INTELLIGENT SYSTEMS GROUP (ISG)

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Background and Mission

The Intelligent Systems Group's mission is to carry out leading edge long-term research on intelligent systems technology. We concentrate on mobile and context-aware systems, data mining methods and secure programming. Our aim is to increase systematically our methodological understanding and to develop components for an intelligent environment that gives versatile services to its inhabitants.

We see behaviour modelling as one of the key challenges in developing intelligent environments. Models of user behaviour are needed to adapt the functionality of the intelligent environment to the situation at hand. Further, it is essential to be capable of modelling the behaviour of the devices the intelligent environment controls, as it enables adaptation to environmental changes without reprogramming. In other words, a system learns and adapts automatically to perform behaviour fulfilling the requirements set to it.

The significance of developing this kind of calm technology is evident. The user does not have to command everything but the system can give commands on behalf of the user. In other words, the intelligent environment provided by calm technology enables people to do more by doing less. Our quality of life could thereby be improved, and for example by supporting the independent coping of the elderly, the expenses incurred by society would decrease.

We tackle the research challenge of the intelligent environment by increasing systematically our methodological understanding of the problem and applying the methods developed in realistic prototypes. We need to work on emergent intelligence by developing methods for self-organization and evolution of adaptive behaviours, and applying them with mobile robots and devices. We need to have a good understanding of signal analysis and sensor fusion, including structural and statistical pattern recognition. To acquire the knowledge embedded in the raw signal data, different data mining methods are required (softcomputing, clustering and visualization).

In the applied research, prototypes will be implemented for evaluating the developed learning methods. This work consists of specifying the applications, developing the software architectures, building the infrastructure, implementing the prototype systems, and testing them. We also target robust software architectures that follow good information security practices.

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 National Technology Agency (Tekes) and industry. The group and its members are active in the scientific community. For example, Prof. Juha Röning served as Co-chair on the program committee of Intelligent Robots and Computer Vision XXII: Algorithms, Techniques, and Active Vision (25-29 October 2004, Philadelphia, Pennsylvania) and as a Member of Steering Committee of the OpticsEast Symposium. Also several members of the group were on the committees of international conferences. As recognition of profound work in the software vulnerability process, Tiina Havana gave an invited talk at the "Cybersecurity, research, and disclosure" conference which was held at the Stanford Law School in Palo Alto, California, on 22nd November, 2003. The quality of research training in our group is high. Two recent master's theses (Kari Kangas and Heikki Pylkkö) have been awarded the title of the best thesis of the year and Ilmari Juutilainen received the Leo Törnqvist award for the best pro gradu thesis from the Finnish Statistical Society in 2003.

Interest to our research has been strong. For example this year the Prime Minister of Norway, Kjell Magne Bondevik, and the Prime Minister of Finland, Matti Vanhanen, 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 2004, the research at ISG concentrated on mobile and context-aware systems, data mining methods 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.

Context Aware Systems

The core of context aware systems research is realized in the Beacon (Behavioural Modelling in Context-Aware Systems) research project which is part of a research program on Proactive Computing (PROACT) organized in co-operation with Tekes, the National Technology Agency of Finland and the French Ministry of Research. A proactive system adapts and adjusts to the user and his or her environment without requiring any conscious control.

The objective with context aware systems is to develop methods for learning behavioural models. Two kinds of models are needed: models for user behaviours and models enabling devices to adapt to their environment. Methods for learning models are needed to develop devices capable of adapting to different environments without reprogramming. Models of user behaviours are essential in proactive computing, as they are needed to adapt the functionality of the proactive system to the situation at hand. For example, a model might show that an elderly person walking in her apartment is probably heading towards the hallway. Using such a model, the proactive system could switch on the lights in the hallway. Methods for analysing sensor signals will be developed as well, as they produce the parameters used by the learning methods. The final goal is to enable the proactive system to adapt to environmental changes in real time.

The research on context-aware systems involves the development of proactive, context-aware environments. 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 have been continued this year. With this environment we can demonstrate and validate our research results.

