INTELLIGENT SYSTEMS GROUP (ISG)

Professor Juha Röning, Professor Jukka Riekki and Professor Tapio Seppänen,
Computer Engineering Laboratory, Department of Electrical and Information Engineering,
University of Oulu
juha.roning(at)ee.oulu.fi, jukka.riekki(at)ee.oulu.fi, tapio.seppanen(at)ee.oulu.fi
http://www.ee.oulu.fi/research/isg

Background and Mission

The Intelligent Systems Group's (ISG) mission is to carry out long-term research on novel technologies and applications of intelligent systems. The main objective is to develop enhanced adaptivity and context-awareness for smart environments. The research specifically focuses on the creation of dynamic models that enable monitoring, diagnostics, prediction and control of target systems (living and artificial) or operating environments. It is our aim to make the environment adapt to the users, instead of making the users adapt to an inflexible environment. We believe that by creating these novel components for smart environments, important enabling functionality will emerge that will multiply the versatility and applicability of such living environments.

We see behaviour modelling as a major challenge in developing truly intelligent and proactive environments. Human users of smart environments often behave in such a complex manner that it is hard to predefine and pre-program all of their behavioural patterns in the software. Models of user behaviour are required that are able to grasp the user's context at any moment, and to enable adaptation of the functionality of the intelligent environment to the situation at hand. Further, it is essential to model the behaviour of the devices controlled by the intelligent environment, as this enables adaptation to environmental changes without reprogramming. Systems should eventually learn and adapt automatically through these models to perform their duties effectively.

Our research group combines a variety of key skills and technologies to aim at the goal described above. We have experience in the following key technologies: system architectures and implementation of context-aware systems; modelling and recognition of contexts from sensor signals; data mining algorithms; learning nomadic robots; embedded systems technologies; software security; and smart environment implementations. The key application areas are: smart living environments in homes and institutes; industrial automation; mobile robots; context-aware mobile devices; and wellness and medical applications. Each of these domains possesses special characteristics, but, from the point of view of developing algorithms for an intelligent system, they also possess remarkable similarities. They all produce a multitude of signals that represent the status of the system. The target system behaviour should be modelled and recognized from the signals. The application service should then act accordingly. The availability of several application domains yields many advantages: a solution to a special problem in one domain may offer added-value functionality in some other domain; our solutions are deployed by many of our client industries; solutions to a wide range of real-world problems define a credible and versatile toolbox that has a major impact on our development-oriented sub-contractual projects.

The group co-operates with many international and domestic partners. In applied research, the group is active in European projects. The group hosted the ROBOSWARM European Union project final review meeting in 2009. In addition, several joint projects are funded by the Finnish Funding Agency for Technology and Innovation (Tekes) and industry. The group is a research partner in the Cooperative Traffic ICT SHOK, and the Devices and Interoperability Ecosystem (DIEM) ICT SHOK. In 2009, the group started two international collaboration projects: II City together with the University of Lapland and Sonic Studio from Piteå, Sweden, and Pervasive Service Computing together with Shanghai Jiao-Tong University from China. These projects are funded by the European Union (Interreg IVA North) and the Academy of Finland (the MOTIVE program). Prof. Jukka Riekki visited the Keio University and Tokyo Denki University for two months in summer 2009 and gave over ten invited talks during the visit. He also participated in negotiating and signing of the Memorandum of Understanding with the Keio University in November 2009. Collaboration with the Tokyo Denki University will start in 2010.

The group and its members are active in the scientific community. For example, Prof. Juha Röning co-chaired numerous international workshops in the software security area, including the 5th Crisis Management Workshop (CRIM 2009) in Oulu, Finland. He also acted as a member of the SAFECode International Board of Advisors, 2009. The group organized the Civilian European Land Robot Trial (Celrob 2009) in Oulu in June. C-Elrob is the biggest outdoor robot event in Europe, and participants are research facilities and companies that represent the state-of-the-art in Europe in this research area. Prof. Jukka Riekki co-chaired the Second Asia-Europe Workshop on Ubiquitous Computing 2009 (AEWUC'09), organized in August 2009 at Shizuoka, Japan.

Prof. Tapio Seppänen is a leading figure in both the WellTech Oulu Institute, and the Oulu School of Biomedical Engineering, an umbrella organization of wellness and medical technology education at the University of Oulu and the Oulu University of Applied Sciences.

Several members of the group were also on the committees of international conferences. The group's expertise is recognized, testified by the many invited talks and lectures that have been given. The Intelligent Systems Group has

communicated its research to the public and its research areas have attracted interest in the media.

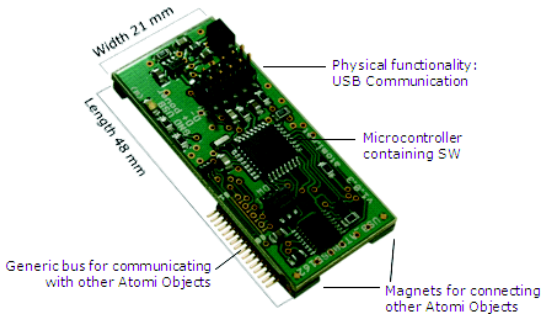
Scientific Progress

In 2009, the research at ISG concentrated on prototyping smart environments, mobile and context-aware systems, data mining methods, signal analysis and secure programming. These were applied in context-aware mobile systems, intelligent service robots, quality control of steel plant and spot welding processes, and analysis of biomedical ECG and EEG signals.

Research on Prototyping: from a Smart Environment towards Remote Distributed Intelligence

Verification of the developed methods and models in prototypes will be an important part of the research. To support this activity, we will develop software and hardware architectures for smart environments. In addition to verification, prototypes speed up the commercialization of the research results. In prototyping, we have set and tackled the following objectives:

Developing Hardware And Software for Prototypes And Commercial Devices: The goal is to make designing of embedded systems faster and easier, while preserving the commercial applicability of the resulting device. This has been approached via the Embedded Object Concept (EOC). EOC is a concept that utilizes common object-oriented methods used in software by applying them to combined Lego-like software-hardware entities. This approach enables people without comprehensive knowledge in electronics design to create new embedded systems. For experts, it shortens the design time of new embedded systems. The conceptual idea of embedded objects has been successfully implemented with the Atomi II framework, which provides so called Atomi modules.



Atomi module.

The EOC research has proceeded by developing new objects. The focus of the research has been on improving their robustness, and testing the concept in practice by supporting other research projects. The research will continue towards user friendly development tools in order to further improve the concept.

Research on Nanoresolution Tools for Interdisciplinary Applications: The project "Nanoresolution tools for interdisciplinary applications" develops novel research, manipulation, and manufacturing methods for micro- and nanotechnology components and instruments. This means ever smaller objects, which are adhered to surfaces not measurable with existing tools. A network of contacts and collaborators is used to select the objectives where commercial instruments are not yet available. One basis of the selection is a study of the commercial potential and value. Commercial potential affects the cost and selection of the components to be used also enabling the commercialization process. In order to improve the regional effect of the project, market studies will look into the regional effects.

The tools developed in NRT are based on a Scalable Modular Control Architecture (SMCA) that is developed in the project. It is a generalized modular architecture for both the device hardware and the control software on a PC. The architecture is extensible, scalable and portable, and it enables reuse of modules. It is hierarchically layered hybrid architecture to implement research equipment. The SMCA enables swift changing of actuators, sensors and tools with minimal effort, thus being an ideal frame for various applications.

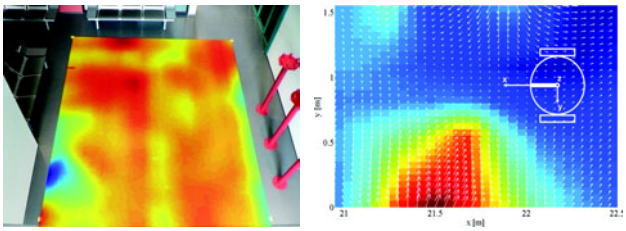
Implementation of SMCA is included in the framework within the project. The framework aims to improve the quality of the developed tools and enable fast prototyping. To achieve these goals, the framework includes reusable components that perform the tasks needed in all developed measurement tools such as data management, data visualization and configuration of devices. It also supports run-time specialization of measurement tasks to enable the use of the same hardware to perform different measurement tasks easily.

