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 preprogram all of their behavioural patterns in 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; 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 work towards this goal. We have experience of 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 of 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 based on 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 tool-box that has a major impact on our development-oriented subcontractual projects.

The group co-operates with many international and domestic partners. In applied research, the group is active in European projects, and several joint projects funded by the Finnish Funding Agency for Technology and Innovation (Tekes) and industry.

The group and its members are active in the scientific community. For example, Prof. Juha Röning served as Chair on the program committee of IEEE International Symposium on Computational Intelligence in Robotics and Automation (June 27-30 2005, Espoo, Finland) and Co-chair on the program committee of Intelligent Robots and Computer Vision XXIII: Algorithms, Techniques, and Active Vision (23-26 October 2005, Boston, Massachusetts, USA). In software security, the European Intensive Programme on Information Security Management and Technology 6th Winter School was arranged in Oulu March 30 - April 7, 2005, and the Midnight Sun Vulnerability Disclosure Workshop in Hailuoto in June 2005 where 40 experts in the field representing governmental organizations, industry and academia were present. Also several members of the group were on the committees of international conferences.

Interest to our research has been great. For example, this year delegates from Canada (Lakehead University, University of Manitoba and University of Waterloo) and Iceland (University of Akureyri, University of Iceland and Iceland University of Education) visited our research group. During the visit, robotics research was demonstrated.
The activities of the ISG are led by professors Juha Röning (Director), Jukka Riekki and Tapio Seppänen.

**Scientific Progress**

In 2005, 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, steel plant and spot welding processes quality control, 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 is an important part of the research. To support this activity, we are developing 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 software architectures for a smart environment.* The aim is to create a software architecture supporting the development of context-aware applications for a smart environment. We have developed a Property Service Architecture, a modular and scalable software concept that allows us to connect resources to larger systems. The distributed system consists of device services that provide features and functionalities to systems, and control services that create smart functionalities for the whole system. Different kinds of devices can be tested on the system as they communicate similarly, and even complex applications can be built rather easily using higher level control services. The dynamic capabilities of the general interface permit expanding and adapting of the system to match the task and environment requirements.

The other main objective here is to develop architecture that provides a software library that integrates all our research work to rich set of tools. Therefore these methods and solutions are easily usable on forthcoming projects, which speeds up and develops our research work and capabilities.

*Developing hardware architecture for a smart environment.* The aim is to develop a basis for devices operating in a smart environment. We have recently developed a modular electronic concept, called Atomi, and created general software components for building complex activities. Atomi electronics provide us with a possibility to modify the hardware easily: new functionalities are available immediately in a plug-n-play way. Modularity has been achieved using Atomi electronics and modular software architecture - Property Service, which provides an interface for these resources and an opportunity to control different robots and other devices of a smart environment. The figure below shows the second generation Atomi objects.

*Building a testing environment.* In addition to software and hardware architectures, a test environment will be needed. We are building a prototype of a smart living room in our laboratory. This living room will be a large, proactive system. The technology and computation will be hidden as far as possible; the goal is to provide the user with a natural environment that offers advanced services. The hardware for the first version of the prototype has been installed. The implementation of the basic software and the development of the computational methods will continue.

*Remote Distributed Intelligence.* The aim is to develop a prototype for testing and verifying Remote Distributed Intelligence. This is realized by implementing a multi-agent system composed of state-of-the-art miniature mobile robots equipped with sensors and communication devices which support a wide range of applications including guarding, inspection, and environment monitoring. This research will give us valuable knowledge about the possibilities of a multi-robot team in real world applications.

The multi-robot team has interesting prospects, as each robot has sensor capabilities rarely seen in small robots. Each robot is capable of colour stereo vision processing, they can sense accelerations, temperature,
lighting, magnetic fields, and they can communicate with each other using the radio link. We have demonstrated how two robots can co-operatively create a 3-D model from an object in the environment, while the first robot uses a laser projector to scan the object, and the second extracts the laser features from the surface of the object with its on-board camera system. This kind of co-operation provides capabilities for sensing tasks, like 3-D scanning, in places where it is difficult or impossible to use traditional measurement devices because of their size or fixed structure. A group of miniature robots can enter these places, find suitable measurement geometry, perform the measurements, and send the data for further analysis.

One of the primary applications is to use the multi-robot team as a distributed measurement instrument. For example, the robots can enter a building and transmit data such as images, temperature, and lighting from the areas of interest given by the human operator. The multi-robot team can also operate fully autonomously. In one application, the team of robots can monitor the status of a building and send information to a remote operator from any exceptional situation.