Research with a pressure sensitive floor focused on improving the methods used for segmenting footstep profiles from EMFi-data and finding a person's identification. The methods for person identification based on footstep profiles are delivered from the pattern recognition and machine learning domain, originating from statistical pattern classification as well as from neural computation. Different studies have been made, utilizing Hidden Markov Models, Multilayer perceptrons and Learning Vector Quantization, for example. In addition, the methods for combining multiple independent classifiers have been developed, due to possibility of using multiple consecutive footstep samples from the same person, as well as different feature sets for single footsteps, to make the final decision. The research is part of proactive computing, where data mining has been utilized in finding the users routines from a vast amount of data. The study aims at making the computing environments calm and proactive.

Another environment utilized in the research of context aware systems has been built in the centre of Oulu, in a pedestrian precinct called Rotuaari. The Rotuaari project consists of developing a research environment, executing field trials in the research environment and developing the value network related to the context. The group also maintains a test network infrastructure on the Linnanmaa campus. This is used also by other groups, for example MediaTeam.

For handling devices and services in our smart living room, we continued the development of a distributed architecture, called Property Service architecture. Through Property Service architecture, new devices are easy to append to the system. The focus is also on high reusability of existing code and software components as the same control algorithms can be used on various devices. Markers and behaviours have been developed to act as general tools for robot control regardless of the type of the robot that is used. A part of the architecture is work on dynamic state machines that are used for controlling multiple devices in cooperation. Easy to use tools like a graph editor were developed for the system to provide a possibility for a non-technical person to use the devices in the system. Both architectures have been utilized and further developed in the All-IP (Application Supernetworking) project (coordinated by MediaTeam).

All-IP is a three-year national project (began in February 2004) which is focused on developing methods and the technology needed for inter-application connectivity and compatibility. The role of ISG in All-IP is to research and develop robust methods of controlling software and providing the communications between software modules. We have developed a state machine execution framework based on the experience gained in previous research projects in the past years. The framework is modular by nature and the design supports an abstract definition of a state machine. The concrete description used in the developed prototype, State Machine Markup Language, is based on Resource Definition Framework (RDF), which is usually formatted as XML.

The second research issue has been approached with a second-generation implementation of a transparent resource manipulation framework, also known as

Property Service 2. It provides the application developers with an abstract, location-independent view of resources in the system. It is in a way a middleware solution, but it is not restricted by the underlying transmission methods, like most available techniques. A prototype has been developed and it supports multiple endpoint types, ranging from pure TCP/IP to XML-RPC.

Together these two provide a solid basis for developing robust distributed systems. The applications built on top of them can vary from robot control to third-generation content sharing networks. Research will continue by bringing the two frameworks seamlessly into smaller and smaller hosts, such as mobile phones, where they will serve the important role of controlling ubiquitous networking and application connectivity.

The focus of the CAPNET program is on context-aware mobile technologies for ubiquitous computing. These are technologies, which allow communication anytime and anywhere, with any kind of terminal device, automatically taking into account the characteristics of the network and the terminal. The ISG participates in the CAPNET program by studying context-awareness and developing software architectures. Context-awareness research concentrates on identifying the user's routines, utilizing location information acquired through a WLAN, and a pressure sensitive floor in a smart living room.

We have also started research on utilizing Property Service architecture and markers for controlling swarms of robots. A simulator for a large number of robots has been developed. The program contains two main parts; the simulator and user interface. The simulator is able to simulate a simplified environment containing over 200 robots and several thousand environment objects in real-time. We have also started the development of a miniature robot. The aim is to provide a small sized mobile agent with powerful audio-video processing capabilities and sophisticated on-board sensors for proactive computing. The first working prototypes were finished during the reporting period.