The project utilizes also the previously developed Embedded Object Concept (EOC), which utilizes common object-oriented methods used in software by applying them to combined Lego-like software-hardware entities. These modular entities function as the building blocks of embedded systems. This concept enables one to build new embedded systems from electronic Lego-like building blocks, and it enables people without comprehensive knowledge in electronics design to create new embedded systems. For experts, it shortens the design time of new embedded systems.

Research on Mobile Robotics

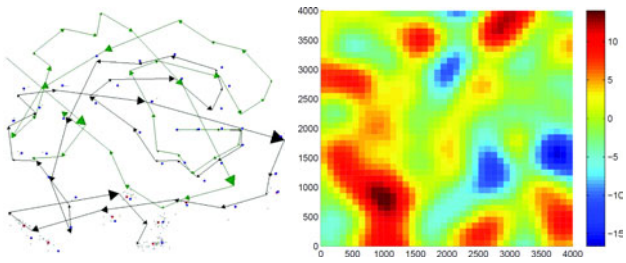
Global pose estimation is of fundamental importance in various mobile robot applications where the accurate pose of the robot in a given environment is needed in order to successfully perform application specific tasks. Today, numerous techniques exist for indoor pose estimation. The most common techniques are based on range sensors and computer vision and these techniques have been successfully applied to various environments and mobile robot applications. Despite the fact that good solutions already exist for indoor pose estimation there is room for new techniques which can make the pose estimation more accurate when combined with other techniques, more robust against possible changes in environmental conditions, and perhaps provide more cost efficient solutions for pose estimation. We proposed a global indoor pose estimation technique utilizing the ambient magnetic field. The technique is based on the well known observation that magnetic field fluctua-

tions commonly exists inside buildings. These fluctuations arise from both natural and man-made sources, such as steel and reinforced concrete structures, electric power systems, electric and electronic appliances, and industrial devices. Assuming the anomalies of the magnetic field inside a building are nearly static and they have sufficient local variability, the anomalies provide a unique magnetic landscape that can be utilized in global pose estimation. Our experiments suggest that the ambient magnetic field may remain sufficiently stable for longer periods of time giving support for pose estimation techniques utilizing the local fluctuations of the magnetic field.



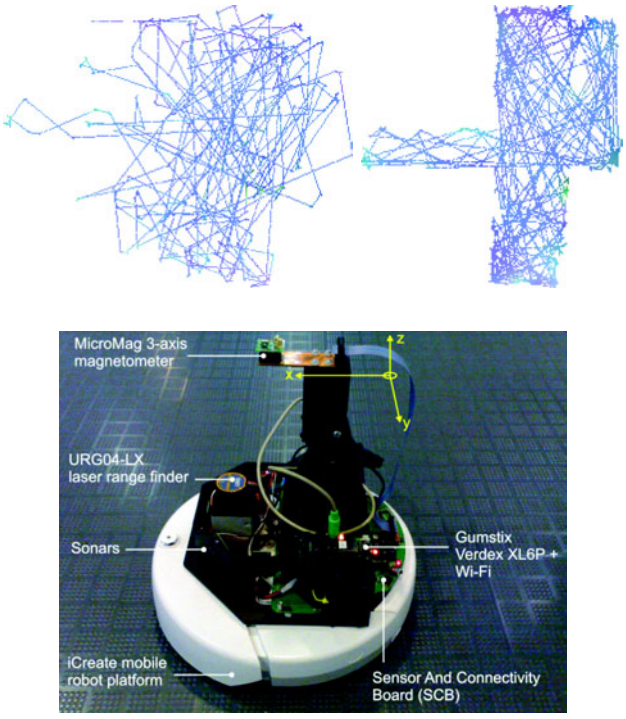
An indoor ambient magnetic field (left) and a close up from an ambient magnetic field showing the magnitude of the field (color) and the direction of the field (arrows) in x-y plane.

We have studied near-optimal Simultaneous Localization and Mapping (SLAM) exploration utilizing Gaussian processes (GP). As part of this work, we have proposed a submodular sensing quality function which extends studies from discrete sensor placement into an autonomous sampling scheme where sensing sites must be visited frequently. This is beneficial in a SLAM context where sensing sites themselves bear uncertainties. Also in time critical applications, the modelling accuracy has to be balanced with the sensing time. Our SLAM studies are inspired by our research on indoor mobile robot localization, utilizing ambient magnetic fields which can be modelled by three orthogonal GPs providing a flexible framework for localization and SLAM. We have proved that for applications where sensing sites must be visited frequently, mutual information provides near-optimal solutions. We have extended this into metric probability spaces where sensing sites are treated as random variables. We have shown that with particle filter discretization, this framework can attain near-optimality.



Left: particle distribution after 40th iteration on a sine mean function. The black and green arrows are the true and mean control (odometry) paths, respectively. The grey dots represent particles, red dots expected sensing sites and blue dots are the most likely sensing sites. Right: an illustration of a component of the true vector field used in the simulations to emulate the ambient magnetic field, which provides the necessary information for the proposed nearoptimal SLAM.

SLAM is one of the most fundamental challenges in mobile robotics. With the SLAM problem, the robot has no prior map nor pose information, and it tries to simultaneously acquire a map and localize itself. In addition to odometric information, sensor information from the surrounding environment is also needed in SLAM in order to compensate for the effect of cumulative error introduced by odometric sensors. To the best of our knowledge, we are the first ones to utilize spatial anomalies of indoor magnetic fields to solve the SLAM problem, yielding a low-cost, simple, and space efficient SLAM solution for cost and space sensitive application domains. Particularly low-cost domestic robots such as robotic vacuum cleaners would benefit from inexpensive and computationally efficient SLAM methods. The main hypothesis of the approach we have proposed is that the indoor ambient magnetic field contains enough information to overcome the cumulative error of odometric data. Our experiments suggest that this hypothesis is indeed valid, and the magnetic landscape has enough deviation to correct the odometric information.



Top left: a geometrically distorted map (from the CSE laboratory) based on odometric data only. Top right: a geometrically consistent map provided by the SLAM technique that is based on the utilization of the ambient magnetic field. Bottom: the robot used in the real-world experiments.

Research on Context-Aware Services

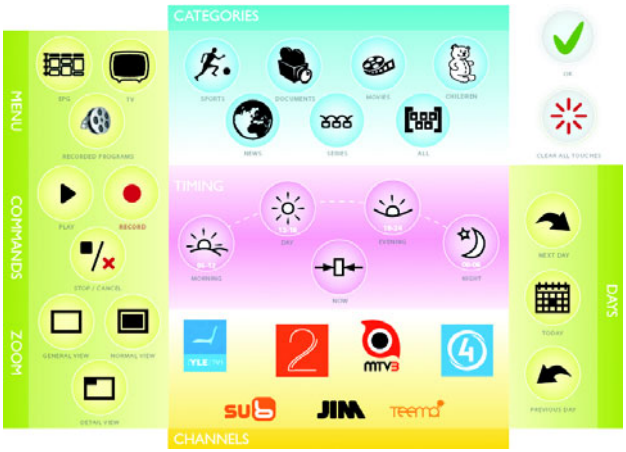
Context-aware services adapt to the user's situation. We have studied context recognition in several different application areas, including human physiology, wellness, urban computing, smart office spaces and body sensor networks. The aim is to find and develop methods for recognizing the user's context from sensor data using signal processing, pattern recognition and machine learning methods. Context can be used to identify the services that are relevant in the situation at hand - and to adapt these services.

