoral program is http://www.infotech.oulu.fi/doctoral_program, where students can also register to the doctoral student mailing list.

76 students from 18 countries attended UBISS 2013 (4th International UBI Summer School 2013) held in Oulu on June 10-15, 2013.
Full Member Groups

- **Algeria**: University of Mostaganem (CMV)
- **Argentina**: Universidad Nacional de Tucumán (WICS)
- **Australia**: Queensland University of Technology, Brisbane (MTO)
- **Austria**: Upper Austria University of Applied Sciences, Hagenberg (CAS); Vienna University of Technology (CAS, MTO, WICS)
- **Belgium**: Ghent University (MTO); Interuniversitair Micro-Electronica Centrum vzw, Leuven (WICS); Magwel N.V. (CAS); Université Catholique de Louvain (WICS)
- **Brazil**: State University of Campinas (WICS); Universidade Tecnológica Federal do Paraná - Campus Curitiba (UTFPR) (WICS)
- **Canada**: Carleton University, Ottawa (CAS, MTO); University of Toronto (MTO)
- **China**: Beijing Jiaotong University (WICS); Beijing University of Post and Telecommunications (MTO, WICS); Chinese Academy of Sciences, Institute of Automation, Beijing (CMV); Chinese Academy of Sciences, Institute of Computing Technology, Beijing (CMV); Chinese Academy of Sciences, Institute of Psychology, Beijing (CMV); Huazhong University of Science and Technology (HUST) (ISG); National University of Defence Technology (CMV); Shanghai Jiaotong University (ISG); Shanghai Research Center for Wireless Communications (WICS); Southeast University, Nanjing (CMV, WICS); Tianjin University (ISG); Tongji University (WICS); Tsinghua University, Beijing (ISG, WICS); University of Electronic Science and Technology of China (WICS); University of Science and Technology Beijing (CMV); Wuhan University (CMV); Northwestern Polytechnical University (NPU), Xi’an (CMV)
- **The Czech Republic**: Academy of Sciences of the Czech Republic, Prague (CMV); Brno University of Technology (CMV); Czech Technical University, Prague (ISG, CMV); Saska (CAS)
- **Denmark**: Aarhus University (MTO); Aalborg University (WICS); Swantec, Lyngby (ISG); University of Copenhagen (WICS)
- **Egypt**: Mansoura University (MTO)
- **Estonia**: ELIKO, Tallinn (ISG); Tallinn University of Technology (ISG, CMV)
- **France**: Atos Origin (MTO); Cea List, (ISG); Centre National de la Recherche Scientifique, Paris (WICS); EADS Defence and Security Systems SAS (ISG); EADS Secure Networks SAS (ISG); École Nationale Supérieure de Techniques Avancées (ENSTA); Paris (WICS); France Telecom-Orange (MTO); INRIA, Grenoble, Rhône-Alpes (CMV); INRIA, Paris (MTO); INRIA, Rennes (ISG); INSa, Rennes (CMV); Institut Eurécom (CMV, WICS); Institut Telecom Sudparis (MTO); Mandriva (ISG); Montpellier 2 University (CAS); MORPHO (CMV); SUPELEC (WICS); Technax Industrie, Genas (ISG); Thomson Video Networks (MTO); Trusted Logic (ISG); University of Avignon (CMV)
- **Germany**: Airbus Deutschland, Hamburg (ISG); Brötje Automation, Wiebefeldt (ISG); Fraunhofer FKIE, Wachtberg (ISG); Fraunhofer IFF, Magdeburg (ISG); Fraunhofer IOSB, Ilmenau (CAS); Fraunhofer IPA, Stuttgart (ISG); German Research Centre for Artificial Intelligence (MTO); Harms & Wende, Hamburg (ISG); IEF-Werner GmbH (ISG); ISG Industrielle Steuerungstechnik GmbH (ISG); Jacobs University, Bremen (WICS); Karlsruhe Institute of Technology (WICS); Karlsruhe University of Applied Sciences (ISG); KUKA Schweissenlagen, Ausburg (ISG); Ludwig Maximilian University of Munich (MTO); Qimonda, Munich (CAS); RWTH Aachen University (WICS); Sick AG, Waldkirch (CAS); Steinbeis-Europa-Zentrum (ISG); Stuttgart Media University (MTO); Technische Universität Dresden (WICS); Technische Universität Kaiserslautern (WICS); University of Bremen (WICS); University of Cologne (CAS); University of Duisburg-Essen (MTO); University of Freiburg (CMV); University of Hannover (WICS); University of Stuttgart (MTO); University of Wuppertal (CAS)
