Centre for Autonomous Systems

# CAS NEWS

## Real World Systems

Recently a number of interesting mobile robot systems have been announced or shown. This includes the demonstration by Electrolux of their autonomous vacuum cleaner for domestic cleaning. Another interesting commercial prototype is the Sony Dog, which is a reconfigurable four legged robot, with a size similar to a small dog. These systems clearly demonstrate that companies have adopted the idea of using robots for various purposes. The Sony system is directed at the entertainment market. The potential of that market is significant and it will be interesting to see it develop.

Another area that recently has been very active is robots as tour guides. At Carnegie Mellon University, Pittsburgh, two different systems have been developed, the Minerva and the Sage system. These robots are used as tour guides in museums. The Minerva system was deployed in the National Museum of American History, where it guided visitors between different displays. The Sage system offers tours at the Dinosaur Hall in the Carnegie Museum of Natural History. These systems illustrate how navigation in well-known environments is possible. The above mentioned systems indicate also that some basic robotics techniques are becoming mature. All of the above systems are, however, the result of significant engineering efforts and it is still a major undertaking to deploy systems in a given setting. It is none-the-less encouraging to see such systems deployed in realistic environments.

The Centre for Autonomous Systems has, over the last 6 months, presented two robot systems. The Intelligent Service Robot, which is aimed for use in a domestic setting, has been demonstrated. The system is capable of delivering mail to people in the laboratory. The system utilizes ultra-sonic sonars and laser ranging for localisation, obstacle avoidance, and docking. The system automatically identifies landmarks for navigation. It uses a speech interface for receiving instructions from a user. Presently the system is being extended to include more advanced capabilities for manipulation, human-robot interaction and robust mapping of the environment.

The second robot is a legged platform for out-door operation. This robot is a quadruped system, where each leg has three degrees of freedom. The system includes a combustion engine and a generator to facilitate autonomous out-door navigation. Presently the basic control and software facilities for walking are developed.

Both systems are outlined in this newsletter. An article about localisation and position estimation using laser ranging is also included. The series on courses offered by the centre is continued with an outline of a course on design and implementation of real-time systems. Finally the newsletter includes a new feature, presentation of some of our Ph.D. students. By now the centre has a total of 23 full time Ph.D. students.

We hope that you will find the information provided of interest and as always we would like to receive feedback from our readers.

*-Henrik I Christensen*

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# The Intelligent Service Robot

*Dr. Magnus Andersson, ISR Project Manager*

The advancement of science and technology makes it possible to create more and more intelligent machines. The goal of the Intelligent Service Robot (ISR) project is to show that it is possible to build a flexible robot that can operate in an ordinary home or office environment. Such a robot might be able to perform a number of tasks, e.g., cleaning a floor, setting a table, delivering mail or assisting a handicapped person. We believe that the need for this type of robots are greatest in industry/offices or for handicapped/elderly people. Due to the costs, it will likely take time before such systems become part of an ordinary home.

We call the project a demonstrator. A demonstrator is both a concept and a physical object. As a concept it defines the research problems which need to be addressed to construct an intelligent service robot; researchers should keep the application in mind while working on individual topics. As a real robot it is used to perform empirical evaluation of methods. Simulation, which is often used for evaluation, cannot compete with tests using a real robot in a real environment. At present the project involves more than 10 researchers from 3 different departments at KTH.

**Where are we today?**

The first two years of the project has focused on providing a basic functionality for our Nomadic Technologies Nomad 200 robot. With its limited capabilities of manipulating objects in the environment, our main efforts have been to develop methods for navigation, i.e. to make it possible for the robot to figure out where it is and how to move from one place to another, while avoiding obstacles in its way. Navigation is currently relying on ultrasonic or laser based sensing. Using ultrasonic sensors the robot can automatically create a landmark based map of a room. This map, together with information about how rooms are connected is used by the robot to find out where it is and where to go, see e.g. [Wijk] for more details. The sonar sensors are also used for obstacle avoidance. Using a laser range finder, navigation has been further improved, see the separate article in this issue of CAS News.