**Research on context-aware services**

A growing variety of services are nowadays available for users. We are approaching a situation where the sheer number of services hinders their utilization. Our hypothesis is that this service overload can be managed by utilizing the user’s context. To develop context-aware services, we have set and tackled the following objectives:

**Recognizing the user’s context.** The aim is to find and develop methods for recognizing the user’s context from sensor data. Context can be used to identify the services that are relevant in the situation at hand - and to adapt these services. In earlier research, our focus has been on position data, data produced by our EMFI floor and heart rate measurements.

The research of user modelling on the EMFI floor has continued. It has been concentrating on the development of machine learning and pattern recognition methods for footstep-based person identification as well for real-time multiple tracking. In the person identification domain, different base classifiers, from the statistical and neural computation field, are tested. An ensemble learning method, which is using multiple base classifiers trained on different features sets, is developed. In ensemble learning, two level combinations of the base classifiers’ probabilistic outputs and multiple adjacent footstep profiles are fused to perform an accurate decision on a person’s identity. The best results were achieved using Support Vector Machine (SVM) base classifiers and the features based on spatial, statistical, and spectral properties of footstep patterns. A 95% success rate from ten different walkers was achieved. A preliminary study of real-time multiple person tracking was also performed. It is based on dynamic sequential modelling of moving objects which are individually tracked using Particle Filtering (PF). The method is able to track a small number of objects simultaneously on the floor and is leading to future work on higher level contextual and behavioural modelling of users and robots.

One of our researchers is currently a post doctoral visitor in the Distributed Computing Laboratory (DCL) at Waseda University in Tokyo, Japan. The research aims at reliable context recognition utilizing different sensory devices and sentient artefacts. Together with DCL members, pattern recognition methods for extracting people’s context, the management of contextual information, and ways of dealing with heterogeneity of sensing device and contextual information are studied.

**Modelling user’s behaviour.** The aim is to find models that can be used to predict users’ behaviour. User models will enable services to be adapted automatically according to users’ personal preferences and also enable proactiveness. Objective 1 will create the necessary basis for this work; the model will be created by observing the user’s context changes and actions over time. In earlier research, we have created rule-based models of user behaviour by utilizing data mining algorithms to associate different contexts in order to better serve the user. In the future, adaptive models will be applied. We have continued this work in cooperation with Waseda University.

**Labelling personal information with context.** The aim is to develop methods that could help the management and utilization of the growing quantities of digital information related to our lives. The hypothesis is that context is an intuitive way of organizing personal information, as it allows users to relate information to experiences. We especially aim to produce a methodology for collecting and storing an extensive set of digitally available, context-labelled data from a person’s everyday actions and to outline data mining methods for accessing, visualising and utilising such data.

**Providing easy access to services through tangible interfaces.** The aim is to develop an intuitive tangible interface for requesting services with a single touch. We utilize RFID tags mounted in the environment and RFID readers integrated in mobile phones. The tags connect the physical and digital environments. Visual symbols communicate to users the objects that can be
touched and the services that can be activated. When a user touches such a symbol with a mobile phone, the data stored in the tag and other contextual information related to the situation trigger the requested service. This work is related to Objective 1, as touching an RFID tag produces accurate information about user’s context. We have designed a set of visual symbols in co-operation with the Department of Industrial Design at the University of Lapland. The usability and user experience studies indicate that touching visual symbols with a mobile device is an easy way to activate services. Based on our findings, we list security, controllability and public acceptance as the main challenges in deploying this interaction method into everyday use.

**Research on data mining**

**Biosignal 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.

Our approach to studying the heart is based on the analysis of a 12-lead ECG (electrocardiogram). ECG contains information of cardiac function that is highly relevant to diagnosis and treatment. This information includes signals of atrial electrical activity (P-wave of ECG and the corresponding atrial repolarization signal mixed with the QRS complex) and also of ventricular repolarization (T-wave). We have set and tackled the following objectives:

- **Computation of risk markers from ECG characteristics.** The aim is to develop new methods and algorithms for the analysis and interpretation of electrophysiological signals and the autonomic regulation of the cardiovascular system. The digital 12-lead ECG was decomposed into multi-dimensional dipolar and non-dipolar components in the depolarization and repolarization phases in order to derive new risk markers of heart diseases. 12-dimensional principal components analysis was performed to extract dipolar (vector cardiographic) and non-dipolar components from the measurement signal. The depolarization and repolarization phases were analysed separately, and various parameters (e.g., VCG loop descriptors and singular value-based descriptors) were developed that describe the electrical functioning of the heart during one beat or in continuous ECG.

