Dagstuhl-Seminar 98391

Modeling and Planning for Sensor-Based Intelligent Robot Systems

(28.09.1998 - 02.10.1998)

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Summary

During the week of September 28th to October 2nd 1998, the International Seminar on "Intelligent Robot Systems" was held at Schloss Dagstuhl. This Seminar was the third of this series started in 1994.

Intelligent Robot Systems are very complex soft- and hardware systems. These robots include facilities for action selection based on sensory input and prior knowledge. Intelligent algorithms are interface between sensors and actions. The research area includes significant theoretical and practical problems, especially high-level planning (using AI techniques), geometric methods, real-time software systems and methods for interpretation and fusion of sensory information.
A significant problem is modelling of dynamically changing environments, and robust methods for sensory perception. The gap between theory and practice is a wide one and a lot of research must be done for example of building a human-like robot.

Results

Many researchers from Europe, Asia and the USA met in an ideal setting and discussed in depth the following issues:

- Path and Motion Planning, Navigation
  The problem of exploring a simple unknown environment and searching for the best competitive ratio.
- Localization and Pose Tracking
  Relocalization especially using partial map matching or polygonal distances.
- Vision, Shape and Object Recognition
  Theoretical and practical shape and object recognition using 2D or 3D sensing is the main objective.
- Distributed Systems
  Using multiple robots interacting and cooperating together and solving distributed problems is an important question.

- Applications
  Intelligent, helpful and social missions of an intelligent robot are demonstrated.

- Human Robot interaction
  The interface between human and robot is an important research topic. Here some aspects are showed.

- Current state of the art discussions
  How to design working and climbing machines, discussion about telerobotics, and an open problem discussion session.

Perspectives

It is now recognised that the ultimate flexible robot is a fantasy. The trend is towards specialised robots that are designed for a particular application. The manufacturing of specialised robot must however be based on standardised components to make the final product economically tractable. Overall trends in end-user products and the corresponding needs for basic research was discussed in the open problem session.

Thanks

The abstracts of all 24 talks and 4 sessions are contained in this report, which was compiled by Dirk Schäfer. The organizers would like to thank all participants and espacially the governing board of Schloss Dagstuhl for giving us the opportunity to hold the workshop. The familar and friendly atmosphere greatly contributed to the success of the meeting.

The Organizers

R. Bolles (Menlo Park),
H. Bunke (Bern),
H. Christensen (Stockholm),
H. Noltemeier (Würzburg)

Talks in order of appearance

Exploring a Simple Environment

Rolf Klein, Christian Icking, F. Hoffmann, K. Kriegel, FernUniversität Hagen, Germany

We consider a point-shaped robot moving in an environment modelled by a simple polygon. The robot is equipped with an accurate $360°$ vision system that provides, in real time, the visibility of the current position. The robot's task is as follows. It has to start from a fixed position on the boundary and walk around until it has seen each point of the polygon. Then, the robot returns to the start point.
We present a competitive exploration strategy that guarantees that the length of the robot's path does never exceed 27 times the length of the optimum watchman tour through the start point.
Our analysis uses the following independent result. Suppose a connected set, D, is enclosed in a simple polygon, P. Let A denote the set of all points in P that can see two points of D at a $90°$ angle (A has been named the *angle hull* of D in P, its boundary the *photographers path* of D). Then the perimeter of A is at most twice as long as the perimeter of D, and this bound is tight.

Robot Localization Using Polygon Distances

Oliver Karch, Hartmut Noltemeier, Thomas Wahl, University of Würzburg, Germany

We present an approach to the localization problem, for which polygon distances play an important role. In our setting of the localization problem the robot is only equipped with a map of its environment, a range