To be useful in a home or an office it is also important that communication between humans and the robot can be done in an simple and easy to learn fashion so that non-experts can use the robot. Therefore the demands on the human-robot interface are high. The robot is equipped with a speech recognition system and a speech synthesizer, which makes it possible to give simple voice commands to the robot and to get spoken response back. Different aspects of speech and task analysis are investigated in a collaboration with the Human-Machine Interaction project (HMI) at KTH. However, some commands are difficult to explain using speech only. To overcome this problem, we perform research on gesture recognition using visual input from one or two cameras. Today the robot understands simple pointing gestures.

An important aspect of building an operational system is how different pieces can be integrated into a working system. During the last year, a software platform has been built that allows, in an easy and flexible way, new capabilities to be included as they become available.

To show the different capabilities of the robot, a mail delivery task has been implemented, which consists of the following steps. The robot is told to deliver mail to a specific room (speech interface), it plans its action (planning, software platform), goes to the mail slots (navigation using sonar and laser sensors), picks up the mail using a fork lift (simple manipulation) and delivers it to the correct room (navigation again). The robot does automatic map generation and it includes basic facilities for error recovery.

**And next?**

The most important change during the next year (1999) is the transfer of the software system to the new Nomad XR4000. This robot, apart from being able to move around in the environment, has a robot arm on top. This facilitates more advanced manipulation. Thus we will in the near future be able to pick up and put down objects in the environment, open drawers and doors etc. During the following years our work on navigation, human-robot interface, manipulation and systems integration will continue, but we will also start research on cooperating robots, i.e. robots that work together to solve tasks.

[Wijk] Olle Wijk. Navigation of mobile robots usingnatural landmarks extracted from sonar data. Lic. thesis, TRITA-S3-REG-9801, 1998.

*The Nomad 200 robot getting mail from a mailslot.*


*The Nomad XR4000 with the onboard Puma 560*

# The Walking Robot Project (WARP)

*Dr. Tom Wadden, WARP Project Manager*

In the walking robots project we study locomotion for difficult terrain. The choice of legs as a means for locomotion in difficult terrain is due to their potential for quickly and agilely crossing rugged terrain. More specifically we have chosen a four-legged platform as this allows three to be used for support during slow walking. Adding further legs was decided against due to the added complexity and weight.

There are, at present, 3 robot platforms. Two single leg prototypes, one electric (M3L; [WAD1]) and the other hydraulic, plus a 4-legged electrically actuated robot which is in the final stages of completion and will be described here.

WARP1 is the name of our four-legged robot, the construction of which was initiated by 39 KTH students in their advanced course in Machine Elements and Mechatronics. Since then further developments and modifications have been made to the platform which should be fully functional and walking in spring 99.

Although primarily for outdoor purposes, WARP1 has been constructed to move through compact spaces such as staircases and doorways. It has a body width/length of 0.4 m and 0.8 m respectively, and a leg length of 0.6 m from the hip to the ground. Each leg has 3 controllable degrees of freedom, two at the hip and one in the knee. These are powered by 150W MAXON DC motors using harmonic drive transmissions, while the feet are passive. Rubber torsion springs have been placed at the hip and knee joints to add shock tolerance and energy efficiency.

Since the long term goal is an autonomous platform, WARP1 is self-contained, i.e. it has on-board computing and power generating capabilities. This latter is accomplished by a power module consisting of a combustion engine and electrical generator. The two-stroke brush saw engine has a power of approximately 3kW at 8400rpm. For indoor use the robot is connected to a three-phase regulator via a rectifier that generates 48V.

