

Modelling of Sensor-Based Intelligent Robot Systems

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organized by

H. Bunke (Bern), H.I. Christensen (Stockholm), G. Hager
(Baltimore), R. Klein (Hagen)

During the week of October 16th to 20th, 2000, the International Seminar on “Modelling of Sensor-Based Intelligent Robot Systems” was held at Schloss Dagstuhl. This Seminar was the fourth of a 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

Researchers from more than ten different countries met in an ideal setting and discussed in depth the following issues:

- Mapping and navigation
- Visual servoing
- Planning
- Learning
- Exploration and coordination
- Vision
- Applications
- System architectures and implementation

Perspectives

It became obvious that the ultimate flexible and intelligent robot is a fantasy. The trend is towards specialised robots that are designed for a particular application. The manufacturing of specialised robots 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 intensively discussed.

Thanks

The abstracts of all 27 talks are contained in this report, which was compiled by Sven Wachsmuth. The organisers would like to thank all participants and especially the governing board of Schloss Dagstuhl for giving us the opportunity to hold the workshop. The familiar and friendly atmosphere greatly contributed to the success of the meeting.

The Organisers

H. Bunke (Bern)
H. Christensen (Stockholm)
G. Hager (Baltimore)
R. Klein (Bonn)

Contents

1	A Programming Framework for Perception-Action Systems	4
2	Software and Language Concepts for Robot Task Specification	4
3	A Short History of Cleaning Robots	5
4	Realtime Mapping in Large Cyclic Environments	6
5	Reasoning and Condensation	6
6	Large Consistent Geometric Feature Maps	7
7	Dynamic Navigation in Natural Environments	8
8	A New Partitioned Approach to Image-Based Visual Servo Control	8
9	Dynamic Aspects of Visual Servoing and a Framework for Real-time 3D Vision for Robotics	9
10	Vision and Touch for Grasping	10
11	Vision for Manipulation and HCI	10
12	Feature Selection for Appearance-based Robot Localization	11
13	A new technique for the extraction and tracking of surfaces in range image sequences	11
14	Field Robotics	12
15	AURORA: An Autonomous Robotic Airship for Environmental Research and Monitoring	13
16	Multiple-Robot Motion Planning = Parallel Processing + Geometry	14
17	An integration perspective for planning in robotics	15
18	Geometry and Part Feeding	15
19	On Learning Problems in Robotics	16

20 Interactive Learning of Skills and Environment Representations for a Mobile Service Robot	16
21 Structure and Process: Learning of Visual Models and Construction Plans for Complex Objects	17
22 Exploring an Unknown Cellular Environment	17
23 Coordination of Multiple Heterogeneous Robots	19
24 Exploiting Context in Function-based Reasoning	20
25 Towards robust perception and sensor integration	21
26 Use of Robots in Computer Aided Surgery	21
27 Vision for the Disabled: Navigation and Recognition	23

1 A Programming Framework for Perception-Action Systems

J. Cabrera-Gómez, A.C. Domínguez-Brito, D. Hernández-Sosa
Universidad de Las Palmas de Gran Canaria, Spain

In this paper we introduce CoolBot, a Component-Oriented programming framework for robotics. This framework's main element is a language, which is presented at the specification level, and has been designed to assist robotic system developers in obtaining more structured and reusable systems without imposing any specific architecture. Within this framework components are conceived as Port-Based Automata (PBA) that interact exchanging events and that can be composed to build up new components from existing components. Components, no matter if they are atomic or composite, are internally modeled as Discrete Event Systems and controlled using the same state control graph. CoolBot hides the programmer any aspects related to communications and provides standard mechanisms for different modes of data exchange between components.

In the actual version of the system, CoolBot is used to declare the interfacing characteristics (number and type of input and output ports), parameters, internal variables, and a number of other aspects that affect the definition of the component as a PBA. This specification is then compiled to generate a C++ shell that the designer must complete supplying the required code to implement the component's functionality.

As a proof of concept we present two applications, an active vision system and a museum mobile robot, that have been developed on the basis of the ideas presented in this paper.

2 Software and Language Concepts for Robot Task Specification

Greg Hager
Dept. of Computer Science
The Johns Hopkins University

We have applied methodologies developed for *domain-specific embedded languages* to create a language for robot control, called *Frob* (*Functional Robotics*), and a language for dynamic vision, called FVision (*Functional Vision*). These languages support a programming style that cleanly separates the **what** from the **how** of

a robot program. That is, the *what* is a simple, easily understood definition of the control strategy using groups of equations and primitives which combine sets of these control or vision system equations into a complex system. We show, though example, how this general approach to robotic programming supports rapid prototyping of new control strategies, enables software reuse through composition, and defines a system in a way that can be formally reasoned about and transformed.