sensor, and possibly a compass. In particular, it is not allowed to use any artificial landmarks nor has the robot any knowledge about previous positions. The application we have in mind with this setting is a wake-up situation, where the robot is placed somewhere in its environment, powered on, and then has to perform a complete relocalization, that is, it has to determine map positions, at which it might be located.
To solve this problem, we first study an idealized version of it, where all data is exact (that is, without any noise) and where the robot has an exact compass. This leads to the pure geometrical problem of fitting a visibility polygon into the map (by a translation). This problem was solved very efficiently by Guibas, Motwani, and Raghavan. Unfortunately, their method is not applicable for realistic cases, where all the data is noisy.
To overcome the problems we introduce a *distance function*, that models the resemblance between a range scan and the structures of the original method. For the localization process we then perform a Nearest Neighbor query according to this distance to find the best matching robot position. We introduce the *polar coordinate metric* as a suitable distance in the context of our approach, show some important properties of it, and how we can compute it efficiently. Finally, we show how the polar coordinate metric is used in our approach and in our experimental Robot Localization Program RoLoPro.

Carrying an Object under Distributed Control

Masafumi Yamashita, Kyushu University, Japan

Consider two omni-directional robots carrying a ladder, one at each end, in the plane without obstacles. Given start and goal positions of the ladder, what is a time-optimal motion of the robots subject to given constraints on their kinematics such as maximum acceleration and velocity? Applying the optimal control theory, Chen, Suzuki and Yamashita solved the problem under a constraint that the speed of each robot must be either 0 or a given constant v at any moment during the motion. Their solution is centralized and off-line: we calculate the motion and give it to the robots in advance.

The objective of this talk is to demonstrate that even without the complicated calculation, a motion that is sufficiently close to time-optimal can be obtained using a simple distributed strategy in which each robot decides its motion individually based on the current and goal positions of the ladder.

Integrated Percept-Response Structures

Goesta H. Granlund, Linkoeping University, Sweden

It has become increasingly apparent for the design of artificial vision systems, that perception can not be treated in isolation from the response generation. First of all because a very high degree of integration is required between different levels of percepts and corresponding response primitives. Secondly, it turns out that the response to be produced at a given instance is as much depend upon the state of the system, as the percepts impinging upon the system. Thirdly, it has become apparent that many classical aspects of perception, such as geometry, do not belong to the percept domain of a vision system, but rather to the response domain.

One fundamental consequence of this is that action precedes description and generalization; in contrast to commonly held beliefs. This implies that efficient methods must be developed which can map complex percept structures into actions.

The paper will propose the concept of combined percept-response invariances as important structural elements for vision in robotics. It will be maintained that learning is essential to obtain the neccessary flexibilitys and adaptivity. In consequence it is argued that invariances for the purpose of vision are not geometrical but derived from the percept-response interaction with the environment.

Localization and Online Map Building in an Autonomous Mobile Robot

Ewald von Puttkamer, T. Edlinger, G. Weiß, C. Wetzler, University of Kaiserslautern, Germany

Two basic tasks for an autonomous mobile robot are tackled in this paper: locaization and online map building. The robot uses for localization a laser radar with a resolution of a few mm and 720 data points on a full circle. Localization is done by correlating a point P_1 to a point P_0 nearby. The radar pictures at both locations are transformed into angle histograms and correlated to give the relative rotation delta phi. The maximum in the first angle histogram shows the main direction gamma in the scene.
The histograms are turned into this direction and point histograms calculated and correlated to give the translations δx and δy between the radar pictures. Rotating backwards by γ the position P_1 is given in the coordinate system of P_0. P_0 and P_1 are reference points. Map building uses an overlay of radar pictures from an obstacle avoiding radar with 30 segments in $180°$ and the localization radar. An exploration algorithm is shown using back propagation on a chain of correlated reference points P_k. They form a graph of points-of-interest (POI) exhausting the environment. The robot knows when it has explored the environment.

Active control of resolution for stable visual tracking

Nicola J. Ferrier, University of Wisconsin - Madison, USA

Successful visual tracking systems typically rely on prior models of target shape and/or dynamics. These models facilitate tracking by enabling one to restrict the target search to a region of interest (ROI). In recursive filtering formulation of tracking (e.g. Kalman-Bucy filtering), one can determine the size of the ROI based on the current uncertainty in the state estimate (i.e. the covariance). If the computational delay is proportional

to the ROI then under certain conditions, tracking can be shown to be unstable. Also, when tracking multiple targets with a single sensor, their is a delay due to the sensor being ”time-shared” between the targets. To bound the time-delay, one must adjust the resolution within the search region thus stabilizing tracking at the cost of tracking accuracy (positional covariance).