Real-time measurement and interpretation of ECG includes challenging signal processing problems that are related to false alarms caused by motion artefacts of the patient. New adaptive signal processing solutions were developed that filter motion artefacts effectively through VCG-based modelling of heart behaviour and produce significantly enhanced ECG signals. Novel solutions for automatically detecting ECG morphology changes were derived from a theory of invariant pattern recognition.

- **Modelling of the functioning of the autonomic nervous system.** The relationships between ECG, blood pressure, breathing and sympathetic nervous activity signals were modelled and identified from actual signals in order to develop new models for the autonomic control of the cardiovascular system. We applied the sequence method, the alpha method, the transfer function method and parametric modelling of open-loop systems. From the identified models, various important parameters related to cardiac state were computed, such as baroreflex sensitivity (BRS). A novel method was developed for adaptively filtering respiration artefacts from ECG and blood-pressure signals. This method produces a significantly improved BSR estimate than has been earlier reported in the literature. Measurement equipment was used that only few research groups possess in the world.
Estimation methods of anesthesia depth. The aim of this task is to develop new methods and algorithms for estimating the depth of anesthesia from multi-channel EEG. A new concept of relative induction time was developed, 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 instance of loss of consciousness.

Industrial data mining. The aim is to apply data mining methods to industrial process data sets. The purpose of this work is to extract useful information from the data in the form of prediction models, for example. An advanced method for scale defect identification in the measurement of steel strip surfaces has been developed using self-organizing maps (SOMs). The method developed is capable of identifying seven out of eight defects. In addition, the development of a production line software implementation of a model tracking and predicting the temperatures of steel slabs heated in a reheating furnace was continued.

Application driven development of computational intelligence methods was continued based on a spot welding application. The main aim was to develop methods for identifying similarities between welding processes. Through a comparative study, the most suitable method for process identification was discovered. In addition, an optimal feature set to be used in training the model was extracted from measurements recorded during welding. The benefits achieved were: the time needed for the set-up of a new process can be substantially reduced by restoring the process parameters leading to high-quality joints, and the quality of new welding spots can be predicted and improved using the stored information of a similar process.

Smart Archive. The aim is to develop a framework for real-time modelling of phenomena that continuously produce new measurement data. The focus area of the technology to be developed is intelligent on-line data processing for the purpose of on-line modelling. The development of a software framework that enables the rapid realisation of new models as software applications is currently in progress. By using the framework the implementation and set-up times of models can be significantly reduced and their operational reliability...
improved. A specific issue to be addressed is the selective storage and effective utilisation of history data that accumulates over time, and eventually comes to represent the full spectrum of the phenomenon being modelled. The technologies to be developed are collectively known as the Smart Archive. An advanced prototype version, now close to completion, of the software framework will be used to create a series of data mining solutions for diverse industrial application domains, and from the resulting experience, the design of the framework will be further refined. The ultimate goal is a truly generic data mining meta-application with a graphical user interface that allows application instances to be constructed parametrically with the minimum quantity of application specific code.

Research on software security

Within the Intelligent Systems Group, the Oulu University Secure Programming Group (OUSPG) has continued research in the field of implementation level security issues and software security testing. Software implementation may introduce potential for unanticipated and undesired program behaviour, e.g. an intruder can exploit the vulnerability to compromise the computer system.

In 2005, the research focus has been on the implications and relationships of the different technologies in complex systems. Information network environments are more complex than ever before and the complexity will increase in the future. One important factor affecting the increase of the complexity is the convergence of information networks. One seemingly simple event may generate a number of small actions in different parts of the network. Additionally, different components may use varying protocols. Thus the development, deployment and management of complex networks is laborious and requires in-depth understanding of different fields. OUSPG has approached the area from three different directions, namely, causal relationships, protocol genes and protocol dependence.

Causal relationships. The aim is to develop methods for inferring causal relationships in complex systems. The research applies data mining to network traffic to find data relevant to the system being analysed. Applications of the method include getting an overall view of the communication patterns of complex systems, diagnostics, security risk assessment by visualizing information propagation throughout the system and discovering abnormal behaviours when running protocol robustness test suites. The tool has discovered unexpected information leaks in systems considered to be fully understood.

Identification of protocol genes. The aim of this research is related to Objective 1, but the problem of complexity is approached from the other direction by developing tools and techniques for reverse-engineering and identification of protocols based 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.

Different visualization levels for network traffic serve different audiences.