3 A Short History of Cleaning Robots

Erwin Prassler
Autonomous Systems
FAW Ulm

The definition of the desired functions and the design of an ultimate versatile personal robot is an ongoing debate. Meanwhile, however, precursors of this yet to evolve species are well on their way to become commercial products. Cleaning robots for public environments as well as for private households seem to be able to provide the breakthrough which the designers of non-industrial robot systems have long awaited.

This survey describes a selection of 30 different cleaning robots, with the first developments reaching back more than 15 years. With a few exceptions we have focused on floor cleaning, in particular indoor floor cleaning. We describe a variety of scrubbing and vacuuming robots which were developed for this task. The described systems range from heavy, large, and expensive industrial cleaning vehicles to small-size, light-weight, low-cost household devices. The survey does not include, however, systems for cleaning facades of buildings, or windows, or production tools.

Although not all of the 30 cleaning robots abovementioned have yet reached the state of commercial products, their number alone certainly reflects the expectations regarding the economic value associated with the automation of cleaning tasks. In Europe only the estimates for the market for cleaning services range up to the order of US\$ 100 billion per year. It is therefore not surprising that the cleaning industry and the manufacturers of cleaning devices are rather enthusiastic with respect to the automation of cleaning tasks using (semi-)autonomous mobile robot systems.

4 Realtime Mapping in Large Cyclic Environments

Kurt Konolige
Senior Computer Scientist
Artificial Intelligence Center
SRI International

Joint work with: Keith Nicewarner (SRI), Steffen Gutmann (Siemens), and Luca Iocchi (University of Rome).

In my talk, I give a general overview of recent work related to probabilistic methods for mapping in the domain of mobile robots (Simultaneous Localization and Mapping [SLAM], Expectation Maximization [EM], and Consistent Pose Estimation [CPE]). The method of Lu and Milios for CPE yields good results for topologically correct sensor scans, but has several limitations. The first is that the data association problem is not solved: overlapping scans must be correctly identified. The second is computational: the method works after all scans have been input, and is not realtime. In our research, we have solved these problems by formulating an incremental approach to CPE, and by identifying large mapping cycles using correlation of mapped areas. We have used these methods to automatically and efficiently generate globally consistent maps with very large loops.

While the CPE method works well with the floor-plan geometry of laser range scans, we are also interested in extending the mapping work to the 3D case. Here, we have exploited 3D stereo information and a wall-plane assumption to create visually-realistic and geometrically correct 3D reconstructions of an indoor environment.

5 Reasoning and Condensation

Christopher Eveland
Dept. of Computer Science
University of Rochester

Particle filtering has come into favor in the computer vision community with the CONDENSATION algorithm. Perhaps the main reason for this is that it relaxes many of the assumptions made with other tracking algorithms, such as

the Kalman filter. It still places a strong requirement on the ability to model the observations and dynamics of the systems with conditional probabilities. In practice these may be hard to measure precisely, especially in situations where multiple sensors are used.

In this talk, an algorithm for particle filtering in an evidential reasoning framework is presented. This algorithm relaxes the requirement to accurately model the observations. In addition, it eases sensor fusion, and provides an explicit model of ignorance. Furthermore, this ignorance model reduces the total number of particles needed by guiding observations towards areas of ignorance, and dynamically adjusting the sample set size.

6 Large Consistent Geometric Feature Maps

W.D. Rencken, W. Feiten, M. Soika, Siemens AG
Corporate Department Technology
81730 Munich, Germany
Wolfgang.Rencken@med.siemens.de,
{Wendelin.Feiten,Martin.Soika}@mchp.siemens.de

The autonomous operation of an intelligent service robot in practical applications requires that the robot builds up a map of the environment by itself, even for large environments like supermarkets.

This paper presents a solution to the problem of building large consistent maps consisting of geometric landmarks. This solution consists of three basic steps:

- incremental extraction of geometric features from range data
- recognition of previously mapped parts of the environment and identification of landmarks originating from the same structure and finally
- removing the inconsistencies by unifying those landmarks while retaining local relations between the other landmarks.

The recognition is based on comparing partial maps of geometric landmarks. This is done by enhancing an individual landmark with features derived from its environment. Care is taken that these features are invariant with respect to missing landmarks, rotation and translation of the map and varying landmark lengths. Based on this set of features, different landmarks originating from the same real world object can be identified.