Towards Smarter Cars and Systems

Karin Sobottka, Horst Bunke, University of Bern, Switzerland
Esther Meier, Frank Ade, Swiss Federal Institute of Technology Zurich, Switzerland

Most approaches for vision systems use greyscale or color images. In many applications, such as driver assistance or presence detection systems, the geometry of the scene is more relevant than the reflected brightness information and therefore range sensors are of increasing interest. In this paper we focus on an automotive application of such a range camera to increase the safety on motorways. This driver assistance system is capable of automatically keeping the car at an adequate distance or warning the driver in case of dangerous situations.
The problem is addressed in two steps: obstacle detection and tracking. For obstacle detection two different approaches are presented based on slope evaluation and computation of a road model. For tracking, one approach applies a matching scheme, the other uses a Kalman filter. Results are shown for several experiments.

Interactive Robot Programming based on Human Demonstration and Advice

Rüdiger Dillmann, Holger Friedrich, University of Karlsruhe, Germany

Programming of robots by human demonstration is an attempt towards natural interactive programming of robots and human skill transfer. The programming strategy is a multi-step approach starting with the natural demonstration of the task to be programmed. With the help of multiple sensors like a data glove, stereo vision, polhemus sensor or haptic sensor devices a trace of the demonstration is generated. Because the demonstration is usually noisy, non-optimal and disturbed by events like faulty spontaneous motion, a set of processing steps is necessary to filter, to smooth and to segment the trajectory. On the basis of the user's intention a series of parametrised operators can be obtained, representing the learned task. To verify the systems's task hypothesis geometrical and technical background knowledge may be referenced to ensure correct frames, correct objects relations and an efficient control strategy. The generated operator sequence can be generalized and mapped on different robot target systems considering the robot configuration space restrictions. It can be shown, that pick and place operations, active compliant operations, different grasp operation, assembly and disassembly operations can be learned, using multimodal user input in form of demonstration of the physical task. Programming by demonstration is a base technology for service-robots.

An intelligent service robot

Henrik I. Christensen, Royal Institute of Technology Stockholm, Sweden

An intelligent service robot for use in regular homes is presented. The robot uses a hybrid deliberative architecture. Input to the planner is received from a speech and gesture interface, that also provides spoken feedback to the user. The reactive control is built using a behaviour based approach. Information about the environment is received through use of vision, laser ranging and sonars. The system includes behaviours like avoid, goto, traverse-door, pickup, follow, track, and localize. Each behaviour generates a histogram as output, that specifies allow, forbidden and preferred actions. The histograms from different behaviours are fused into a coherent action model, using voting. The system has been implemented in an object oriented architecture that provides maximum flexibility. The implemented system has been tested on a Nomad 200 robot for mail delivery missions in a regular house setting. So far about 150 missions have been completed at a successrate $> 95\%$. In total the system has traveled several kilometers.

The Interactive Museum Tour-Guide Robot

Wolfram Burgard, Armin B. Cremers, Dieter Fox, University of Bonn, Germany
Dirk Hähnel, Dirk Schulz, Walter Steiner, University of Bonn, Germany
Gerhard Lakemeyer, Aachen University of Technology, Germany
Sebastian Thrun, Carnegie Mellon University Pittsburgh, USA

In this talk we describe the software architecture of an autonomous tour-guide/tutor robot. This robot was recently deployed in the "Deutsches Museum Bonn", were it guided hundreds of visitors through the museum during a six-day deployment period. The robot's control software integrates low-level probabilistic reasoning with high-level problem solving embedded in first order logic. A collection of software innovations enabled the robot to navigate at high speeds through dense crowds, while reliably avoiding collisions with obstacles-some of which could not even be perceived. We also describe a user interface tailored towards non-expert users, which was essential for the robot's success in the museum.