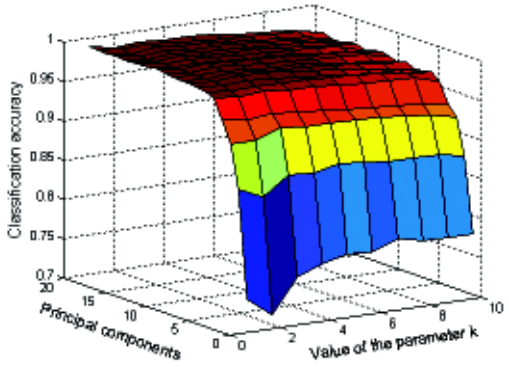
Data Mining

The data mining research in ISG is driven and inspired by applications. State of the art data mining methods are applied and developed in order to extract knowledge from data originating from real world systems and phenomena. The two main sources for the data are: industrial and biomedical measurements.

Industrial Data

Industrial data mining is often focused in developing and optimizing production processes based on data gathered from production lines. The benefits can be realized in a higher level of automation, increased quality of goods (usually manufactured in large batches) and customer satisfaction. During the last year research and application development was conducted with partners from the spot welding and steel industries.

The spot welding research was carried to a successful conclusion in a two year EU-project (SIOUX) completed last September. Real-time, non-destructive, methods for estimating the quality of welding spots and methods for reducing the set-up time of welding processes for different welding applications were developed. The approach used does not require extra instrumentation and is based solely on the information produced during the normal operation of spot welding processes. It is therefore very affordable, easy to manage and can be applied to all the produced parts.



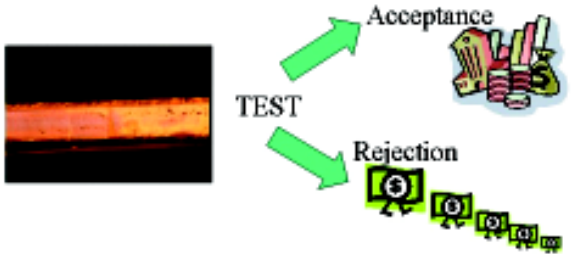
A surface plot of the results of tenfold cross-validation of the parameters used in the process identifier developed in the SIOUX project.

The system developed consists of a central database and data mining algorithms accessing it. The developed algorithms compare data from the user's welding process to data stored from various welding processes in the database and return settings and quality control algorithms from the most similar process found in the database. The system is not just capable of identifying the most similar process, but it can also tell how similar the closest matching process is in order to prevent the use of a control algorithm from too dissimilar a process.

Long-term co-operation with the Finnish steel producer Ruukki (formerly Rautaruukki) was continued in the completed VALTA and the new TASA projects. The goal of the projects is to increase the quality of steel products and to implement and test real-time data mining solutions in production lines.

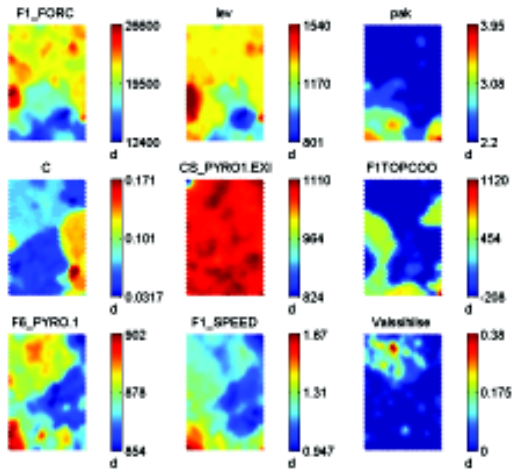
Methodology for joint modelling of mean and dispersion based on large data sets was developed. The methodology was applied to predicting the probability of

rejection in qualification tests of steel plate products. The models developed are now used on a production line for optimizing process settings. An advanced method for scale defect identification on the measurements of surfaces of steel strips was developed using self-organizing maps (SOMs). The method developed is capable of finding seven out of eight defects. In addition, the development of a production line software implementation of a model tracking and predicting the steel slab temperatures as they are heated in a reheating furnace was continued.