These inconsistencies are then corrected by representing the landmarks by support points and linking the support points in a flexible truss. Replacing two identified support points by their mean introduces energy in the truss, which is

minimized by means of numerical optimization. Fitting the landmarks onto the new support points leads to a consistent map. Experience in the field with about 20 robots has shown that the robot is able to build up maps of large environments robustly in real-time. ¹

7 Dynamic Navigation in Natural Environments

Boris Kluge
FAW Ulm

Being able to deal with rapidly changing, dynamic environments is an important requirement for intelligent robots. We present an approach using a network flow algorithm to track objects extracted from laser range finder images. Our tracking system is implemented on a robotic wheelchair that is enabled to navigate in dynamic, natural environments by using the observed motion of surrounding objects as input to a reactive motion scheme following the “velocity obstacle” paradigm. Furthermore object tracking is used for following a guide person and some simplistic reasoning about intended obstructions of the robot.

8 A New Partitioned Approach to Image-Based Visual Servo Control

Peter I. Corke¹ & Seth A. Hutchinson²,
¹ CSIRO Manufacturing Science&Technology
² University of Illinois

In image-based visual servo control, since control is effected with respect to the image, there is no direct control over the Cartesian velocities of the robot end effector. As a result, trajectories that the robot executes, while producing image trajectories that are pleasing, can be quite contorted in the Cartesian space.

We introduce a new partitioned approach to visual servo control that overcomes this problem. In particular, we decouple the z-axis rotational and translational components of the control from the remaining degrees of freedom. Then, to guarantee that all features remain in the image throughout the entire trajectory,

¹This work forms part of the INSERVUM project, partially funded by the German Ministry of Education, Science, Research and Technology under the number 01 IN 601 A2.

we incorporate a potential function that repels feature points from the boundary of the image plane. We illustrate our new control scheme with a variety of results.

9 Dynamic Aspects of Visual Servoing and a Framework for Real-time 3D Vision for Robotics

Markus Vincze
Inst. für Flexible Automatisierung
TU Wien

Vision-based control needs fast and robust tracking. The study of the dynamics of the visual servoing loop indicates how to build the vision system to obtain high dynamic performance of tracking. Maximum tracking velocity is obtained when running image acquisition and processing in parallel and using properly sized tracking windows. Robust feature tracking is obtain with Edge Projected Integration of Cues (EPIC), which uses object knowledge (a wire-frame model) to select the correct feature in real-time. The object pose is calculated from the features. To automatically initialise tracking, the object knowledge is also used to find the target object. First object indicators are colour and texture, which are integrated using multi-spectral classification. Colour is adapted to the ambient light. Due to the integration, finding the object is robust and achieved without tuning thresholds.

10 Vision and Touch for Grasping

Rolf P. Würtz
Institut für Neuroinformatik
Ruhr-Universität Bochum, Germany

Joint work with: Mark Becker, Efthimia Kefalea, Hartmut Loos, Eric Maël, Christoph von der Malsburg, Abdelkader Mechrouki, Mike Pagel, Gabi Peters, Peer Schmidt, Jochen Triesch, Jan Vorbrüggen, Jan Wiegardt, Laurenz Wiskott, and Stefan Zadel.

The long-term goal we pursue on our one-armed stationary humanoid robot GripSee include enabling it to analyze a table scene and manipulate the objects; make it learn new objects autonomously; know enough objects for robust scene analysis; and to communicate with a user in a natural way. The steps implemented so far are a hand-gesture-driven pick-and-place behavior; learning of objects in a user-assisted manner; and imitation of grip trajectories.

Object and gesture recognition are correspondence-based and use elastic graph matching. The extension to bunch graph matching has been very fruitful for face and gesture recognition, and a similar memory organization for aspects of objects is a subject of current research.

In order to overcome visual inaccuracies during grasping we have built our own type of dynamic tactile sensor. So far they are used for dynamics that try to optimize the symmetry of the contact distribution across the gripper. With the help of those dynamics the arm can be guided on an arbitrary trajectory with negligible force.

11 Vision for Manipulation and HCI

Henrik I Christensen & Jan-Olof Eklundh
Numerical Analysis and Computer Science
Royal Institute of Technology
SE-100 44 Stockholm, Sweden

Service robotics in general has limited utility without facilities for interaction. Meaningful interaction requires methods for recognition of objects and places. The by far most flexible modality for recognition is computational vision. Notorious problems in vision includes robustness and modularity. To address these problems a task oriented approach to integration is introduced together with

voting methods. The combination of these methods allow for design of a flexible framework for mobile manipulation in a domestic setting. The framework has been implemented on a Nomadic XR 4000 robot for tasks such as door opening and mail delivery.