3D Purposive Sensing and Modelling for a Service Robot

Steen Christensen, Daimler-Benz AG Berlin, Germany

In this talk, the problem of generating a suitable environment model for a service robot is addressed. For a service robot to be commercially attractive, it is important that it has a high degree of flexibility and that it can be installed without expert assistance. This means that the representations for doing planning and execution of tasks must be taught on-line and on-site by the user. As a solution to this problem it is suggested to-in interaction with the user-use the robot's navigation system and (purposive) perception modules to respectively drive the robot and gather relevant environment information. With this simple strategy it is shown that compact, symbolic representations sufficient for the planning and execution tasks can be generated.

MAid: A Robotic Wheelchair Moving in a Rapidly Changing Environment

E. Prassler, J. Scholz, M. Strobel, FAW Ulm, Germany

We present the hardware design and the control and navigation system of the robot wheelchair MAid (Mobility Aid for Elderly and Disabled People). MAids general task is to transport people with severely impaired motion skills such as, for example, paraplegra or multiple sclerosis. In our work we focused on the implementation of maneuvers which are very burdensome because they take a long time and require extreme attention. One of these functions is deliberative locomotion in rapidly changing large-scale environments, such as shopping malls, entry halls of theaters and concourses of airports or railway stations, where tens or hundreds of people and objects are moving around. MAid's performance was tested in the central station of Ulm during rush-hour, and in the exhibition halls of the Hannover Fair'98, the biggest industrial fair worldwide. Altogether, MAid has survived more than 36 hours of testing in public, crowded environments with heavy passenger traffic. To our knowledge there is no other robotic wheelchair and no other mobile robot which claims to have achieved a similar performance.

Environmental Modeling and Secure Motion in Unknown Indoor Environments with Video Sensors

C.Eberst, D. Burschka, C. Robl and G. Färber, Technical University of Munich, Germany

A dependable representation of the environment is required for a proper operation of an autonomous mobile robot (AMR) or for run-time compensation in tele-operation applications. Permanent changes in the area of operation require frequent updates of the internal representation.
In this presentation we describe our vision-based approach to indoor exploration without usage of specialized hardware. Exploration is improved by cooperative interaction of the perception and control modules. We describe the way the sensor data from a video camera is processed and how this information is transformed into a three-dimensional environmental model of the world. We introduce a data stabilizing module that operates in a closed loop with the sensor systems, improving their performance by verifying the explored information from different positions and by predicting reliable sensor features. An important part of our approach is the interaction between the verification module and the interpretation module that predicts missing sensor features. This interaction helps to generate a more accurate model containing poorly detectable features that are impossible to extract from a single sensor view. The main focus of the presentation is this contribution of sensor data's completions as a feedback of hypothetical sensor features from the interpretation-module to the sensor-system. The recognition of structures and objects in the environment on which these predictions are based on is described.
The control of the sensors and perceptors based on the acquired knowledge is also described.

Range Image Segmentation: Potential of edge-Based Approaches and Performance Evaluation

Xiaoyi Jiang, University of Bern, Switzerland

In this talk we discuss two aspects of range image segmentation that have not been fully exploited so far, namely edge-based approaches and performance evaluation.
We introduce an adaptive edge grouping algorithm that is able to achieve a complete segmentation into regions based on an edge detection. In addition, a framework of experimentally evaluating range image segmentation algorithms is reviewed. It consists of three large real range image databases with manually specified segmentation ground-truth and a set of performance metrics. The adaptive edge grouping algorithm is tested within that framework and shown to be very competitive in comparison with region-based approaches w.r.t both segmentation quality and computation time.
Considering the numerous advantages of edge-based approaches in general, we conclude that edge-based complete range image segmentation possesses a large potential to be exploited.

Telecommands for remote control of robots: Applications, Sensor Properties and Research Issues

Åke Wernersson, Lulea University of Technology, Sweden

The presentation starts with comparing properties of non-contact sensors; time-of-flight lasers, range cameras, vision and ultrasonics/radar. Videos illustrates the use of these sensors for controlling robots:

- Laser Guided Vehicles (LGV's) navigation using directions to reflective tapes at known positions, reversing with a trailer, an articulated lawn mover CALMAN and LHD's in mines. The system LAZERWAY is used in industry (> 1000) installations and an accumulated run time > 20000000 robot hours).