During 2009, the research on context recognition has continued in the application area of cooperative traffic. This research was conducted in the Sensor Data Fusion and Applications project of the Cooperative Traffic ICT SHOK. The group has developed methods for recognizing road conditions from acceleration sensor data. We demonstrated in 2009 a complete prototype that contains acceleration sensors in a car and a server storing and processing data, and delivering results for clients. This research was conducted together with the University of Jyväskylä, the Tampere University of Technology, the Information Processing Department of the University of Oulu, and VTT.

The work in cooperative traffic is an example of the group's shift to studying signal processing in networked sensing systems. The group studies such systems also in the UbiCity and RealUbi projects, where a tool on gathering, storing and processing sensor measurements from a heterogeneous sensor network is being built. The first prototype for measuring the energy consumption of apartments using wireless sensor nodes is to be completed in early 2010.

In addition to recognizing a user's context, sensor data can be used to build a physical user interface in which a user uses a mobile device as a physical object rather as a traditional I/O device. The device is equipped with sensors and the actions of the user are recognized from the sensor data and interpreted as commands. Gesture controlling is an example of a physical user interface; the user commands the system by waving the terminal in the air. In addition to gestures, the group is actively developing touch-based physical user interfaces. These user interfaces are based on RFID technology. An RFID tag storing service parameters is placed behind an icon advertising a service. When a user touches the icon with a mobile device that is equipped with an RFID reader, the service parameters are read from the tag and delivered to the system. Touch-based user interfaces are an effective way of controlling a system, as they produce rich contextual information: who is requesting a service, which service, when, and where. With such interfaces, the user remains in control.

During 2009, the group developed several innovative touch-based user interfaces. The group also developed further the REACHeS platform that can be used to link physical user interfaces to Internet services. The figure below presents a touch-based user interface for controlling a television. This control panel contains 33 icons and an RFID tag under each icon. A user controls an electronic program guide shown on a television screen by touching the icons with her/his mobile phone. The general commands on a green background are sent automatically once touched. For example, a user can switch from a television program to the program guide by touching the top left icon. The rest of the icons allow command composition. For example, a user can create with three touches the command: "I want to see all sports events, during the morning on channel 2." This prototype was developed in the DIEM ICT SHOK together with researchers from the University of Tampere and the Tampere University of Technology.



Touch panel for controlling a television.

In addition to touch-based physical user interfaces, the group developed an easy-to-use user interface for chronic pain patients to report their pain experiences wirelessly to nurses. We built the application for an N810 Internet terminal and developed also sound sets for the user interface. This work was conducted in collaboration with Sonic Studio from Piteå, Sweden, and the University of Lapland.

User interface for reporting experienced pain wirelessly to nurses.

The group presented its work on NFC-based physical user interfaces in the WIMA 2009 NFC Business & Technical Developers Summit, in the 2009 NFC Global Competition. This event was held on April 22-24 in the Grimaldi Forum, Monaco. The group presented three prototypes and demonstrated them over 100 times during the event.

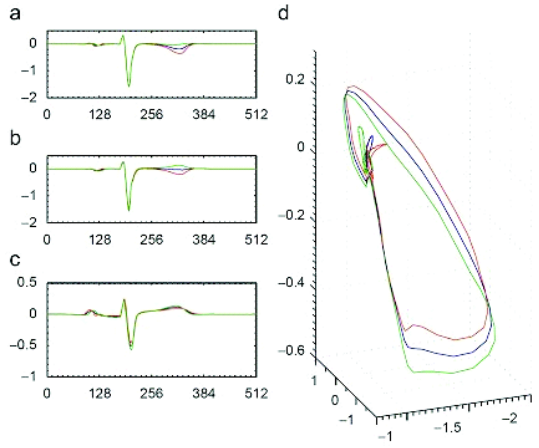
In 2009, the group started to apply architectural principles used in botnets and malware on the REACHeS platform. We identified the command-and-control message bus as the common denominator of botnets, and selected the IRC as the message bus of the new REACHeS version. The resulting system consumes much less resources than the earlier implementation, while the latency is similar in both systems. Moreover, the new system produces much less traffic and the same functionality can be achieved with much less code.

Research on Data Mining

Biosignal Processing

Cardiovascular Signal Processing: Sudden cardiac arrest is the most common cause of death in western countries. It accounts for approximately 50 % of cardiovascular deaths, and apparently has a highly variable pathophysiological etiology. The risk of sudden cardiac arrest is high in certain subgroups of patients with a history of myocardial infarction and depressed left ventricular function. The key question in research is why do some subjects develop ventricular fibrillation during acute coronary occlusion, while others survive this episode without fatal arrhythmia. The challenge for research is to develop approaches or techniques that will allow the screening of the specific risk for fatal ventricular arrhythmias as a predictor of the first event in patient populations that have a low cumulative risk, but generate a large number of victims. In addition, the predictive value of many known risk factors of sudden cardiac arrest among patients with known heart disease has not been definitively established.

Calculating Optimal Virtual Lead from Multichannel ECG by Minimizing Morphological Beat-to-Beat Variability: A novel measure of the morphological beat-to-beat variation of signals derived from multichannel ECG has been presented. It is used to find an optimal linear functional that maps the electrical activity of the heart into a single virtual lead in the sense of least beat-to-beat variability. The results show that for each subject it is possible to find a virtual lead with less beat-to-beat variability compared to the standard ECG-leads. Furthermore, the new measure gives precise quantitative information about the beat-to-beat variability in the standard lead set.



Vectorcardiagraphic loop alignment from multi-channel ECG improves cardiac event detection.

A Method for Robustly Determining the Relative Orientation of Vectorcardiographic Loop Structures: A robust method to determine the relative orientations of vectorcardiographic loop structures has been presented. First, the signal is resampled with respect to arc length. Then, a total least squares plane fit is used to form local coordinate systems of the loop structures. The time behaviour of the signal is used to identify the fitted axes. Finally, an optimal rotation matrix between the two loop structures is estimated. The Euler angle decomposition of the rotation matrix provides a complete description of the relative orientations of the loop structures as a whole. The proposed method is compared with the traditional 'total cosine R-to-T' (TCRT) based approach using a k-nearest neighbours (kNN) classifier. According to the results, the method performs about 20 percent units better on inferior myocardial infarction patients than the TCRT.

Invariant Trajectory Classification of Dynamic Systems with a Case Study on ECG: An invariant pattern recognition framework for classification of phase space trajectories of nonlinear dynamical systems has been presented. Using statistical shape theory, known external influences can be discriminated from true changes of the system. The external effects are modelled as a transformation group acting on the phase space, and variation of the trajectories not explained by the transformations is accounted for using principal component analysis. The approach suggested is highly adaptable to a wide range of situations and individual differences. The methodology presented is applied to detect abnormalities in electrocardiograms. Results based on measured data indicate that the model developed is resistant to the effects of respiration and body position changes, which are abundant in ambulatory conditions and cause significant morphological artefacts in the signal. The results also show that the detection of an artificially induced acute myocardial infarction is achieved with high performance. Due to its low computational complexity, the method developed can be implemented in real-time. It also adapts to morphological changes caused by various heart conditions.

Time-Frequency Representation of Cardiovascular Signals during Handgrip Exercise: Altering cardiovascular oscillation is present during various interventions e.g. autonomic tests. Traditional spectral analysis suffers from non-stationary data and poor time resolution when studying the dynamics and frequency of cardiovascular signals. Smoothed pseudo Wigner-Ville representation method was applied when analysing handgrip (HG) data of healthy men (n = 11). Prevalent low frequency (PLF) and LF/HF powers were estimated from the time-frequency representation (TFR). According to experimental results, PLF increases during HG with both heart rate interval (RRi) and systolic blood pressure (SBP) data. In addition, TFR revealed the increasing LF power during the HG with both RRi and SBP, while HF power increases with SBP and decreases with RRi. This is interpreted as an altered sympatho-vagal balance during the hand grip protocol.