Another aspect of service robotics is human-robot interaction that preferably should be intuitive, robust and flexible. To achieve this a combination of speech and gestures is used for task instruction and feedback. Gestures are particularly useful for action recognition and object specification. A methodology for robust extraction of the position of hands and faces is presented based on use of illumination invariant colour modelling. The gesturing system has been tested extensively for simple commands. The basic operation of the system is presented together with empirical results for operation in a realistic living room setting.

12 Feature Selection for Appearance-based Robot Localization

B. Kröse, N. Vlassis, R. Bunschoten
University of Amsterdam
Dept. of Computer Science

Mobile robots need an internal representation of their environment to do useful things. Usually such a representation is some sort of geometric model. For our robot, which is equipped with a panoramic vision system, we chose for an appearance model, in which the sensoric data (in our case the panoramic images) are modeled as a function of robot position. Because images are very high dimensional data vectors a feature extraction is needed before the modeling step. Very often a linear dimension is used of which the projection matrix is obtained from a Principal Component Analysis (PCA). PCA is optimal for the reconstruction of the data, but not necessarily the best linear projection for the localization task. We derived a method for optimal linear feature extraction for the robot localization task. We tested the method on a real navigation problem.

13 A new technique for the extraction and tracking of surfaces in range image sequences

X.Jiang¹, S.Hofer¹, T.Stahs², I.Ahrns², H.Bunke¹
¹ Department of Computer Science,
University of Bern, Switzerland

² DaimlerChrysler AG, Research and Technology Center,
Ulm, Germany

Traditionally, feature extraction and correspondence determination are handled separately in motion analysis of (range) image sequences. The correspondence determination methods have typically an exponential computational complexity. In this talk we introduce a novel framework of motion analysis that unifies feature extraction and correspondence determination in a single process. Under the basic assumption of a small relative motion between the camera and the scene, feature extraction is solved by refining the segmentation result of the previous frame. This way correspondence information becomes directly available as a by-product of the feature extraction process. Due to the coupled processing of frames we also force some degree of segmentation stability. First results on real range image sequences have demonstrated the potential of our approach.

14 Field Robotics

Peter Corke
CSIRO Manufacturing Science&Technology,
Kenmore, Australia

Field robotics presents significant opportunities as well as challenges for the field of sensor-based robotics. Some of these issues include: robust sensing, dealing with sensor-platform motion, and incorrect assumptions about planar worlds. Architectural issues are also very important for successful implementation. Two field-robotic systems are used to illustrate these issues.

The first is a large underground mining vehicle whose operating environment is a network of tunnels. A reactive control coupled with intersection detection is able to operate the vehicle as well as a human driver but with only very weak localization. The second is an autonomous helicopter which has complex dynamics and full 6DOF motion capability. We are developing spatio-temporal vision sensing techniques and visual servoing control strategies to accomplish tasks based largely on visually sensed data.

15 **AURORA: An Autonomous Robotic Airship for Environmental Research and Monitoring**

Alberto Elfes

Research Institute for Applied Knowledge Processing (FAW) &
Computer Science Department, University of Ulm
D-89069 Ulm, Germany

Robotic unmanned aerial vehicles have an enormous potential as observation and data-gathering platforms for a wide variety of applications. These applications include environmental and biodiversity research and monitoring, urban planning and traffic control, inspection of man-made structures, mineral and archaeological prospecting, surveillance and law enforcement, communications, and many others. Robotic airships, in particular, are of great interest as observation platforms, due to their potential for extended mission times, low platform vibration characteristics, and hovering capability. In this talk we provide an overview of Project AURORA (Autonomous Unmanned Remote Monitoring Robotic Airship), a research effort that focusses on the development of the technologies required for substantially autonomous robotic airships. We discuss airship modelling and control, autonomous navigation, and sensor-based flight control. We also present the hardware and software architectures developed for the airship. Additionally, we discuss our ongoing research in airborne perception and monitoring, including mission-specific target acquisition, discrimination and identification tasks. Experimental results from our work will be shown.