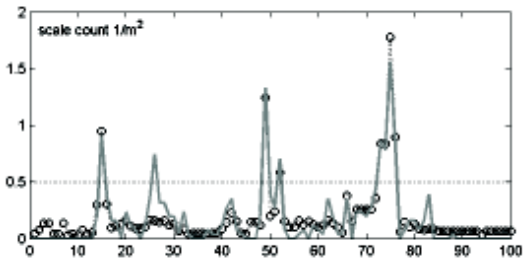


Data mining has been applied to modelling the probability of the acceptability of steel plate products.

A steel slab exiting a re-heating furnace where the slab is heated up to 1200°C. The position of the slab and the measurements from the heating environment are tracked and a prediction for the exit temperature of the slab is given using the software developed in the VALTA and TASA data mining projects.



SOM visualisation of 9 variables used for modelling the surface quality of steel. SOM was used for finding new knowledge. Some non-linear correlations can be seen. The visualized data set contains over 20000 samples from low-silicon steel qualities. The target variable, rolled-in scale, is shown in the right bottom corner.



Surface quality of hot-strip rolled steel products were predicted with a SOM. Target data, containing the rolled-in scale defects, was gathered with a video camera-based surface inspection system. Predicted (marked with circles) and measured (grey solid line) scale content for one product quality is shown for 100 samples. Each sample contains information from a 20 m section of the steel strip.

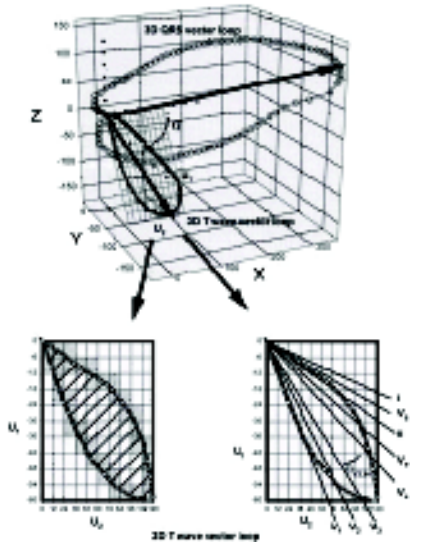
Biosignal Processing

Sudden cardiac arrest is the most common mode of death in western countries. It accounts for approximately 50% of the cardiovascular deaths and has apparently a highly variable pathophysiological basis. The risk of sudden cardiac arrest is high in certain subgroups of patients with a history of myocardial infarction and depressed left ventricular function. A key question in research is why do some of the subjects develop ventricular fibrillation during acute coronary occlusion, but others survive this episode without fatal arrhythmia. The challenge for research is to develop approaches or techniques which will allow the screening of specific risk for fatal ventricular arrhythmias as the expression of a first event in patient populations that cumulatively have a low risk, but generate a large numbers 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). The ECG contains information on the heart function that is highly relevant to diagnosis and treatment. This information includes signals from the atrial electrical activity (P-wave of the ECG and the corresponding atrial repolarization signal mixed in the QRS-complex) and also of the ventricular repolarization (the T-wave). We set two main objectives in this research:

Objective 1: Computation of risk markers from ECG characteristics. The aim is to develop new methods and algorithms for analysis and interpretation of electrophysiological signals and autonomic regulation of the cardiovascular system. The digital 12-lead ECG is decomposed to multi-dimensional dipolar and non-dipolar components of the ECG in depolarization and repolarization phases in order to derive new risk markers of heart diseases. The 12-dimensional principal components analysis is performed to extract dipolar

(vectorcardiographic) and non-dipolar components from the measurement signal (see the figure below). Depolarization and repolarization phases are analysed separately and various parameters (e.g., VCG loop descriptors and singular value based descriptors) are computed that describe the electrical functioning of the heart during one beat or in a continuous ECG. These parameters will be statistically correlated between patients with high and low risk of malignant arrhythmias, respectively. Single-parameter and multi-parameter models will be developed that provide the best discrimination ability. Another important topic is the derivation of markers from heart rate variability (HRV) that describe the dynamic behaviour of the heart from R-peak intervals only.



Vectorcardiographic loop structures of QRS and T waves are described with various morphological parameters.