Objective 3: Vulnerability management of the information infrastructure contributes to protocol dependence: The aim of this research is also related to Objectives 1 and 2. Another way to approach the complexity problem is through protocol dependencies. This activity studies the impact factor of the different technologies on CNI and develops a visual model for understanding the dependencies related to protocols. Information about the technical qualities and the prevalence of protocols will be gathered. Data about public attention to a specific protocol will also be of importance to the research. Comprehensive understanding of the state of the art will be developed by gathering research data through expert interviews. The purpose of the model developed from this data is to facilitate technical and organizational understanding as well as to facilitate risk management, vulnerability analysis and strategic planning.
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.

The Intelligent Systems Group utilizes a robotics laboratory and 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 group’s expertise in robotics was applied in developing a mobile robot for domestic help. A teleoperated robot serves as the remote eyes of the elderly and those who take care of them. During the reporting period, the main task was to develop teleoperation capabilities for the robot. A voice controlled service robot was successfully demonstrated. The purpose of the robot is to assist elderly people in their homes and provide a communication link to health care personnel. A design project was launched with the University of Lapland to further develop the appearance of the robot, and make it suitable for various applications and research studies regarding human-robot interaction.

The development in robotics has continued in the area of mechanical and miniaturization research. Qutie is an interactive mobile robot designed in cooperation with the University of Lapland. In the current year, development has focused on modular electronics, the Atomi concept, and the creation of general software components for building complex activities for the robot. As the robot has several actuators and sensors, it is also a good platform for developing a method for building complex robots with modular methods. Modularity has been achieved using Atomi electronics and the modular software architecture Property Service.

The Atomi electronics is an implementation of our Embedded Object Concept (EOC). The EOC utilizes common object-oriented methods used in software by applying them in combined Lego-like software-hardware entities, embedded objects. This concept enables fast prototyping with target hardware, incremental device development and high-level device building for non-experts. The figure below shows the idea of using the Atomi objects.

The development of a miniature robot is preparatory action towards swarm robotics research. Instead of using large robots, it is often desirable to have multiple small robots to save valuable work space and make the maintenance of the robots easier. Also, the implementation cost of a miniature robot is lower because of the simpler mechanical design. We have developed a novel modular miniature mobile robot designed for swarm robotics research. The sensor set of the robot includes a colour stereo camera system with two CMOS cameras and DSP, allowing each robot to perform sophisticated stereo image processing on-board. The modular design permits the addition of new modules into the system. The modules communicate using three serial buses (SPI, I2C, and UART), which enable flexible, adaptive, and fast inter-module data exchange. The robot is developed for swarm robotics research with the aim of providing a low-cost and low-power miniature mobile robot with capabilities typically found only in large robots.

During 2005, a group of five miniature robots were fabricated, and all the necessary software components were implemented to enable the utilization of the multi-robot team in basic research.

The robot developed is a part of research which aims at understanding how a global objective can be achieved by a multi-agent system without explicit regard for cooperation with the other agents, and to in-
investigate the relationship of spatial patterns composed of interacting entities (agents) and the resulting dynamics.

In addition, we are investigating how humans can effortlessly interact and control a multi-agent system and gain meaningful information about the environment through it, and we study what are the minimal requirements for an agent in order to produce useful behaviour at the system level.

Based on the research in the Rotuaari project, OUSPG published in 2004 a pilot issue of “Ylivuoto”, a magazine devoted to informing Finnish SMEs about issues related to information security. Initial feedback showed that there was a need for such a publication, and further issues have been published in 2005. The purpose of Ylivuoto is to offer SMEs a new channel of receiving information security related knowledge in an easily understandable form.

One protocol robustness test suite, for the ISAKMP/IKE protocols used for securing VPN connections, was released to the public in cooperation with FICORA and NISCC. Several vulnerabilities were found using the test suite.

In addition to the core research, OUSPG also maintains a test network infrastructure for research groups such as OUSPG, ISG and MediaTeam. Test networks are required for the safety of both our own research and innocent bystanders, and one was constructed for internal use in the laboratory. The network provides a fully functional infrastructure with services such as storage, backups, DNS and mail.

The infrastructure started life as an isolated test network for OUSPG use, but has expanded to provide basic infrastructure to others with similar needs. There are three separate networks: a core network for basic services, the panOULU combined playground and wireless access network, and an Internet-connected network with connectivity independent of the main university network.

**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 in 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 6th framework as a Network of Excellence. We will strengthen our international research co-operation. One of our staff is currently working as post doctoral researcher with Professor Tatsuo Nakajima at Waseda University, Tokyo. Prof. Riekki is preparing a co-operative seminar in Tokyo to be active in Spring 2006.

**Personnel**

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**Doctoral Theses**


**Selected Publications**