- **Greece**: Institute of Accelerating Systems and Applications, Athens (WICS); Ionian University (MTO); National and Kapodistrian University of Athens (WICS); ISSC, Athens (CAS); University of Central Greece (MTO); University of Patras (MTO)
- **Hungary**: Gamax, Budapest (ISG); University of Debrecen (MTO)
- **Iran**: Sharif University, Tehran (WICS)
- **Ireland**: Tyndall Institute (CAS); Xiulinx, Dublin (WICS)
- **Israel**: Technion - Israel Institute of Technology, Haifa (WICS)
- **Italy**: Center for Science, Society and Citizenship (CMV); Centro Ricerche Fiat, Torino (ISG); Centre for Maritime Research and Experimentation (CMRE) (ISG); Consorzio Nazionale Interuniversitario per le Telecomunicazioni (CNIT) (WICS); Istitel (ISG); Politecnico di Torino (CMV, WICS); Università della Calabria (WICS); University of Bologna (WICS); University of Cagliari (CMV); University of Florence (WICS); University of Genoa (ISG); University of Rome (Tor Vergata) (WICS); University of Sassari (CMV); University of Trento (CMV); Fondazione Bruno Kessler (FBK), Trento (CAS)
- **Japan**: Hiroshima University (WICS); Hokkaido University (ISG); Japan Advanced Institute of Science and Technology (WICS); Keio University, Tokyo (MTO); Nagoya University (ISG); Osaka University (WICS); Tokyo Denki University (ISG, MTO); Tokyo University of Agriculture and Technology (ISG); University of Tokyo (ISG, CMV); Waseda University, Tokyo (ISG, MTO); Yokohama National University (WICS)
- **Luxembourg**: BCE Broadcasting Center Europe (MTO); Public Research Centre Henri Tudor (ISG, MTO)
- **Malaysia**: Multimedia University, Selangor Darul Ehsan (CAS)
- **Mexico**: Center for Research and Advanced Studies (CINVESTAV), Guadalajara (WICS); Universidad de Guanajuato (CMV)
- **The Netherlands**: AWL-Techniek, Harderwijk (ISG); Gemalto (ISG); ERCOM (ISG); NXP Semiconductors B.V. (CAS); University of Twente (WICS); Utrecht University (MTO)
- **New Zealand**: University of Auckland (CMV)
- **Poland**: Poznan University of Technology (WICS); Instytut Spawalnictwa, Giwice (ISG)
- **Portugal**: Critical Manufacturing (ISG); Critical Software (ISG); IdMind, Lisboa (ISG); Ines Inovação - Instituto de Novas Tecnologias (INOV), Lisboa (WICS); Institute of Systems and Robotics, University of Coimbra (ISG); University of Madeira (MTO); University of Porto (ISG, CMV)
- **Russia**: A.F. Ioffe Institute, St. Petersburg (CAS); The Siberian Branch of the Russian Academy of Sciences (CMV)
- **Singapore**: Agency for Science, Technology and Research (A*STAR) (CMV)
- **Spain**: Acotec Castilla, Boecillo (ISG); Caixa d’estalvis de Catalunya, Barcelona (ISG); Centre Tecnologic de
Telecomunicacions de Catalunya, Barcelona (WICS); Centre for Advanced Aerospace Technologies (CATEC) (ISG); Fagor Automation S. Coop. (ISG); Fatronik (ISG); Fundación Robotiker (ISG); GMV (ISG); Plataforma Oceánica de Canarias (PLOCAN), Canary Islands (ISG); Sturlab Barcelona (CMV); TB-Solutions (ISG); Technical University of Madrid (UPM) (ISG); Universidad Autónoma de Madrid (CMV, MTO); Universidad de Murcia (MTO); Universidad Politécnica de València (WICS); Universitat Pompeu Fabra, Barcelona (ISG); University of Vigo (MTO)