Objective 2: Modelling of the electro-physiologic functioning of the heart. The aim is to find simulation models that are able to generate the ECG behaviour of healthy humans, but also able to reproduce that observed with real measurements from patients suffering from heart disease. We especially aim to derive electro-physiologic models that can explain the genesis of the non-dipolar components of the ECG during QRS and T waves.

Objective 3: Modelling of the functioning of an autonomic nervous system. Relationships between ECG, blood pressure, breathing, and sympathetic nervous activity signals are modelled and identified from actual signals in order to find new models for the autonomic control of the cardiovascular system. The methods we use are the sequence method, the alpha method, the transfer function method, and parametric modelling. From the identified models, various important parameters related to cardiac state are computed, such as the baroreflex sensitivity (BRS). Measurement equipment is used that only few research groups possess in the world.

The medical part of the research is performed in the Oulu University Hospital and Merikoski Rehabilitation and Research Centre, while our group is responsible for the signal analysis algorithms. The work is partly international, including universities from Europe and the USA.

The team is involved also with anesthesiology research. The goal of anesthesia is to render the patient unconscious and painless in a controlled way. In routine surgery, the nursing staff mainly evaluates consciousness and pain subjectively by observing the appearance of the patient and using measures like drug concentration and blood pressure. The purpose of monitoring automatically the effects of anesthesia would be to provide an objective indicator of the state of a patient for individualized drug administration. Individual monitoring would be helpful in titrating the drugs to the desired clinical endpoints with dosing-to-effect strategy. Predetermined fixed dosing regimens have a problem of wide pharmacokinetic variation in the patient population. Excessive doses may lead, for example, to cardiovascular instability and prolonged sedation after discontinuation of titration. Inadequate sedation predisposes to pain and suffering that increase the stress reactions and morbidity, not to mention intraoperative awareness. Our efforts concentrate on characterizing EEG changes during anesthetic induction and deriving new descriptors for monitoring automatically the level of anesthesia. Part of the work includes the physical reaction to pain during medication. The research is performed in cooperation with the Oulu University Hospital and the Lappeenranta University Hospital while our team is responsible for algorithm and software development.

Secure Programming

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 provide potential for unanticipated and undesired program behaviour, e.g. an intruder can exploit the vulnerability to compromise the computer system. The group has researched different approaches to testing implementations of protocols using black-box (i.e. functional) testing methods (PROTOS).

A major theme in 2004 has been the implications and relationships of 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 in complexity is the convergence of information networks. It is difficult for network admin-

istrators to keep up with the development when even a single network device may implement tens of different protocols from several interfaces. Just the network management may require the use of several experts from different fields.

OUSPG approaches this problem from several directions. In the FRONTIER-COMPAT project, methods for inferring causal relationships in complex systems are developed. 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.

The PROTOS-GENOME project approaches the problem of complexity 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. The project funding started in 2005, but some preliminary documents and prototypes were written in 2004.

Another angle for approaching this problem is through protocol dependencies. This activity studies the impact factor of different technologies on CNI, and develops a visual model for understanding dependencies related to protocols. Information about technical qualities and prevalence of protocols is gathered. Also data about public attention to a specific protocol is of importance to the research. Wider understanding of the state of the art is developed by gathering research data with expert interviews. The purpose of the model developed based on this data is to help technical and organizational understanding as well as to help risk management, vulnerability analysis and strategic planning.

Coping with complex information network environments requires effective communication channels and forms in society. OUSPG has concentrated on researching the methods and practices of information security related communication in the context of the Rotuaari research project. In this research, attitudes and perceptions related to information security as well as present communication channels have been evaluated, and suggestions for effective ways of communication will be presented. The central question in this research is to evaluate how information security knowledge management is and should be handled in companies, and society in general.