16 Multiple-Robot Motion Planning = Parallel Processing + Geometry

Susan Hert

Max-Planck-Institut für Informatik
Saarbrücken, Germany

Brad Richards

Vassar College
Poughkeepsie, NY, USA

Computing processors come in many different forms including both stationary processors (*i.e.*, those used in parallel computers) and mobile processors (*i.e.*, those used in mobile robots). Problems that arise in settings in which multiple processors are working differ depending on the types of processors and the types of environments in which they work. However, the overarching goals in these settings are often quite similar – minimize the processing time while avoiding interference among the processors. This suggests that the techniques used to solve problems in one setting may be successfully applied in another setting as well. We illustrate through two examples that this is in fact the case when one setting involves parallel computer processors and the other involves many processors in motion, *i.e.*, mobile robots. The first example we give is the problem of load balancing in which a pool of work must be divided among the processors in order to minimize the amount of time required to complete all the work. The second example is that of collision avoidance in which you must avoid that two (or more) processors occupy the same resource at the same time. The techniques of parallel processing can be applied in the robotics setting only after solutions to the geometric problems that arise in the second setting have been provided. For the load balancing problem, the pool of work to be divided among the robots corresponds to a polygonal region the robots must cover using a terrain-acquisition algorithm. The amount of work to do corresponds roughly to the area of the polygonal region. This means that an algorithm for partitioning a polygon into pieces of certain areas is required to divide the work among the robots. We outline a simple, linear-time algorithm for this problem. In the collision-avoidance setting, the geometric problem that arises is that of providing fast and accurate answers to queries about intersections of the traces of arbitrarily-shaped robots. We discuss some preliminary work on the design of a data structure for answering such queries.

17 An integration perspective for planning in robotics

Malik Ghallab
LAAS - CNRS, Toulouse

Planning in robotics is a computational activity, among several others, carried out for the purpose of achieving a task. It is neither central nor is it focused into a single system. Planning in robotics takes several forms and uses different types of representations for, e.g., path and motion planning, perception planning, navigation planning (which combines the previous two forms), manipulation planning, communication planning, or task planning. A central issue is the integration of these various forms of planning together and to the sensory-motor capabilities of the robot.

This talk surveys several contributions from LAAS aimed at such integration. There is in particular the integration of time and resource to task planning within the IxTeT planner; the integration of task planning in IxTeT to the motion planner MOVE3D, which relies on randomly generated graphs in configuration space. There is also the integration of these planners into the robot architecture, and specifically the on-line interaction between planning and supervision, together with the problem of specifying in a uniform consistent representation descriptions of actions and tasks as perceived by the various function. There are finally operations on plans to enable the coordination of several robots.

18 Geometry and Part Feeding

A. Frank van der Stappen
Institute of Information and Computing Sciences
Utrecht University

Many automated manufacturing processes require parts to be oriented prior to assembly. A part feeder takes in a stream of identical parts in arbitrary orientations and outputs them in uniform orientation. We consider part feeders that do not use sensing information to accomplish the task of orienting a part; these feeders include vibratory bowls, parallel jaw grippers, and conveyor belts with so-called fences. The input of the problem of sensorless manipulation is a description of the part shape and the output is a sequence of actions that moves the part from its unknown initial pose into a unique final pose. For each of the part feeders we consider, we determine classes of orientable (or feedable) parts,

give algorithms for synthesizing sequences of actions, and derive upper bounds on the length of these sequences.

19 On Learning Problems in Robotics

Wolfgang Maass,
Institut für Grundlagen der Informationsverarbeitung,
TU Graz

In the first part of the talk I reported about the results of a student competition at my university, where the students had to construct a robot that is able to learn to solve a (constantly changing) task. The task is to shoot a billard ball with just the right speed and angle so that it comes to rest in a small dip on the top of a small hill. Both the hill and the position of the hill change, and the solution space is so small, so that for each new instance the robot has to learn through trial and error to solve this task. Since the robot is completely autonomous, he has to extract the required feedback for this learning task himself, through clever feature extraction from his video-input. Detailed reports (and videos) on this competition and the very successful winning robot "Oskar" are online available from: <http://www/igi/maass/robotik/>

In the second part of the talk I sketched the deficit of algorithms for learning action strategies that are suitable for implementation on real robots, and discussed some promising research approaches.

20 Interactive Learning of Skills and Environment Representations for a Mobile Service Robot

Steen Kristensen, Sven Horstmann, Frieder Lohnert, Andreas Stopp

DaimlerChrysler Research and Technology
Cognition and Robotics Group
Alt-Moabit 96a, D-10559 Berlin, Germany

The aim of this work is to develop methods that will allow non-expert users of service robots in office and factory environments to quickly and intuitively adapt the robot to new tasks and environments. We believe that this is best done in

interaction with the user as opposed to autonomous exploration and learning strategies where the robot has to adapt without human feedback. The most important reasons for having the human "in the loop" is that this ensures a safe operation of the robot also during the learning phase and that this furthermore guarantees that the learned representations (and associated behaviour) is what the human user intended. Additionally, supervised learning is normally much faster than non-supervised learning.