- Robot navigation using time-of-flight lasers: The range weighted Hough / Radon transformation is very robust for extracting feature coordinates to be used inside the feedback loop during navigation.

The second part will be on current efforts towards controlling robots over large distances by telecommands. The operator specifies each task that is executed autonomously by the robot using feedback from non contact sensors to the surrounding workspace. This use of telecommands is in sharp contrast with remote control of actuators where the operator is inside the dynamic servo loop. Research issues includes needs for self monitoring systems

Vision Based Behavior Control of an Autonomous Vehicle by Fuzzy Reasoning

Wei Li, Tsinghua University of Bejing, China

Vision based motion control of an autonomous vehicle operating in real world requires fast image processing and robustness with respect to noisy sensor readings and with respect to varying illumination conditions. In order to improve vehicle navigation performance in out-door environments, this paper presents methods for recognizing landmarks based on fuzzy reasoning. Firstly, a fuzzy threshoding algorithm is proposed to segment roads and to extract white line marks on streets from images. Secondly, some special domain knowledge about edges on roads represented by fuzzy sets is integrated into the rule base of a fuzzy edge detector. Based on this, the fuzzy thresholding algorithm is adopted to recognize road edges. In addition, a method for path planning in sensor space is presented and a path following behavior based on a fuzzy rule base is defined to control vehicle motion. The proposed methods are applied to navigate the THMR-III autonomous vehicle in out-door environments. Some experimental driving maneuvers have been performed to prove their effectiveness and their robustness.

Relocalisation by Partial Map Matching

Wolfgang Rencken, Wendelin Feiten, Siemens AG, Germany
Raoul Zoellner, Siemens AG, Uni Karlsruhe - IPR, Germany

The autonomous operation of an intelligent service robot in practical applications requires, that the robot itself builds up a map of its environment. A prerequisite for building large scale consistent maps is that the robot is able to recognise previously mapped areas and relocalise within these areas.
The recognition is based on constructing partial maps of geometric landmarks which are then compared to yield the optimal correspondence between these landmarks. For each landmark a signature is constructed which contains additional information about its immediate environment and its non-geometric properties. It is ensured that the signatures are robust with respect to missing landmarks, rotation and translation of landmarks and varying landmark lengths.
Both simulation and experiments on real robots have shown, that the approach is capable of recognizing previously mapped areas robustly in real-time.

On the Near-Optimality of Sensor-Based Navigation in a 2D Unknown Environment with Simple Shape

Hiroshi Noborio, Osaka Electro-Communication University Japan

In the last decade, many sensor-based path-planning algorithms have been proposed. These algorithms completely guarantee that a mobile robot arrives at its destination in an unknown 2-D environment if a deadlock-free path to the destination exists. However, due to no information of obstacle shape and location, a mobile robot frequently makes a longer path to its destination. To overcome this drawback, we consider how a mobile robot selects its direction to follow an encountered obstacle. For this purpose, in

an uncertain 2-D environment with simple shape, we propose new sensor-based navigation algorithms Simple(Class1) and Simple(Bug2) based on classic good algorithms Class1 and Bug2. Moreover in order to show a near-optimality of the proposed algorithms, we determine a competitive ratio r1=((Path length selected by Simple(Class1))/(The shortest path length selected by the model-based path-planning)), and also a worst ratio r2 = ((Path length selected by Class1)/(Path length selected by Simple(Class1))). Also, we determine a competitive ratio r1 = ((Path length selected by Simple(Bug2))/(The shortest path length selected by the model-based path-planning)), and also a worst ratio r2 = ((Path length selected by Bug2)/(Path length selected by Simple(Bug2))). Because the competitive ratio r1 is bounded by a small finite value, the new algorithms are regarded as near-optimal algorithms. On the other hand, because the worst ratio r2 is determined by a large finite value or infinite, the new algorithms are extremely improved against their classic algorithms.