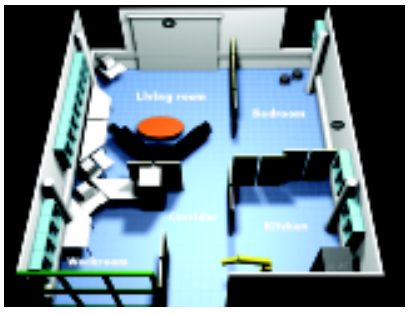
In addition to proactive information security research, in the Rotuaari project OUSPG has also tested an incident response service. Incident response means effective methods of reacting to information security problem situations. An incident response business plan was created and a test offering this kind of service was completed. According to the preliminary results, companies are not willing to outsource this function. However, the need for further research exists.

The results of OUSPG's work published in 2004 consist of one journal article, "Agents of responsibility in software vulnerability processes", three conference articles and one magazine article.

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.



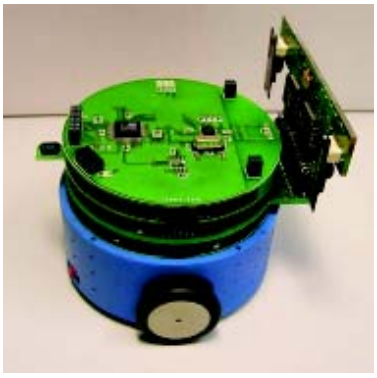
A computer generated view of a smart living room in our laboratory. EMFi-sensor stripes are illustrated on the floor.

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 con-

trolled 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 co-operation 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 method for building complex robots with modular methods. Modularity has been achieved using Atomi electronics and modular software architecture Property Service. Atomi electronics provides us with the possibility to modify the hardware of the robot easily and new functionalities are available immediately in plug-n-play way. Property Service provides an interface for these resources and an opportunity to use Qutie as a part of an intelligent environment.

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. In the Computer Engineering Laboratory, 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.



The miniature mobile robot developed in the Computer Engineering Laboratory of the University of Oulu. The modules shown here are (from the top): the radio, the environment, and the stereo camera modules, respectively. All modules have an 8-bit low power 8MHz MCU (ATmega32), which implements the serial interface for accessing the module services, and controls the logic in the module.

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 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 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 will be 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.

Two robustness test suites for widely used network protocols used for critical applications were developed. Both are currently in the pre-release stage and will be published once the vulnerability handling process for them has been completed.

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 combined playground and wireless access network panOULU, 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. We are preparing with Professor Tatsuo Nakajima from Waseda University, Tokyo, a post doctoral research position in Japan for one of our researchers.

Personnel

professors & doctors	7
graduate students	13
others	36
total	**56**
person years	32

External Funding

Source	**EUR**
Academy of Finland	4 000
Ministry of Education	168 000
Tekes	321 000
domestic private	335 000
EU + other international	136 000
total	**964 000**

Doctoral theses

Haverinen J (2004) Adaptation through a stochastic evolutionary neuron migration process. Acta Universitatis Ouluensis C 202.

Pirttikangas S (2004) Routine learning: from reactive to proactive environments. Acta Universitatis Ouluensis C 212.

Selected Publications

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Junno H, Laurinen P, Tuovinen L & Röning J (2004) Studying the quality of resistance spot welding joints using self-organising maps. Fourth International ICSC Symposium on Engineering of Intelligent Systems (EIS 2004), February 29 -March 2, Madeira, Portugal.

Juutilainen I & Röning J (2004) Modelling the probability of rejection in a qualification test based on process data. COMPSTAT 2004, 16th Symposium of IASC, August 23-27, Prague, Czech Republic, 1271-1278.

Kiviniemi A, Hautala A, Mäkikallio T, Laukkanen R, Nissilä S, Seppänen T, Huikuri H & Tulppo M (2004) Saturation of vagally mediated heart rate variability after aerobic training. American Journal of Physiology.

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Koho K, Suutala J, Seppänen T & Röning J (2004) Footstep pattern matching from pressure signals using segmental semi-Markov models 12th European Signal Processing Conference (EUSIPCO 2004), September 6-10, 2004, Vienna, Austria.

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Takanen A, Vuorijärvi P, Laakso M & Röning J (2004) Agents of responsibility in software vulnerability processes. Journal of Ethics and Information Technology 6:93-110, Kluwer Academic Publishers.