There are at present five optical encoders (HP HEDS 5500), one placed on each motor plus one at the hip and knee joints. By having encoders placed on each side of the spring we are able to record its displacements. This can be used as a warning for unexpected joint movements, such as contact with an obstacle. For detection of ground contact each passive foot has a single axis force sensor.

WARP1 is designed to be modular in terms of mechanics, electronics, software and control. This enables easier replacements and modifications. The computers, sensors, electronics, and cabling are integrated with the mechanics, and a distributed control architecture is being constructed in order to reduce cabling. At present the robots mechanical system is fully constructed and we are working with the electronics hardware and software. The power to weight ratio of the robot will most likely prevent it from running and jumping, although we are working on ways to increase power and decrease the weight

(67kg in total). We are, for example, presently testing a single leg hydraulic prototype which has an excellent power/weight ratio.

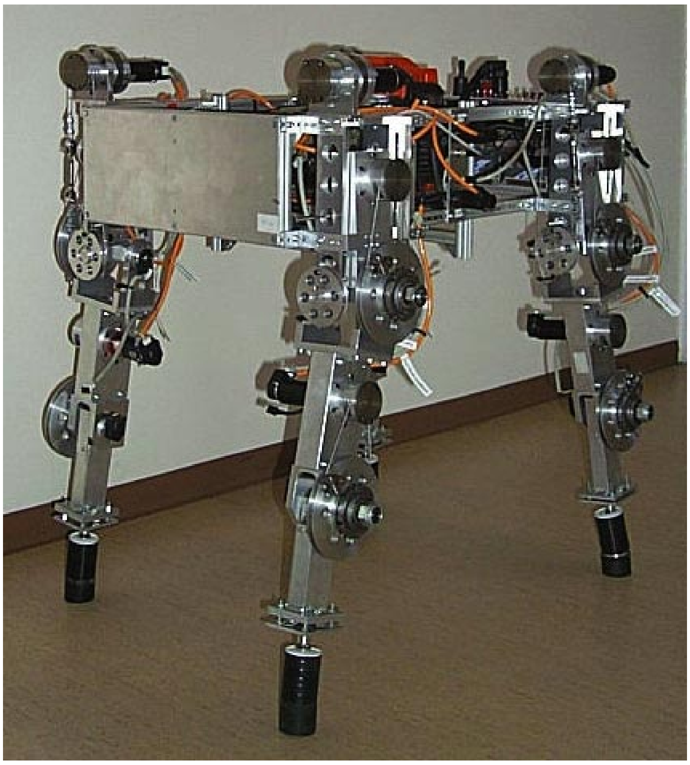
Once WARP1 is completed we will implement controllers tested in simulation and on M3L. These include: a model of the robot which uses a behaviour based paradigm to control basic stepping movements, leg coordination and higher level terrain adaptation [PJR]; A biologically inspired neuro-mechanical model of stepping [WAD2]; A model based controller which has produced stepping at different velocities on M3L; A model for attitude control which has indicated that rate gyros and inclinometers can complement each other to provide good control of pitch and roll movements [RR].

[PJR] Lennart Pettersson, Kennet Jansson, Henrik Rehbinder, Jan Wikander, "Behavior-based Control of a Four Legged Walking Robot", Proceedings of Mechatronics'98, pp. 361-366, Eds J Adolfsson & J Karlson, 1998.

[WAD1] Tom Wadden, Karim Benjelloun, Freyr Hardarson, Jan Wikander and Orjan Ekeberg, "Biologically Inspired Design of a Leg for Dynamic Walking", Proceedings of Euromech Colloquium 375: Biology and Technology of Walking, pp 228-235, 1998

[WAD2] Tom Wadden and Orjan Ekeberg, A Neuro-Mechanical Model of Legged Locomotion: Single Leg Control, Biological Cybernetics 79, pp 161-173. 1999

[RR] Henrik Rehbinder and Christian Ridderström, Attitude Estimation for Walking Robot. ICRA-99, Detriot, 1999 (submitted).