RSA Component Extraction from Heart Rate Signal by Independent Component Analysis: Respiratory sinus arrhythmia (RSA) is a phenomenon where heart rate changes synchronously with respiration. It can be measured by high frequency power (HF power, 0.15 - 0.4 Hz) of heart rate interval (RRi) series, which is an important and widely used parameter in cardiovascular research. Due to the altering respiration rates, it is important to have methods to separate the RSA from the RRi. We applied Independent Component Analysis (ICA) to extract the RSA from the RRi series. The performance of ICA was evaluated with a simulation

study where real 5 min RRi (n = 20) and respiration data (n = 2) of spontaneously breathing males were superimposed. According to residual analysis in the time and frequency domain, the extracted RSA follows the shape of simulated RSA (3.3 - 5.4 % RMS error of total variability), and ICA is able to remove RSA without changing the power content of RRi ($p < 0.05$). Thus, ICA is a usable method to extract RSA from RRi series.

Beat-to-Beat Variation of Three-dimensional QRS-T Angle Measures during an Exercise Test: Dynamical beat-to-beat behaviour of the spatial QRS-T angle features is largely unknown. In this study, an automatic beat-to-beat method for calculating the features from standard 12-lead ECG was developed, and the variability of three QRS-T angle measures (TCRT, cos(QRST-angle), and cos(PlaneAngle)) during an incremental exercise on a bicycle ergometer was specified. The trend of the TCRT during exercise was negative, and it was more negative in healthy subjects (n = 10) compared to coronary artery disease (CAD) patients (n = 10), p-value was 0.01 between the groups. However, all the QRS-T angle measures did not appear to behave similarly, and therefore, they should not be paralleled with each other. In addition, beat-to-beat variability of all the QRS-T-angle measures was so extensive that this should be taken into account when considering the reliability of one-beat analyses of the angle measures.

New Vectorcardiographic Non-planarity Measure of T-Wave Loop Improves Separation between Healthy Subjects and Myocardial Infarction Patients: Principal component analysis of vectorcardio-graphic T-wave loop has been shown to be a potential tool to describe the abnormality of the cardiac re-polarization, and to predict cardiac events in patients with cardiac disease. A new method for estimating the non-planarity of the T-wave loop was introduced and tested with healthy subjects and subjects with anterior or inferior myocardial infarction. The method is based on the re-samping of T-wave data points with respect to the arc-length, the total least squares plane fitting, the identifying and reordering of the fitted axes, and decomposing the optimal rotation matrix. A recently published related measure, PCA3, was used for comparison purposes. The results showed that the non-planarity of the T-wave loop increased significantly in patients with myocardial infarction compared to the healthy group. The new method separated healthy and patient groups with p-value 0.002, while PCA3 only had a p-value of 0.075. The new method was superior to PCA3 in separating the healthy patients from both infarction types.

EEG Signal Processing: The aim of this task is to develop new methods and algorithms for estimating the depth of anaesthesia and the effects of multiple medication in anaesthesia from multi-channel EEG. A new concept of relative induction time was recently developed by our group, which enables a significant improvement in the depth estimation from EEG. The new method produces a time-continuous value for the depth estimate, and accurately predicts the instant of loss of consciousness. The method was extended so that it can model the depth of anaesthesia to such a depth that burst-suppression of EEG starts to evolve. The team has so far focused on describing the spectral characteristics of EEG related to the induction of anaesthesia with propofol. The relationship between the EEG frequency progression pattern and the clinical end-points, such as loss of obeying verbal command, was shown. A mathematical method was developed for describing the consistent EEG frequency progression pattern during anaesthesia. The method has provided us with the possibility to study in detail the effects of analgesic drug (remifentanil) on the EEG-based depth of anaesthesia estimation.

Effects of Remifentanil on the Spectrum and Quantitative Parameters of Electroencephalogram in Propofol Anaesthesia: A high dose of opioids associated with a low dose of propofol has become a popular anaesthetic technique. However, the influence of opioids on the electroencephalographic phenomenon related to induction of anaesthesia and, thereby, on the quantitative parameters used in the depth-of-anaesthesia estimation is not well known. Twenty-seven patients were divided into three groups to receive saline, low-dose remifentanil ($7.5\ \mu g \cdot kg^{-1} \cdot h^{-1}$), or high-dose remifentanil ($30\ \mu g \cdot kg^{-1} \cdot h^{-1}$) during induction of anaesthesia with propofol ($30\ mg \cdot kg^{-1} \cdot h^{-1}$). Electroencephalogram was recorded from Fz electrode, and its time-frequency properties in the patient groups were analysed from the induction of anaesthesia to the occurrence of burst suppression pattern. The group differences in fourteen quantitative spectral parameters used in the depth-of-anaesthesia estimation were examined as well. The time-frequency properties of electroencephalogram were different between groups. The high frequency (> 14 Hz) activity during light anaesthesia was decreased in remifentanil groups, whereas, during deep anaesthesia, increased activity in extended alpha band (7 - 14 Hz) and decreased activity in delta band (0.5 - 4 Hz) was observed. This resulted in statistically significant changes in all fourteen quantitative parameters. The effect of remifentanil on the spectrum and quantitative parameters of electroencephalogram is significant and strongly dependent on the level of anaesthesia. Co-administration of opioids therefore challenges the reliability of the spectral properties of electroencephalogram in the depth-of-anaesthesia estimation using a frontal montage. Furthermore, the finding has implications for the design of opioid co-administration studies.

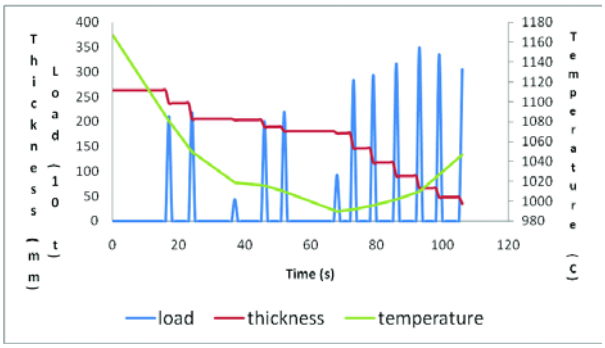
Effect of Remifentanil on the Nonlinear Electroencephalographic Entropy Parameters in Propofol Anaesthesia: Nonlinear electroencephalographic entropy parameters have been proposed for the assessment of the depth of anaesthesia. The influence of remifentanil, a commonly used intraoperative opioid, on these parameters, namely approximate entropy (ApEn), sample entropy (SampEn), and permutation entropy (PeEn), during induction of propofol anesthesia was studied. Remifentanil was shown to reduce the propofol-induced changes in ApEn and SampEn throughout the transition from awake to burst suppression state. Co-administration of opioids therefore challenges the reliability of these parameters as indicators of depth of anaesthesia. No consistent influence on PeEn was observed. However, this may have been due to strong inter-individual variation in PeEn values.

Continuous Assessment of Nasal Airflow Resistance by Adaptive Modelling: A method to assess nasal airflow resistance was presented that provides a continuous resistance value, and applies a novel minimally obtrusive measurement technique. Instead of calculating the resistance once for each breathing cycle, as is conventional, it is calculated for each signal sample at any sampling frequency. The continuous pressure recording is produced with a nasopharyngeal catheter inserted 8 cm deep along the floor of one nasal cavity and the flow recording is produced with respiratory effort bands. A least-mean-square (LMS) extension for the resistance model of Broms is developed that dynamically adapts to the time-varying characteristics of the nasal functioning, and produces the continuous resistance values. Experimental results are shown that demonstrate the uniqueness and applicability of the new technique in assessing quickly changing resistance in histamine/xylometatsolin challenges, the differences between normal and symptomatic patients, and the effect of nasal treatment of patients.