On-line Searching in Simple Polygons

Sven Schuierer, University of Freiburg, Germany

We consider the problem of a robot searching for a target in an unknown simple polygon. We assume that the robot is equipped with a range sensor that gives it access to its local visibility polygon. The search cost is proportional to the distance traveled by the robot. We are interested in the competitive ratio, that is, the ratio of the distance traveled by the robot to the length of the shortest path to reach the target.
We present two algorithms. One algorithm is a simple modification of Dijkstra's shortest path algorithm and achieves a competitive ratio of $1 + 2(r - 1)$ where r is the number of reflex vertices of the polygon. The second algorithm is based on an optimal algorithm to search in geometric trees. If the boundary of the polygon can be decomposed into k convex and k reflex chains, then this algorithm achieves a competitive ratio of $1 + 2\,(2k)^{2k}/(2k-1)^{2k-1}$, which can be shown to be optimal.

Realistic Environment Models and Motion Planning

Frank van der Stappen, Utrecht University, Netherlands

We consider the exact solution of the motion planning problem. Exact approaches to motion planning must report a path if one exists. Their ability to handle all possible inputs often makes exact algorithms too inefficient for application in practice. It has been noted, however, that certain weak assumptions on the size of the robot and the distribution of the obstacles in the workspace lead th a drastic reduction of the complexity of the motion planning problem. We extend the known result for one robot amidst stationary obstacles to one robot moving obstacles and to two or three robots amidst stationary obstacles. In addition, we deduce bounds for environments that satisfy even weaker assumptions on the arrangement of the obstacles in the workspace.

Statistical Motion Planning for Mobile Robots

Eckhard Kruse, Technical University of Braunschweig, Germany

Regarding advanced applications, mobile robots have to operate in dynamic environments, i.e. they have to cope with moving and/or movable obstacles (people, fork-lift trucks, pallets, etc.). Most obstacle motions are non-deterministic, such that it is not possible to pre-plan guaranteed collision-free robot paths. However, by incorporating statistical data about prevailing obstacle motions it is possible to plan paths which are *likely* to be collision-free (e.g. by avoiding regions where obstacles appear frequently). Thus, costly evading maneuvers can be reduced, the robot reaches its goal more efficiently and reliably, and the environment is less disturbed by the robot. Both theoretical and practical aspects of this so-called *statistical motion planning* approach have been investigated. Based on stochastic models a new method for path planning with minimum collision probability has been developed. The concepts are put into practice with an experimental system which gathers statistical data automatically. Sensing is done with an external multi-camera system, which also supports robot localization and collision avoidance. Experiments which have been performed within this system show that in dynamic environments statistical motion planning may yield better results than conventional planning approaches.

The Computational Geometry Algorithms Library CGAL

Stefan Schirra, Max-Plack-Institut Saarbrücken, Germany

CGAL is a C++-Softwarelibrary of geometric algorithms and data structures. It is developed by several research institutes and universitys in Europe and Israel. We give a brief overview on the structure of CGAL, discuss the difficulties in the implementation of geometric algorithms, and show applications of the generic programming paradigm in CGAL. Finally we discuss the benefits and drawbacks of the generic approach. In particular, we show how CGAL eases efficient robust geometric computation.

Modelling and Stability Analysis of the Dynamic Behavior in Cooperating Robot Systems

Robert Lammert, University of Stuttgart, Germany

The main subject of our work is the analysis of multi-agent-systems, of their dynamic behavior. Therefore we've tried to use some tools and principles of the theory of non-linear dynamic systems. This seems to be possible, because the single agents are involved in some kind of cyclic behavior, which we could describe through dynamic systems of equations (iterative systems). The main goal is the development of a stable and optimally operating system, but these two goals are unfortunately conflicting sometimes.