*The WARP-1 Walking Robot Prototype*

# Laser-Based Navigation

*Mr. Patric Jensfelt & Prof. Bo Wahlberg, S3*

One of the most fundamental and still challenging issues in the field of mobile robotics is the problem of self localisation. The key question is ”where am I?”. Different sensors are used to answer this question. Models of the sensors and of the environment allow efficient processing of the sensory information. Commonly used models of the environment can be divided into grid-based models [rhino,xavier,moravec] and feature-based [crowley,leonard]. Both these classes of models have their pros and cons. Grid-based methods have the ability to represent structures which do not have a straightforward geometrical representation, the complexity increases with more detailed resolution. Feature-based methods on the other hand can only handle structures which belong to the set of given building blocks (e.g. lines, arcs,..). This allows compact descriptions, but the matching problem can become quite difficult. For our project, we have chosen to study simple feature based world models for indoor environments.

The ultrasonic (sonar) sensor is the most widely used sensor for indoor mobile robot navigation. However, recent developments in laser scanner technology has reduced its price, and made laser scanners an economically feasible alternative for more low cost applications. The main advantage of laser scanners is the improved resolution and high scanning rates. We are currently evaluating a PLS 200 laser scanner from SICK Electro-Optics, which previously has been successfully tested in e.g. [Kristensen].

Let us now more in detail describe our results and preliminary experience of a model based estimation method for wall estimation and localisation in an office environment.

**The Model**

Each room is modelled as a rectangle, and is represented by width and length. Furthermore, information how the different rooms are connected is stored.

**The Algorithm**

We have mainly been studying the problem of pose tracking (pose is position and orientation). It is assumed that the robot initially knows its pose, and the problem is to keep track the pose as the robot moves. The updating procedure is based on a Kalman filter. Define the state vector $\mathbf{x}_k$ to represent the pose of the robot at time k. By modelling the odometry as a deterministic input (with some noise) the following state space model is obtained:

$$\mathbf{x}_{k+1}=\mathbf{x}_k + \mathbf{g}_k+\mathbf{w}_k$$

where $\mathbf{g}_k$ is the input from the odometry and $\mathbf{w}_k$ represents the process noise. By extracting the walls from the sensor data, we will have measurements of the pose of the robot. The coordinate system has been chosen in such a way that the distance to a wall corresponds directly to either the x- or the y-position of the robot. The angle of the wall is a measure of the angle of the robot. The measurement equation can be described by

$$\mathbf{z}_{k,i} = \mathbf{H}_i \, \mathbf{x}_k + \mathbf{v}_{k,i}$$

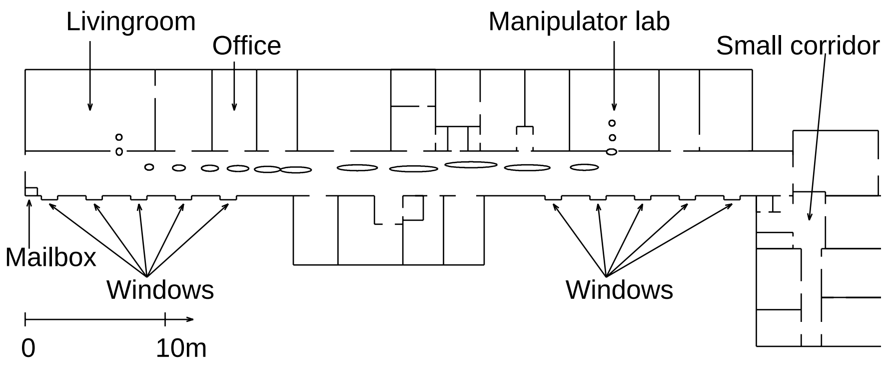
where $\mathbf{H}_i$ is either [1 0 0 ; 0 0 1] or [0 1 0 ; 0 0 1] depending on the wall and $\mathbf{v}_{k,i}$ is the corresponding measurement noise.