- **Sweden:** Chalmers University of Technology (WICS); Ericsson (ISG); Luleå University of Technology (ISG, MTO); Malmö University (CMV); Mobile Life Centre (MTO); Royal Institute of Technology, Stockholm (ISG); Stockholm University (MTO); Volvo, Gothenburg (CAS); University of Gävle (MTO)
- **Switzerland:** BIOMETRY.com AG (CMV); Ecole Polytechnique Fédérale de Lausanne (ISG, CMV); EyePmedia (CMV); IdeArk (CMV); Idiap Research Institute (CMV); KeyLemon (CMV); PARO AG (ISG); Swiss Federal Institute of Technology Zurich (ETH) (WICS); University of Lugano (MTO); Z.E.C. AG (ISG)
- **Thailand:** Asian Institute of Technology, Bangkok (WICS)
- **Turkey:** Bilkent University (WICS)
- **The United Kingdom:** Heriot-Watt University, Edinburgh (ISG); Imperial College London (CMV); Lancaster University (MTO); Microsoft Research Ltd., Cambridge (ISG); National Infrastructure Security Co-ordination Centre (NISCC) (ISG); University College London (MTO); University of Bath (MTO); University of Birmingham (MTO); University of Cambridge (WICS); University of Coventry (MTO); University of Manchester (CMV); University of Nottingham (ISG); University of Oxford (CMV); University of Southampton (CMV); University of Surrey (CMV, WICS); University of York (CAS)
- **The United States:** Carnegie Mellon University, Pittsburgh (ISG, MTO); Columbia University, New York (ISG, MTO); Dartmouth College, Hanover (ISG); Drexel University, Philadelphia (WICS); IBM Research (MTO); Massachusetts Institute of Technology (WICS); National Science Foundation (NSF) (ISG); Nokia Research Center, Cambridge (ISG); NVIDIA Research (CMV); Purdue University, West Lafayette (WICS); Rice University, Houston (CMV, WICS); Stanford University (WICS); University of California, Santa Barbara (CMV); University of Maryland (ISG, CMV, MTO, WICS); Virginia Tech (WICS); Worcester Polytechnic Institute (WICS)
- **France:** French National Center for Scientific Research - Laboratory for Analysis and Architecture of Systems (CNRS-LAAS), Toulouse (EMPART); XLIM, Limoges (EMPART)
- **Germany:** Fraunhofer FIT, Bonn (INTERACT); Fraunhofer ISC, Würzburg (EMPART); Laser-Laboratory Göttingen GmbH (EMPART); RWTH Aachen University (EMPART); Technical University of Ilmenau (EMPART); Technische Universität Darmstadt (EMPART)
- **Greece:** Institute of Communication and Computer Systems (EMPART); National Technical University of Athens (EMPART)
- **Hungary:** Budapest University of Technology and Economics (EMPART); Debrecen University (BME); University of Szeged (EMPART)
- **India:** Council of Scientific and Industrial Research, Thiruvananthapuram (EMPART)
- **Italy:** Association for European Cardiovascular Pathology (BME); Consorzio per la Ricerca nell’ Automatica e nelle Telecomunicazioni (CRAT) (BME); Istituto Nazionale per le Ricerche Cardiovascolari (INRC) (BME); Klopman International (BME); Labor S.r.l. (BME); STMicroelectronics S.r.l. (BME); Telbios S.p.A. (BME); Unità di Telemedicina Ospedale San Camillo (BME)
- **Japan:** Mushiushi University, Yokohama (INTERACT); Tohoku University (BME)
- **Korea:** Kyonggi University, Seoul (EMPART); Yonsei University, Seoul (EMPART)
- **Latvia:** University of Latvia, Riga (EMPART)
- **Lithuania:** Vilnius University (EMPART)
- **The Netherlands:** University of Twente (BME)
- **Norway:** SINTEF (EMPART)
- **Poland:** Gdansk University of Technology (EMPART); Institute of Electronic Materials Technology (EMPART); Medical University of Gdansk (BME); Warsaw University of Technology (EMPART); Wrocław University of Technology (EMPART)
- **Portugal:** Aveiro University (EMPART); Portugal Telecom Inovacao (BME)
- **Russia:** Kurchatov institute, Moscow (EMPART); St. Petersburg Electrotechnological University (EMPART)
- **Slovenia:** Josef Stefan Institute, Ljubljana (EMPART)
- **Sweden:** Chalmers University of Technology (EMPART); Ericsson (EMPART); Linköping University (EMPART); Luleå University of Technology (BME); Royal Institute of Technology, Stockholm (EMPART); Umeå University (EMPART)
- **Switzerland:** Ecole Polytechnique Fédérale de Lausanne (EMPART)
- **Taiwan:** National Taiwan Normal University, Taipei (EMPART); National Taiwan University (EMPART); National United University (EMPART)
- **The United Kingdom:** Cranfield University (BME); Imperial College London (EMPART); University of Birmingham (BME, EMPART); University of Cambridge (INTERACT); University of Hull (BME); University of Manchester (EMPART); University of Nottingham (EMPART); University of Salford (EMPART); University of Southampton (BME, EMPART); University of Surrey (EMPART)
- **The United States:** Arizona State University (EMPART); Rensselaer Polytechnic Institute, Troy (EMPART); Rice University, Houston (EMPART); Rutgers University, New Jersey (EMPART); University of Arizona (EMPART); University of California, Berkeley (EMPART); University of Minnesota (BME); University of Missouri - St. Louis (EMPART)