Infrared as a Ranging Device: an on-line calibration approach

Nicola J. Ferrier, University of Wisconsin - Madison, USA

Most lieterature claims that infrared (IR) cannot be used for accurate range measurements because the sensor response depends heavily on how the IR energy reacts with surfaces in the environment. We show that it is possible to determine surface reflectance properties during robot operation. Given prior information about the environment (from sonar, laser, or maps), one can fit parameters to the Phong Illumination model, then use this model to obtain precise distance measurements from IR sensor output. Results are presented demonstrating that we can obtain range measurements using this model for a variety of surfaces.

Sessions

How to design walking machines

Rüdiger Dillmann, University of Karlsruhe, Germany
Henrik I. Christensen, Royal Institute of Technologie Stockholm, Sweden
Ewald von Puttkamer, University of Kaiserslautern, Germany

The commercial applications for climbing and walking robots were initially recognised by the nuclear and space industries which have had to adress clear and identifiable problems of performing maintenance tasks within hazardous and unstructured environments intrinsically hostile to man. Discussions with industrialists and researchers have highlighted the following:

- Wall climbing vehicles are needed for remote inspection and maintanace especially in the nuclear industry.

- Underwater applications for mobile machines including inspection of bridges, clearing intake pipes of hydrelectric plants, inspection of fouled drains, cooling water ducts and sewage outfalls. Robots able to accomplish these types of tasks would be capable of adaptation for ship cleaning whilst the vessels is at sea.

- The use of climbers and walkers by the emergency services to enter dangerous areas devastated by fire or earthquake to collect samples, and to search for survivors would be invaluable.

- The clearance of anti-personnel land mines within the context of humanitarian missions could be usefully carried out by low cost legged robots with specifically designed sensors.

Research to develop such climbers and walkers continues to focus on these applications. The locomotion can be based on articulated legs if rough ground needs to be negotiated, gripping feet if vertical structures have to be climbed or some special motion capability in certain circumstances.

Telerobotics

Åke Wernersson, Lulea University of Technology, Sweden

This discussion gives a short overview about telerobotics. The first question is, what do we mean? Telerobotics is a master-slave telemanipulation of a robot. What are the problems? We summarize a lot of it without solving them:

- What is the theory for this problem?
- Definition of telecommands for telerobotics. We propose gripping, generating of maps, docking and loading, detecting changes in workspace.
- How can we interprete scenes?
- We need tools for building telecommands.
- We need new ways for transfer of results so we propose a telerobotics lab on the internet.
- We need self monitoring onboard the robot.
- How can we handle the telecommunication time delay?

Most of the problems are unsolved and undefined, so much work must be done to build up a theoretic framework for telerobotics.

Video Session

Many videos are shown from field-tested robots and their missions. The session merged in a wine and cheese session.

Open Problems and wine-/cheese session

The Dagstuhl-Seminar gave a deep view into actual research areas of robotics. But there are a lot of open problems:

- Benchmarking
  How can we compare different robot-systems? Why do we only measure our systems with worst-case scenarios and not with average-case scenarios? How do we define measures, scenarios, rooms that can be used as benchmarks for all robots?

- Human-Robot-Interaction
  How must a interface between a human and a robot appear? Is there a dialogue necessary? Can an interface be designed that is very simple and intuitive for humans?

- Energy
  Mobile robots do have a battery with limited time. We need better batteries with much longer operating time for more complex robots.

- Learning, Adaption and Introspection
  Can robots learn several tasks? Can they do things alone without human control? Can they explain things they do?

- Challenges
  There are a lot of challenges, to be solved:

  - Distributed Robot Systems
    Robots can interact in simple problems. How can they interact to solve large problems? Must they communicate among themselves?

- Reliable object recognition
  Object recognition is highly non-robust today. How can this be performed in a better way?
- Low cost robots
  How can we reduce the cost to design a robot?
- Self monitoring
  Can robots repair themselves? Can they recognize their own failures?
- Large c-space mobile manipulation
  Robot motion nowadays is a discrete thing and not an continuous thing. How can we design smooth motion?
- Theoretical vs. experimental use
  There is a gap between theoretical and experimental research. How can we overcome this problem?
- Telerobotics
  We must define a model of telerobots. What does it mean?
- Emotions
  Does a robot need emotions?
- Wine and Cheese
  Does a robot like wine and cheese, too?