The odometry has been modelled to design realistic variance of the process noise $\mathbf{w}_k$. There are certain situation for which the process noise may increase, e.g. due to slippage on thresholds when passing from one room to another. To compensate for this the uncertainty in the pose estimate are increased when the robot passes from one room the another.

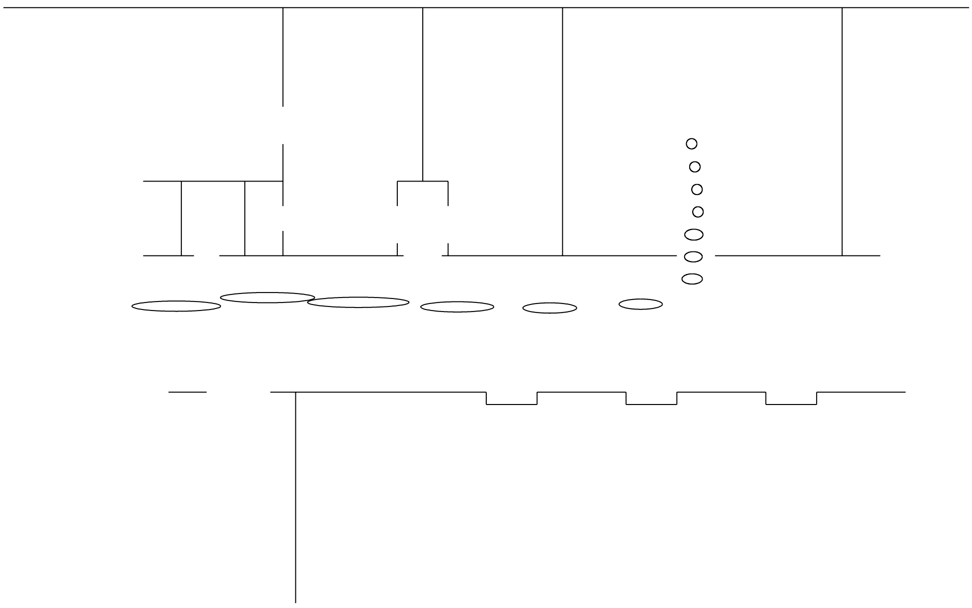
**The Results**

We have experimentally tested the pose tracking method in many different type of rooms as well as driving in a long corridors. The corridor used for our experiments will be modelled as a rectangle, and has length 55m and width 2.3m. Since the laser scanner only give reliable estimates for distances less than 15m, little or no length information is obtained in the middle of the corridor. This will lead to an increased uncertainty in that direction, and might potentially make the robot loose track of its pose. In the figure below we give an example when driving from the so-called the living-room to the manipulator lab at the other end of the corridor. When leaving the living-room the uncertainty starts to increase, but when coming close enough (< ~15 m) to the other end of the corridor the robot starts to track again. This effect is illustrated in the next page.

The results are very promising, but also points out the need for a strategy to handle situations where extracting only walls provide little information. By using active sensor strategies one can at least make sure that the sensor is facing in the direction where there is most likely to be walls that can be used to update the position. By extending the model to include the position of other feature, e.g. doors, one can also overcome some of the difficulties. But our aim is to investigate how far we can come, using the very simple rectangular model for each room.




*Result of moving from the living-room to the manipulator lab. The size of the uncertainty ellipses has been enlarged for illustrative purpose.*



*A close up of the situation when passing from the corridor to the manipulator lab.*

Another option is to combine the information from the laser scanner with other sensors. We are currently investigating how to fuse the laser scanner estimate with information from a sonar based scheme using natural landmarks. It is still too early to present any results and considering the fact that the sonar based navigation system also has problems in the corridor, it is likely that corridors will still be a challenge.

[Crowley] J. L. Crowley. World modeling and position estimation for a mobile robot using ultrasonic ranging. In Proc. of International Conference on Robotics and Automation, 1989.