**Associate Member Groups**

- **Armenia:** Scientific Production Enterprise of Material Science (EMPART)
- **Austria:** Graz University of Technology (INTERACT); Paracelsus Medical Private University (BME); Vienna University of Technology (INTERACT)
- **Belgium:** Interuniversitair Microelectronic Centrum (IMEC) (EMPART); Katholieke Universiteit Leuven (BME)
- **Canada:** Carleton University, Ottawa (EMPART); Communications Research Centre, Ottawa (EMPART); University of Waterloo (BME)
- **China:** Tsinghua University (BME, EMPART)
- **The Czech Republic:** Academy of Sciences of the Czech Republic, Prague (EMPART); Czech Technical University, Prague (BME)
- **Denmark:** Aalborg University (INTERACT)
Biomimetics and Intelligent Systems (BISG)
The Biomimetics and Intelligent Systems Group (BISG) is a fusion of expertise from the fields of computer science and biology. In BISG, our bread and butter is intelligent systems, and our research areas include data mining, machine learning, robotics, and information security. More precise research topics vary from data mining algorithm development and optimization of industrial manufacturing processes all the way to environmental monitoring with mobile robots. In addition to the group’s long term research strands, it also aims to provide concrete new openings for the purpose of reacting to fundamentals and novelties to integrate better ICT and biotechnology/biomedicine. The rapid development of ICT and Bio has opened up new unexpected ways to achieve better and concrete synergies and integration of these research fields.

Biomedical Engineering (BME)
The mission of the Biomedical Engineering Group (BME) is to carry out top-level basic, applied and translational research in biomedical engineering. The aim is to develop, apply and evaluate novel biomedical measurement technologies in health and wellbeing. The research is interdisciplinary, and focuses on measurement problems with the cardiovascular system, central nervous system, respiratory system and musculoskeletal system, together with applications in biomedicine and eHealth. The research profile is based on linking information technology and medicine, with an aim to utilize methodologies of information engineering, signal and image processing, pattern recognition, biophysics, medical imaging, applied mathematics, simulation, biomedicine and clinical medicine. BME has strong national and international collaborative networks, including partners in the USA, Japan and many European universities.

Center for Machine Vision Research (CMV)
The mission of the Center for Machine Vision Research (CMV) is to develop novel computer vision methods and technologies that create the basis for emerging innovative applications. CMV plans to carry out well focused cutting-edge research, for example, on novel image and video descriptors, perceptual interfaces for face to face interaction, multimodal analysis of emotions, 3D computer vision, and energy-efficient architectures for embedded vision systems. The application areas to be considered include human-computer interaction, biometrics, affective computing, mixed reality, and biomedical image analysis. CMV has an extensive international collaboration network in Europe, the USA, and China.

Circuits and Systems (CAS)
The interest of the CAS group (Circuits and Systems) is devoted to certain novel devices, circuit topologies and functional units, although the group is also working with applications, especially in the field of electronic/optoelectronic measurements and radio telecommunications. The main research fields of the CAS group are high speed pulse electronics and linearization of electronics. In high speed pulse electronics, the research focus is on pulsed time-flight techniques and the development of related circuits, devices and applications. The group represents, for example, the current state of the art in the field of long-range of time-to-digital converter circuits. The specialty of this group is that in addition to electronics, it has also solid experience in optoelectronic circuits and devices. Within the topic of linearization of electronics the emphasis is on analysis and correction of non-linear distortion. In this field, the group has carried out fundamental work in explaining distortion memory effects in RF power amplifiers.