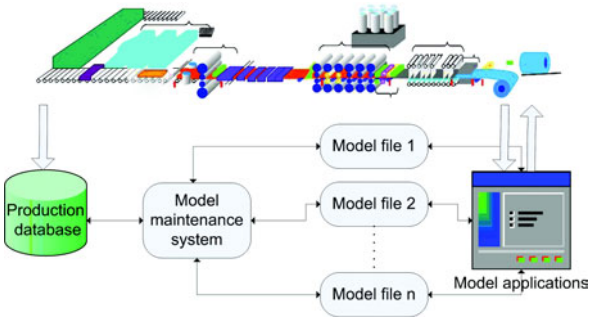
Data Mining Systems

The data mining systems research challenges are divided into three mutually supportive categories; the research of algorithms producing knowledge, software running the algorithms and knowledge bases storing the acquired knowledge. When put together, these three categories form a strong combination which can be applied to virtually any phenomena where data can be processed into knowledge.

The research on algorithms was focused on advancing methods for time series analysis, variance modelling and novelty detection. Special interest was directed to establishing data driven methods for these areas, where the exact shape and nature of the observed data can be used to characterize the phenomena under study. In software research, the implementation of the first version of new software architecture for running the algorithms came to successful conclusion. The architecture presents the algorithms as information generating logical devices to which the information measuring physical devices connect. A suitable combination of logical and physical devices can thereafter be used to form a data mining software application. In knowledge base research, the general ideas behind the role of knowledge bases were established, and the implementation of the first version of a concrete knowledge base was carried to a successful end.



A slab of thickness 264 mm was rolled into a plate of thickness 35 mm with 12 rolling passes.

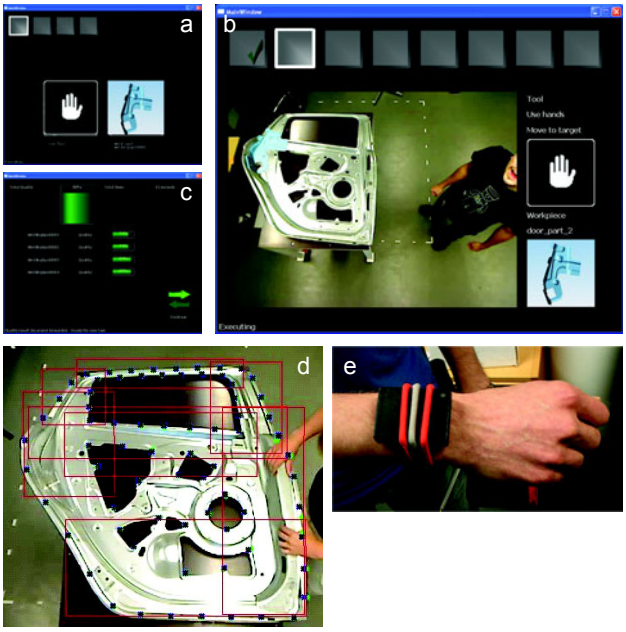


The model maintenance system processes production data to keep up-to-date the prediction models used by software applications whose purpose is to improve production efficiency.

During year 2009, the combination of the three data mining focus areas (algorithms, software and knowledge bases) proved its efficiency. Prototypes were implemented utilizing all the focus areas while the interfaces developed enabled modifications in the three areas individually. For example, inside the prototypes the algorithms in use could be modified without extra work in software implementation or effect on the knowledge base structure.

The actual research has focused on three projects, XPRESS (2007–2010), MIDAS (2008–2010) and PISKET (2009–2011). XPRESS is an integrated (IP) EU-project, where new approaches for managing and optimizing the operation of entire production facilities are being developed. In 2009, the progress in algorithms, software and knowledge bases separately was remarkable, enabling the combination of the results from different research directions to produce a working demo of car door assembly. In the demo, an online guidance system for the worker was presented, where tool tracking, part recognition and gesture recognition methods were utilized to help the worker to assemble a car door, to monitor that the parts are assembled into the correct places and to move in the guidance system, respectively (see the next figure).

Computer Vision / Augmented Reality: In the online car door assembly guidance system presented in the same figure, different computer vision, machine learning, and pattern recognition methods are applied to track the pose of the car door and to recognize if particular door parts are installed. Model-based tracking where a CAD model of the door, along with edge-based image data is applied to estimate the door position and orientation, as well as to segment different door parts. Support Vector Machines (SVM) are trained to recognize the existence of door parts to detect correct work phases. In SVM, an exponential sum kernel is applied to image sets consisting of gray-level features calculated around local interest points. These methods are capable of detecting installed car door parts automatically to monitor assembly and to recognize work phases done correctly. In addition, 3D model-based tracking, which uses a CAD model and point-based image data is applied to an augmented reality application equipped with moving camera. In this application, the user is guided towards a predefined interest point on an aircraft shell using camera view and visual guidance. The target surface consists of a large number of similar, but structured points (i.e., rivets).



An online guidance system for car door assembly. a) in the first step, tasks, tools and work pieces are introduced step by step to a worker using augmented reality animation, b) during the assembly, the worker is guided in real-time by showing objects and their positions based on door tracking and part recognition (Figure d), c) when the door is assembled a quality summary telling total and step times is shown, d) door tracking and part recognition is based on computer vision, e) the user interface can be controlled using wearable sensors: manual control is performed using predefined gestures and automatic control using worker activity recognition.

Without the vision based tracking system, it would be very difficult for the user to find the correct rivet among the large number of rivets.

Gesture / Activity Recognition: In assembly guidance, the wearable inertial measurement units can be used in two different ways: using gestures as control commands, and monitoring the work tasks performed by the worker. In some situations, gesture recognition is a good option for handling human-computer interaction because it enables natural interaction and no input devices, such as a keyboard and a mouse, are needed. In this scenario, the gestures are recognized by matching the shapes of wrist movement to predefined time series templates. The second approach, where the wearable sensors are used for activity monitoring has not yet been implemented to the online guidance system of the figure. Nevertheless, acceleration and angle speed information have been studied with promising results for recognition of the tasks performed by the worker. In the approach, the data is divided into two second intervals for which the performed activity is recognized using a knn-classifier.

The Intelligent Systems Group has long experience in advancing data mining methodologies in the steel industry, and ISG 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 2009, advanced data analysis solutions for the needs of the steel industry were developed in two active projects.

In the MIDAS-project (Methods for Innovative Data Analysis Solutions), the aim is to develop generic software for the maintenance of statistical prediction models employed in the manufacturing industries. Manufacturing industries commonly employ statistical models to improve the planning, optimization and control of production processes. However, as processes and products are developed, also the models have to be updated so that they work properly for the new products, and adapt to the process improvements. The process data that is measured from the production process contains hidden information that can be employed to keep the prediction models up-to-date. The system being developed analyses the production data and monitors the performance of models. When a need for model update actions is detected, the system serves as a tool which process engineers can easily use to generate a new model candidate, validate it and accept it for on-line utilization. The model candidates and earlier models are stored in a model archive and the system works as a diagnostic tool that helps to compare different models and to select the best model for production use.

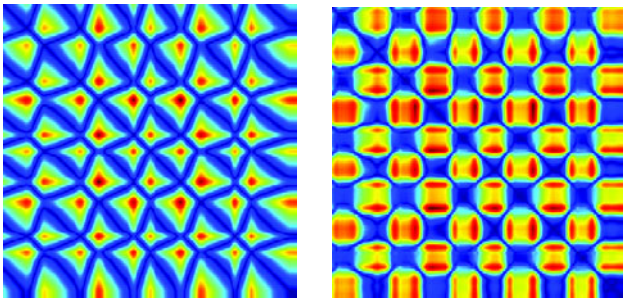
The quality of steel plates can be improved by optimizing the rolling pass schedule. An accurate prediction for rolling temperatures and loads is necessary. The statistical prediction of rolling loads and temperatures is demanding and application of advanced functional data analysis methods is needed. In the PISKET-project (Improving Pass Scheduling Calculation Taking into Account Flatness) prediction models are developed to predict the rolling temperatures and loads. In 2009, the focus has been in the prediction of rolling temperatures. An accuracy of 20 ºC has been achieved by employing non-linear regression models.