[Xavier] S. Koenig and R. G. Simmons. Xavier: A Robot Navigation Architeture Based on Partially Observable Markov Process Models, chapter 4, pages 91-122. AAAI Press/ The MIT Press, 445 Burgess Drive, Menlo Park, CA 94025, 1998.

[Kristensen] S. Kristensen, V. Hansen, K. Kondak, and S. Horstmann. A modular architeture for a flexible autonomous service robot. In International Symposium on Intelligent Robotic Systems, pages 93-100, 1998.

[Leonard] J. J. Leonard and H. F. Durrant-Whyte. Directed Sonar Sensing for Mobile Robot Navigation. Kluwer Academic Publisher, Boston, 1992.

[Moravec] H. Moravec and A. Elfes. High resolution maps form wide angle sonar. In Proc. of International Conference on Robotics and Automation, pages 116-121. IEEE, 1985.

[RHINO] S. Thrun, A.Bücken, W. Burgard, D. Fox, T. Fröhlingshaus, D. Henning, T. Hofmann, M. Krell, and T. Schmidt. Map Learning and High-Speed Navigation in RHINO, Chapter 1, pages 21-54. AAAI Press/ The MIT Press, 445 Burgess Drive, Menlo Park, CA 94025, 1998.

# Course: Software for embedded real-time control systems

*Prof. Jan Wikander, DAMEK*

Mechatronic applications, such as autonomous robots, often include an extensive set of embedded microprocessors, organised in a distributed architecture. The major functionality is of course implemented in software and the trend is that the amount of software is increasing rapidly. Many of the applications are time- and safety-critical and must therefore have a predictable and robust performance. Safety and robustness are key requirements in for example automotive, medical and manufacturing applications.

This course on real-time control software focuses on the interaction between mechanical, control and software engineering in order to develop embedded real-time control systems. The prerequisites are basic skills in control and programming including both high level languages and hardware oriented programming. The objective is to learn how to use models and methods for design of hard real-time control software for the control of mechanical systems. The text book used is ”Software Design for Real-Time Systems” by J.E. Cooling, Thomson Computer Press. Project orientation and hands on experiences are key features, the goal being to cover the whole development cycle from modelling of the mechanical system to implementation of real-time control software.

The students learn how to use modern computer-based control engineering tools for modelling, simulation, controller synthesis and rapid prototyping of control applications but also learn how to implement the control algorithms on microprocessors/computers with a real-time operating system, in this case the so called RUBUS operating system. The course is composed of lectures, reading material, tutorials and exercises and a final project covering state feedback and modelling following control of a 4th order robot like mechanism. Course examination is done based on a set of exercises and the completed and orally presented final project.

The course has been adapted for both M.Sc. level and as an introductory doctoral level course. The latter has been successfully given on a nation wide basis using recorded lectures which are taken over the internet through a web browser. When using distance learning over the internet the lectures and computer based exercises are complemented with an intensive week in the lab with supervision while finalising the project.

# Ph.D. Student Gallery

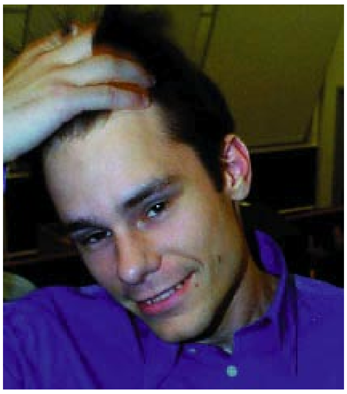
The Centre for Autonomous Systems has by now a total of 23 Ph.D. students. As a new feature in this and forth comming issues a set of six students will be presented in each issue.

**Anders Orebäck**

My name is Anders Orebäck and I am 32 years old. I have studied Electrical Engineering (specialization computer science) at KTH. As masters project, I worked on visual tracking at CVAP. After that I was at a small private company for a little more than three years. This company worked with exciting technology such as VR, graphics and stereoscopic 3D. My work also involved a lot of television production.