Communications Signal Processing (CSP)
The Communications Signal Processing (CSP) Research Group (RG) focuses on technologies required for efficient implementation of a multitude of devices or network nodes of the future connected society. The focal area of the research is to develop algorithms and their realizations for dense wireless networks, in particular for relatively small communication ranges in indoor and urban areas. This enables new massive multi-antenna access points or base stations, as well as user cooperation to realize the vision of virtual multiple-input multiple-output (MIMO) communications in both peer-to-peer and cellular networks. The system level algorithms are considered both for high rate access connections and their down-scaled versions for low-power and low-complexity wireless sensor network (WSN) applications, with a significant emphasis on medical applications.

Electronics Materials, Packaging and Reliability Techniques (EMPART)
The group consists of specialists in micro/nanoelectronics, materials, process, mechanical and electrical engineering. The research group brings together all the essential know-how to accomplish embedded multifunctional electronics integrations. These are based on new, difficult to copy hyper-active materials, high dielectric and optical performance materials, the most feasible, cost-aware fabrication technologies for hybrid electronics, and high-end state-of-the-art electronics integrations enabling functional diversification in line with, for example, the “More-than-Moore” concept for future electronics.
Networking (NET)

NET consists of three research groups: 1) Networking 2) Future Wireless Internet and Sensor Network Architectures and 3) Sensor Networking. In the search for future new networking paradigms, NET is doing research in the field of 5G/6G network architectures, wireless internet, cognitive networks, spectra management, networks economics and security, low exposure wireless networks, as well as future Internet applications. Scientific problems the group is engaged in include: network optimization on layers 2.5 (MAC), 3 and 4, development of secure network architectures, development of efficient sensor networks architectures, and efficient protocols on the application layer. Mathematical tools used in the research are network optimization theory, network information theory, queuing and game theory. The NET group also runs an extensive doctoral program to educate our students in the field of networking.

New Generation Optoelectronics for Measurement Applications (NeGOMA)

The NeGOMA group focuses on development of solution processable components and systems (sensors and sensor networks, light sources, light detectors, optical components etc) for different kinds of measurement applications. Printing technology is one very promising fabrication concept for solution processable optoelectronics, but also some other methods are possibly used (evaporation, spin coating, dispensing etc.) to find the most feasible fabrication methods. The motivation is to find new ways of applying new generation optoelectronics to generate high level scientific knowledge, but also to find solutions which have real commercial potential in industry and health care.

Radio Access Technologies (RAT)

The Radio Access Technologies group is strongly focusing on 5G mobile cellular systems research. The key drivers in the research are densification of cells, improving transmission efficiency under interference, more efficient use of the existing spectrum in a multi-operator environment, radio access for future spectrum allocations, as well as radio channel modeling for beyond 6 GHz frequencies. The target is to develop fundamental theoretical tools for analysis and synthesis of future mobile systems, as well as development of selected key technology components needed in 5G systems.
Oulun yliopiston yksi neljästä strategisesta painoalasta on informaatioteknologia, jonka fokusalueiksi on määritelty konenäkö ja jokapaikan tietotekniikka, langaton viestintä, nopea elektroniikka ja fotoniiikka, lääketieteen teknikka, sekä tietojärjestelmat. Infotech Oulu on Oulun yliopiston vuonna 1996 perustama informaatioteknian tutkimuksen, sateenvarjo-organisaatio, Tutkimuksen pääaloina ovat elektroniikka, tietoliikennetekniikka sekä tietojenkäsittelytekniikka.

Infotech Oulun tehtävänä on luoda ympäristö, jossa kansainvälinen tason tutkimusryhmät voivat kehittyä ja toimia parhaalla mahdollisella tavalla. Infotech Oulu edistää pitkäaikaiseksi tutkimusta, tutkijankoulutusta, kansainvälistyyttä sekä tutkimusryhmien ja eri sidosryhmien välistä yhteistyötä. Perus- ja soveltuvaan tutkimuksen vuorovaikutus nähdään tärkeäksi, mutta parhaat tulokset saadaan, kun liikkeellepanevana voimana on ulkoaaltouutiset.


Vuoden 2013 lopussa täysjäseninä toimivissa tutkimusryhmissä työskenteli 269 henkeä. Liitännäisiä ryhmää mukaan lukien henkilömäärä oli 361. Edellisvuoteen verrattuna luvut ovat kasvaneet 22,5%.

Infotech Oulun tutkimusryhmässä työskenteli 269 henkeä. Liitännäisiä ryhmää mukaan lukien henkilömäärä oli 361. Edellisvuoteen verrattuna luvut ovat kasvaneet 22,5%.

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