In 2009, ISG has continued to develop its probability based approach for planning and control. In the approach, the actions of planning and control are decided on the basis of the predicted risk of disqualification instead of predicted mean. In the approach, the software used in the planning or control employ statistical models that predict accurately the risk of disqualification. In 2009, quantile regression models were developed to predict more accurately the risk of disqualification in the Charpy-V testing of steel plates and heteroscedastic regression models were developed to predict the risk of disqualification in Brinell testing. A future direction for research is to investigate what the economical benefit in other application domains is if the decisions are based on models that are tuned to predict the interesting probabilities instead of mean.

Dr. Perttu Laurinen was on a one year research visit (March 2009 - March 2010) at the Idiap Research Institute, affiliated with EPFL, in Switzerland. The topic was on developing new methods for labelling and identifying shapes of interest from time series data. The integration of multiple data sources was of especial interest to make it easier to quickly understand what a numerical time series presents with the help of synchronized audiovisual recording. This was also a natural way to combine the machine vision and time series expertise of Idiap and ISG.

The results can be used, for example, to make it easier to engineer new features for wearable electronics like sports

and security applications. The visit was part of the MIDAS-project, funded by the European Structural Fund Programmes (EAKR), Polar Electro and Ruukki.



Self similarity visualisation of the integral of accelerations (left) and the video tracked trajectory of a repeating handwave gesture (right).

Eija Haapalainen was on a one year research visit (Asla Fullbright scholarship) at CMU and has been working on a study that aims to measure the cognitive load of a person, based on physiological measurements. In the study, a large number of different biosignals are examined, and the best measure or set of measures for assessing the cognitive load is searched for. The signals being measured include pupil size, heart rate, skin temperature and conductance as well as electrical brain activity. These signals are recorded while the test subject solves elementary cognitive tasks of different levels of difficulty. The prospective results of the study have broad applications in systems reasoning about human attention.

The goal of the project is to develop methods for assessing the round-the-clock activity level of a person and to measure the energy expenditure based on this information.

The tasks specified to accomplish these goals are rough recognition of the activity, and identifying the intensity of the activity. To develop methods for detecting the intensity of an activity, a large dataset containing acceleration measurements in different activities at different intensities was collected. Several methods were tested for this task. A large set of features were calculated from the data to compress the information contained in acceleration signals. Especially the computational complexity of the features was considered. The efficiency of different features in recognition of activity intensity was compared, and also several feature selection algorithms were used to find the most suitable set of features for this task. The methods developed for intensity recognition can also be used for rough recognition of the activities as well as estimating the amount of daily activity and rest.

Estimation of exercise energy expenditure has been studied in groups of similar activities. These results will be combined with information about the recognized activity.

Research on Software Security

Within the Intelligent Systems Group, the Oulu University Secure Programming Group (OUSPG) has continued research in 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 sciences 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 In Security: Software quality problems, wide impact vulnerabilities, phishing, botnets, 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 the traditional development life-cycle. Building in security 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 aspects.

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 a different set of vulnerabilities. Technical, social, political and economic factors all affect this process. We have developed and applied processes to handling the vulnerability life-cycle. This work has been adopted in critical infrastructure protection. Awareness of vulnerabilities and processes to handle them for developers, users and society all increase the survivability of emergent intelligent systems. These research goals are reached through a number of research activities.

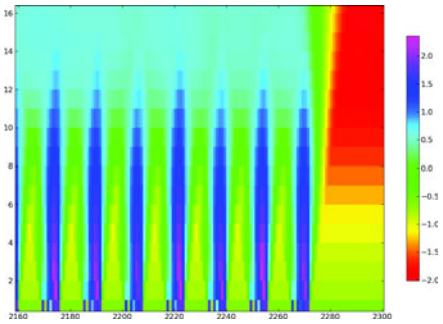
Situational awareness of modern information networks and applications In the MOVERTI project, we approach information systems from above from all three viewpoints, and have developed methods for combining measurements from network traffic, vulnerability feeds and scans, and socio-economical networks to gain situational awareness of modern information systems.

Identification of Protocol Genes: 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 struc-

tural information can then be used to effectively create large numbers of test cases for this protocol. In 2009, the project further developed the existing methodology resulting in improvements in efficacy, and discovering a number of vulnerabilities in widely used products.

RFID Security: The driving factor for this line of work has been the need to understand systems based on measurable external behaviour. The research developed a framework for systematically documenting RFID related threats and how to audit unknown RFID systems against these risks. The methodology systematically applies signal processing methods for analysing unknown protocols, and provides new approaches in understanding emergent behaviour in complex systems.

Hash Function Security Research is a part of cryptography, where hash functions and their properties are studied. Hash functions play a major role in many modern communication protocols, and they are at the moment a very hot topic since NIST (National Institute for Standards in Technology) proposed a competition for a new and more secure hash function standard, SHA-3. This competition vets one best algorithm from 64 different propositions. The study of hash functions has led to some practical results but mostly concerns theoretical advances in the field of hash function security. The results gained form this research and the cryptographic expertise are then applied to the practical information security work being carried out in OUSPG.



Visualization of entropy in a OpenVPN keyfile. Field borders can easily be seen.

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. Some examples of exploitation are described below. Especially during the reported year, outdoor robotics was a new area for exploitation of our research results.

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 (PDAs, a tablet PC, Symbian mobile phones). WLAN positioning covers a large part of the campus (including the laboratory), and a home automation network is being installed. 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.

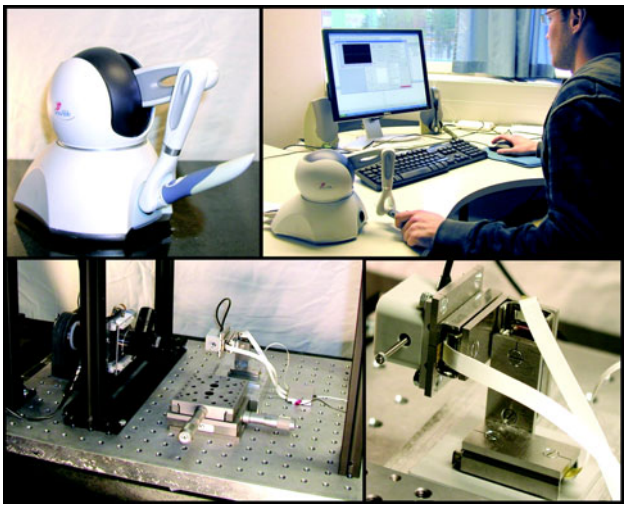
The physical user interfaces have been applied to several prototypes. A prototype for controlling multimedia presentations on a wall screen with an NFC phone was installed in 2009 in front of the V-Lab premises of the University of Oulu. The aim is that presentations about the University of Oulu and its research groups are uploaded to the system and these presentations can then be shown to visitors using the touch-based user interface. The wireless sensor network for measuring energy consumption will be tested in a field trial in 2010.

The embedded objects implemented according to the Atomi II Framework specification are called Atomi objects. Several different Atomi objects have been created for real life tests. The Atomi objects have been used in many projects, and they have proved to be very usable.

The Atomi objects are being used both in pure research projects, and in projects that aim ultimately at commercial products. The Atomi objects have been applied to telepresence robots, nanoscale manipulation and measurement technology, a hand held medical device, and several robot applications.

The SMCA and the framework has been declared open source, and the source is freely available at *http://www.tnt.oulu.fi/oswiki/*. This enables their use in both academic and commercial research and development. Many applications have been built with the developed techniques, and most of them have been disseminated in different journals and conferences. The most recent applications include a cell adhesion measurement device, a nano scale and a paper fibre adhesion measurement device.

The cell adhesion measurement device measures how strongly a cell is attached to its surroundings. The device removes a cell attached to a substrate and measures the force needed for the removal. Cells are manipulated with a specially designed needle connected to a mechanical arm.