In March 1997 I started my Ph.D. studies at CAS/CVAP. The reason for me to return to KTH, was that I became very interested in the field of computer vision during my masters project. At that time, I did not have a clue about robotics, but it sounded exciting to me. During my first months at CAS, I worked with two (now obsolete) robots called Denning. Later I came to be responsible for the speech recognition system that we use.

In the fall of -97, I and Mattias Lindstöm started on the design of the software architecture for the Service robot. Much of this work has dealt with integration of modules that other researchers here at CAS have developed. All this has kept me busy up until now. However, my research topic is to be in the field of robot vision. Therefor I spend a lot of time reading papers in this area at the moment. At CAS, I am in charge of the Nomad robots as well as demonstrating our systems for visitors.



**Mattias Lindström**

My name is Mattias Lindström, born 1971 in the Stockholm area. I took my master at KTH in electrical engineering, and did my last specialization year at Stanford University in applied physics including laser and quantum physics. My master thesis was done in corporation with the Canadian company Mitel Semiconductor. The work consisted of optimizing the optics on light emitting diodes for fiber communication.

I began my graduate studies at CAS/CVAP in april 1997. Robotics in combination with computer vision is an interesting challenge to me, the future of the field is breathtaking. The discipline of autonomous robots demands knowledge from many fields, which give you a chance to broaden yourself considerably.

Most of my time I have worked with Anders Orebäck on the design of the software architecture for our robots. This is an essential part of the robot that enables integration of the software produced by all the students in the Intelligent Service Robot (ISR) project.

At the moment I am working on a visual tracking module to be implemented on the robots. It will also classify moving objects and how they transporting themselves (walking, running, etc.). I also teach in numerical analysis and keep the robots hardware in shape. My spare time interests are swimming, sailing, skiing, and cooking.

**Christian Ridderström**

My name is Christian Ridderström and I recently celebrated my 25th birthday. I have an MSc in Engineering Physics from the Royal Institute of Technology (KTH), where I did my master's thesis work within the Centre for Autonomous Systems. The title of the work was "Corridor Navigation by Visual Servoing". After my thesis work I continued within CAS as a graduate student with the Mechatronics Lab, at the department of Machine Design.

My research focuses on the control of walking robots and I am interested in how to control dynamic walking by exploiting the physics. This requires studying and modeling the dynamics of walking robots, as well as doing research in control algorithms.

I have worked on the automatic generation and simulation of dynamic equations for walking robots. During the summer I worked on designing and implementing controllers for the electric (M3L) and hydralic (HPL) prototype legs. At the moment I am working on a review of control methods for walking robots.

On my spare time, I practice sports such as riflery, windsurfing and field hockey. I also like ballroom dancing and science fiction.

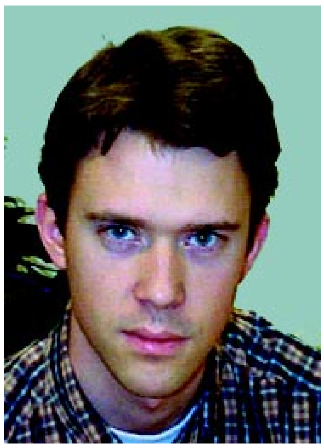
**Freyr Hardarson**

My name is Freyr Harðarson and I'm 27 years old. I graduated from the Department of Mechanical and Industrial Engineering, University of Iceland in June 1995 with specialisation on systems engineering and automation.

My thesis work was on statistical modelling and fault detection but I have also worked with FEM and CFD analysis during the summers at the University and the Icelandic Technical Institute. I moved to Sweden in the fall of 1995 and read courses at KTH the following winter, mainly in control theory and signal processing. This got me interested in applying for graduate studies and when I saw the advertisement from CAS, I realised that most of my scholary interests were combined in robotics. I applied and have been a Ph.D. student with CAS since September 1996 at the Mechatronics division, Department of Machine Design.

I'm working on Walking Robot Project (WARP) and have mainly been involved in the mechanical design and the control of a single leg. My interest is to try to combine these two disciplines, making use of the passive behavior of the mechanics to simplify the control and providing a more energy efficient walk.

**Patric Jensfelt**



My name is Patric Jensfelt, I am 26 years old and have been a PhD student within the CAS project for two years. I was born in Stockholm and I have spent most of my life there. I went through primary school without really knowing what I would like to do later. Mathematics and physics was the subjects I liked so the choice of continuing with three years of "Naturvetenskaplig linje" was natural. After that I did my military service up in the far north of Sweden, in Boden to be exact. I got medical training so I found the time in green clothes quite ok. Having taken off those clothes at the end of March 1992 my biggest decision so far was at hand. Driven by curiousity I decided to apply for the School of Engineering Physics here at KTH. I got in and spent the following four

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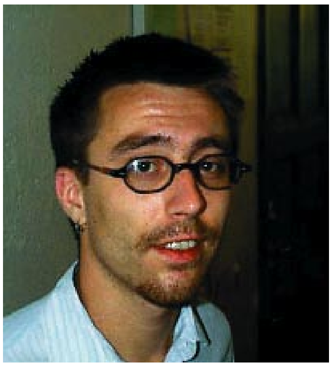
years to prepare for the job in industry I was convinced that I would have. Then it was time to do my Master Thesis project. I was given the opportunity to go down to Canberra in Australia and work with automatic control. That became my first contact with robotics and probably the reason for me writing this now. By the time I finished my Master Thesis, the Centre for Autonomous System had just started and I deciced that industry could wait. Since then I have been working with issues concerning navigation and localization of a mobile robot. At first I was looking at world modeling using sonar sensors inspired by work done by e.g. Elfes and Borenstein. Since new year I am working with a laser scanning sensor. I have been investigating the possibilty to do position tracking using a very simple world model. I spent the last two months in the robotics lab at Daimler-Benz working on global localization.

**Magnus Egerstedt**



Magnus Egerstedt was born in 1971 in Täby, Stockholm, Sweden. He received his Master of Science-degree in Engineering Physics at the Royal Institute of Technology in 1996. His main field of interest was in applied mathematics, and specially in mathematical systems theory. His masters thesis, A Model of The Combined Planar Motion of the Human Head and Eye, written at Texas Tech University, Lubbock, Texas, was in control theory and bio-mathematics, and he has been a PhD-student at the division, affiliated with the Centre for Autonomous Systems since Aug -96. Besides the MSc-degree, he also has a BA-degree from Stockholm's University, majoring in Theoretical Philosophy, specializing in language philosophy.

His main field of research is on Motion Planning and Control of Mobile Robots, and he is involved with the Intelligent Service Agent demonstrator at CVAP, KTH at the same time as he has been working on the radio-controlled car at OptSyst, KTH. Egerstedt has developed theories within both the control area, where a so called virtual vehicle approach has been exploited, and the planning area, where a framework for producing generalized splines has been developed.

This year Egerstedt spent 6 months at the Robotics Lab at University of California, Berkeley as a visiting scholar where he collaborated with Professor Shankar Sastry on hybrid control aspects of mobile robotics. These aspects are important because of need to understand how discrete events, such as the detection of an obstacle, affect the continuously controlled robot. The aim of his current research is basically twofolded. He wants to develop a theory within the hybrid dynamic systems framework for behavior-coordination in mobile robotic systems at the same time as he wants to verify the soundness of this approach by implementing it on a real behavior-based robotic system in a stable and numerically efficient way.

When he's not at work he spends his spare time in the rehearsal room with his band, playing the guitar, or with his team on the soccer field.

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