The cell adhesion measurement device.

The device is mostly composed of off-the-shelf components including a linear piezo actuator device, a haptic 3D controller and a PC. The probe of the device is custom made, along with the ADC and USB Atomi modules used.

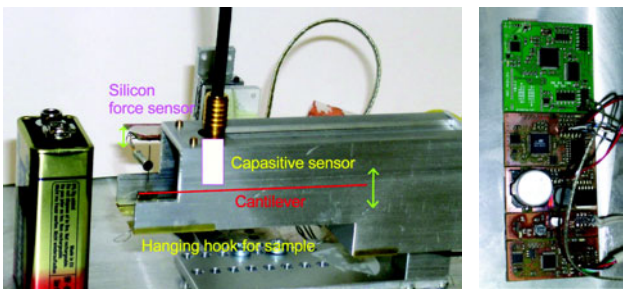
The device developed is a more affordable and flexible alternative to the existing devices on the market such as the Atomic Force Microscope (AFM) and its modifications. The AFM-based solutions are usually very expensive and not well suited to large or non-planar surfaces nor for micron-sized object (such as cell) manipulation.

The device components are relatively small and light-weight. Hence, the device can be moved around and attached to various microscopes. With small modifications, new tasks and features can be added to the device. The main users of the device are cell biologists and medical research scientists.

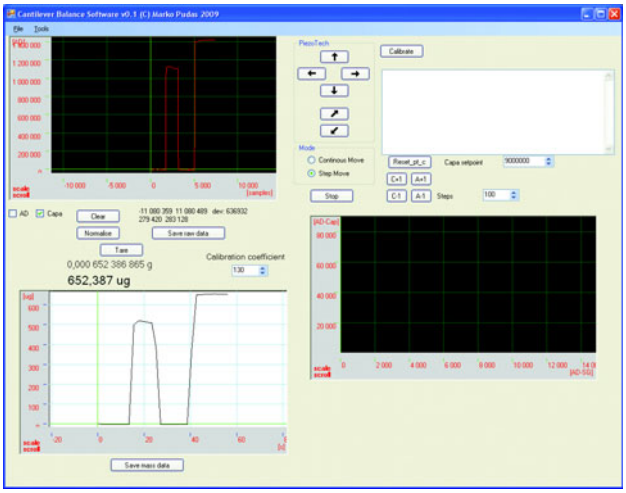
The nano scale (shown below) is a cantilever beam balance with nanogram resolution. The operation of conventional analytical balances is based on electromagnetic force compensation with a flexure strips structure, optical level sensor and current feedback. Cantilever beam type load cells for force and mass measurements are based on strain gauges. The major fallbacks with strain gauges in such an application are low resolution, limited dynamics of measurement and hysteresis.

High resolution capacitive displacement measurement with the cantilever beam makes it possible to manufacture balances with improved performance, which can even exceed the resolution that can be achieved with conventional methods. The nano scale achieves a resolution of < 0.1 µg, with a drift down to 10 ng/s, with possibilities of even higher resolution. High dynamics of > 3 mg has been realized with computer controller compensation. Calibration has been implemented in the system.

The system consists of a static capacitive sensor with a resolution below 1 Å. A sample can be placed on a specified place on the 5 cm long cantilever arm, whose location to the sensor is adjusted with ~100 nm resolution by linear piezo stages. Force calibration is realized by moving a calibrated silicon strain gauge sensor against the cantilever. The instrument is computer controlled, and it utilizes SMCA and the Atomi modules (right).



The construction of the nano scale device (left) and the set of Atomi modules used for implementation of electronics (right).



The user interface of the nano scale device.

The results of the multi-robot and distributed sensing research will be utilized in a real world application scenario as a part of the ROBOSWARM project, which is an EU project that was launched in November 2006. Together with eight other participants, the University of Oulu has an important role in this project, which aims to develop an open knowledge environment for self-configurable, low-cost and robust robot swarms usable in everyday applications. Advances in the state-of-the art of networked robotics are proposed through the introduction of a local and global knowledge base for ad hoc communication within a low-cost swarm of autonomous robots operating in the surrounding smart IT infrastructure. For the ROBOSWARM project, ISG has developed a custom embedded control system for the swarm of robots. The Sensor and Connectivity Board (SCB) was designed with the aim of providing a modular robot platform for swarm robotics research and application development, where simplicity and modularity are key-factors. The SCB is used to integrate all sensor modalities and the motor control into one logical device, which can be accessed through a USB port from any computer having USB host capability. This solution, providing easy access to all sensors, and flexibility for selecting an embedded host computer to perform the high-level data processing, and motion control computing. The sensor set currently supported by the SCB includes an RFID reader, sonars, a laser range finder, a 3-axis accelerometer, a gyroscope, a photo diode, a thermometer, humidity and atmospheric pressure sensors, a 3-axis magnetometer, and a real-time clock. The SCB also features a built-in interface to iRobot's Create mobile robot, but it can easily be connected to any robot platform with an UART connection. In addition, the SCB provides I2C, RS232, and SPI interfaces for adding new external devices to expand the functionalities of the SCB even further.

During the reporting year, the group continued utilizing outdoor robotic systems. Development and utilization of Mörri, a multipurpose, high performance robot platform continued. More focus was put on perception in natural conditions, representation of detections, knowledge, and environment model of 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

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 group is a founding member of the European Robotic Network of Excellence (EURON). The group is a contract member of EURON II which was approved for the EU's FP6 as a Network of Excellence.

We will strengthen our international research co-operation. Within the last years, the group has created collaboration projects with Japanese researchers. In 2009, we continued the collaboration and prepared further collaboration by the MoU with the Keio University. Our aim is to continue and strengthen the collaboration in 2010. We will continue the collaboration with Sonic Studio from Sweden and Shanghai Jiao-Tong University from China as well. With the University of Tianjin, 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. A doctoral student from ISG will make a one year research visit to the institute and co-operate with Assistant Professor Anind K. Dey. The research will be on human modelling in the area of human machine interaction. Shorter research visits to European partners in EC funded projects are also planned.

In 2010, 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 the actors in the areas.

Personnel

professors & doctors	11
graduate students	27
others	35
total	**73**
person years	53

External Funding

Source	EUR
Academy of Finland	122 000
Ministry of Education	304 000
Tekes	669 000
domestic private	275 000
international	592 000
total	**1 962 000**

Doctoral Theses

Koskimäki H (2009) Utilizing similarity information in industrial applications. Acta Universitatis Ouluensis C 317.

Vallius T (2009) An embedded object approach to embedded system development. Acta Universitatis Ouluensis C 343.

Selected Publications

Anttonen O, Junttila J, Giustetto C, Gaita F, Linna E, Karsikas M, Seppänen T, Perkiömäki JS, Mäkikallio TH, Brugada R, Huikuri HV (2009) T-Wave morphology in short QT syndrome. Annals of Noninvasive Electrocardiology 14:262-267.

Davidyuk O, Sánchez I, Duran JI & Riekki J (2009) CADEAU: collecting and delivering multimedia information in ubiquitous environments. Pervasive 2009 Adjunct Proceedings, Nara, Japan, 283-286.

Eronen J, Karjalainen K, Puuperä R, Kuusela E, Halunen K, Laakso M & Röning J (2009) Software vulnerability vs. critical infrastructure - a case study of antivirus software. International Journal on Advances in Security, 2(1): 72-89.

Halunen K, Rikula P & Röning J (2009) Finding preimages of multiple passwords secured with VSH. Proc. ARES 2009, IEEE Computer Society Press, Los Alamitos, 499-503.

Haverinen J & Kemppainen A (2009) A global self-localization technique utilizing local anomalies of the ambient magnetic field. IEEE International Conference on Robotics and Automation, 3142-3147.

Haverinen J & Kemppainen A (2009) Global indoor self-localization based on the ambient magnetic field. Robotics and Autonomous Systems 57(10): 1028-1035.

Haverinen J, Munoz D & Pirttikangas S (2009) A wireless sensor system for global self-localization and collaborative actioning. 6th Int. Conf. Networked Sensing Systems (INSS'09), June 17-19, Carnegie Mellon University, Pittsburgh, USA, 129-132.

Juutilainen I (2009) Generic implementation format of predictive statistical models using Python. European Network of Business and Industrial Statistics (ENBIS9), Gothenburg, September 20-24.

Karsikas M, Noponen K, Huikuri H & Seppänen T (2009) New vectorcardiographic non-planarity measure of t-wave loop improves separation between healthy subjects and myocardial infarction patients. Proc. 31th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Minneapolis, USA, September 2-6, 1754-1757.

Karsikas M, Noponen K, Tulppo M, Huikuri H & Seppänen T (2009) Beat-to-beat variation of three-dimensional QRS-T angle measures during exercise test. Proc. Computers in Cardiology Conference, Park City, USA, 36: 125-128, September 13-16.

Kemppainen A, Haverinen J, Mäkelä T & Röning J (2009) An adaptive model for spatial sampling design. European Conference on Mobile Robots (ECMR), Mlini/Dubrovnik, Croatia, 253-258.

Konomi S, Thepvilojanapong N, Suzuki R, Pirttikangas S, Sezaki K & Tobe Y (2009) Askus: amplifying mobile actions. Pervasive 2009, Nara, Japan, 202-219.

Kortelainen J, Koskinen M, Mustola S & Seppänen T (2009) Effects of remifentanil on the spectrum and quantitative parameters of electroencephalogram in propofol anesthesia. Anesthesiology 111: 574-83.

Kortelainen J, Koskinen M, Mustola S & Seppänen T (2009) Effect of remifentanil on the nonlinear electroencephalographic entropy parameters in propofol anesthesia. Proc. 31th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Minneapolis, USA, September 2-6, 4994-4997.

Koskimäki H, Huikari V, Siirtola P, Laurinen P & Röning J (2009) Activity recognition using a wrist-worn inertial measurement unit: a case study for industrial assembly lines The 17th Mediterranean Conference on Control and Automation, 401-405.

Noponen K, Karsikas M & Seppänen T (2009) A method for robustly determining the relative orientation of vectorcardiographic loop structures. Proc. 11th IUPESM World Congress on Medical Physics and Biomedical Engineering, Munich, Germany, September 7-12, 1158-1161.

Noponen K, Kortelainen J, Seppänen T (2009) Invariant trajectory classification of dynamical systems with a case study on ECG. Pattern Recognition 42(9): 1832-1844.

Noponen K & Seppänen T (2009) Calculating optimal virtual lead from multichannel ECG by minimizing morphological beat-to-beat variability. Proc. Computers in Cardiology Conference, Park City, USA, September 13-16.

Perttunen M, Riekki J & Lassila O (2009) Context representation and reasoning in pervasive computing: a review. International Journal of Multimedia and Ubiquitous Engineering 4(4): 1-28.

Perttunen M, Van Kleek M, Lassila O & Riekki J (2009) An implementation of auditory context recognition for mobile devices. The First International Workshop on Mobile Urban Sensing (MobiUS), Taipei, Taiwan, 424-429.

Rautio T, Laurinen P, Röning J (2009) Component-based framework for mobile data mining with support for real-time sensors. ICAART 2009: Proceedings of the International Conference on Agents and Artificial Intelligence, 208-213.

Sánchez I, Davidyuk O & Riekki J (2009) Towards user-oriented application composition. Proc. of Pervasive Service Computing and Application 2009 in conjunction with Frontier of Computer Science and Technology (FCST '09), December 17-19, Shanghai, China, 698-704.

Sánchez I, Kuusela E, Turpeinen S, Röning J & Riekki J (2009) Botnet-inspired architecture for interactive spaces. Proc. of the 8th International Conference on Mobile and Ubiquitous Multimedia (MUM 09). November 22-25, Cambridge, UK, 91-100.

Sánchez I, Riekki J & Pyykkönen M (2009) Touch & compose: physical user interface for application composition in smart environments. Proc. 1st International Workshop on Near Field Communication (NFC '09), Harenberg, Austria, 61-66.

Seppänen T, Koskinen M, Seppänen TM & Alho O-P (2009) Continuous assessment of nasal airflow resistance by adaptive modeling. Physiological Measurement 30: 1197-1209.

Seydou F, Duraiswami R & Seppänen T (2009) Computation of singular and hypersingular boundary integrals by Green identity and application to boundary value problems. Engineering Analysis with Boundary Analysis, 33: 1124-1131.

Seydou F, Ramahi O & Seppänen T (2009) Computation of the Helmholtz eigenvalues in a class of chaotic cavities using the multipole expansion technique. IEEE Transactions on antennas and propagation, 57(4): 1169-1177.

Seydou F, Ramahi O, Seppänen T (2009) Coated photonic crystals: computation of the green tensor and analysis of the bandgap. Journal of Engineering Mathematics 65: 243-255.

Siirtola P, Laurinen P & Röning J (2009) Mining an optimal prototype from a periodic time series: an evolutionary computation-based approach. Congress on Evolutionary Computation (CEC 2009), May, 2818-2824.

Siirtola P, Laurinen P, Haapalainen E, Röning J & Kinnunen H (2009) Clustering-based activity classification with a wrist-worn accelerometer using basic features. Proc. of the 2009 IEEE Symposium on Computational Intelligence in Data Mining (CIDM 2009), IEEE Press, March, 95-100.

Sipola R, Vallius T, Pudas M & Röning J (2009) Micromanipulation platform for micro- and nanoscale applications. Casasent DP, Hall EL & Röning J (eds.) Intelligent Robots and Computer Vision XXVI: Algorithms and Techniques, Proc. SPIE-IS&T Electronic Imaging, 7252:04-1-04-13.

Su X, Riekki J & Haverinen J (2009) Semantic support for resource-constrained robot swarm. 6th International Conference on Informatics in Control, Automation and Robotics (ICINCO 2009), 271-277.

Su X, Riekki J & Tarkoma S (2009) An approach to achieve context-aware maps: combining semantic web technology with sensor data. 5th International Conference on Intelligent Environments (IE09), Barcelona, Spain, 193-203.

Thepvilojanapong N, Konomi S, Yura J, Iwamoto T, Pirttikangas S, Ishida Y, Iwai M, Tobe Y, Yokoyama H, Nakazawa J & Tokuda H (2009) Exploring energy-efficient human probes for high-fidelity sensing in urban environments. 2009 Fifth International Conference on Intelligent Sensors, Sensor Networks and Information Processing - Symposium on Adaptive Sensing, Control, and Optimization in Sensor Networks (ISSNIP 2009), December 7-10, Melbourne, Australia, 61-66.

Tiinanen S, Kiviniemi A, Tulppo M & Seppänen T (2009) Time-frequency representation of cardiovascular signals during handgrip exercise. Proc. 31th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Minneapolis, USA, September 2-6.

Tikanmäki A & Röning J (2009) Development of Mörri, a high performance and modular outdoor robot. International Conference on Robotics and Automation (ICRA 2009), Kobe, Japan, May 12-17, 1441-1446.

Tuovinen L & Röning J (2009) Everybody wins: challenges and promises of knowledge discovery through volunteer computing. Proceedings of the 8th International Conference of Computer Ethics: Philosophical Enquiry (CEPE 2009), 821-842.

Tuovinen L, Laurinen P & Röning J (2009) Data type management in a data mining application framework. ICAART 2009: Proceedings of the International Conference on Agents and Artificial Intelligence, 333-338.

Tuovinen L, Laurinen P & Röning J (2009) External tool integration with proxy filters in a data mining application framework. Proceedings of the 4th International Conference on Software and Data Technologies (ICSOFT 2009), 249-255.

Vallius T & Röning J (2009) EOC: Electronic building blocks for embedded systems. IEEE Design & Test Magazine 26(6): 74-83.