In this work we demonstrate how a topological world model can easily be taught using a relatively simple user interface. The resulting model can immediately be used for planning and executing relatively complex missions.

21 Structure and Process: Learning of Visual Models and Construction Plans for Complex Objects

Gerhard Sagerer,
Faculty of Technology, Applied Computer Science,
Bielefeld University

Supervising robotic assembly of multi-functional objects by means of a computer vision system requires components to identify assembly operations and to recognize feasible assemblies of single objects. Thus, the structure of complex objects as well as their construction process are of interest. If the results of both components should be consistent there have to be common models providing knowledge about the intended application. However, if the assembly system should handle not only exactly specified tasks it is rather impossible to model every possible assembly or action explicitly. The fusion of a flexible dynamic model for assemblies and a monitor for the construction process enables a reliable and efficient learning and supervision. As an example, the construction of objects by aggregating wooden toy pieces is used. The system also incorporates a natural speech dialog system, which additionally support decisions in the case of ambiguities and uncertainty.

22 Exploring an Unknown Cellular Environment

Rolf Klein,
Institut für Informatik,
Universität Bonn

Joint work with: Th. Kamphans and E. Langetepe, Universität Bonn
and Ch. Icking, FernUniversität Hagen

A mobile robot has to explore an unknown environment that consists of cells on the integer grid. The environment may contain obstacles. The robot starts from a specified cell at the outer boundary, visit each cell, and return to the start. We want this path to be as short as possible, as compared to the shortest path that could be computed off-line were the environment known (however, computing this minimum length path is known to be NP-hard). We show that each possible on-line strategy can be forced to make twice as many cell visits as the optimal path would. On the other hand, the simple depth first search strategy trivially stays within this bound, because it makes $2C - 2$ many cell visits in any environment over C cells. Does this mean DFS is an optimal strategy? Hardly! While long and skinny environments make it necessary to visit each cell twice, we should be able to do better in fleshy environments. In order to differentiate between the two types, we introduce, as structure parameters, the total number E of boundary edges and the number H of obstacles. In a skinny environment, E can be as large as $2C$, whereas E can be in the order of root of C in fleshy surroundings. We propose a exploration strategy that makes at most

$$C + E/2 + H - 3$$

cell visits in any unknown environment. This upper bound can also be written as $2C - 2 - Q$, where Q denotes the number of free 2×2 cell blocks. This shows the improvement over the performance of DFS.

23 Coordination of Multiple Heterogeneous Robots

Reid Simmons

Robotics Institute, School of Computer Science,
Carnegie Mellon University

As the tasks robots are asked to perform become more complex, it is harder to find single robot systems that can do the job effectively. Increasingly, we are finding the need to use multiple robots, each specialized for particular roles.

We have been investigating tasks where explicit coordination between robots is needed. We are extending the traditional tiered architecture [Bonasso] to multi-robot applications: In addition to vertical information flow between layers, our architecture has horizontal information flow between robots. In particular, behaviors can coordinate at the real-time level, and executives coordinate to synchronize distributed tasks.

We are developing these ideas in two applications – multi-robot exploration and multi-robot assembly. In the exploration application, robots bid on locations they want to explore, based on expected information gain and cost, and a global arbiter assigns tasks based on the bids [Simmons]. In the assembly application, three robots coordinate to emplace a beam – an overhead crane provides a heavy, but inaccurate, moving capability, a "roving eye" provides perceptual feedback (distributed visual servoing [Hershberger]), and a mobile manipulator provides fine motion, grabbing the beam and moving it into final position. Our current work is in scaling to teams of robots that can dynamically negotiate with one another.

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24 Exploiting Context in Function-based Reasoning

Louise Stark and Ken Hughes, Univ of the Pacific
Melanie A. Sutton, Univ of West Florida
Kevin W. Bowyer, Univ of South Florida

The GRUFF (Generic Recognition Using Form and Function) project has demonstrated a function-based approach to object recognition. Initial work focused on the functional evaluation of isolated objects, reasoning about 3-D object shape, producing the symbolic labeling of potential functionality. Two recent subsystem extensions to the GRUFF project address the issues of verification and validation through interaction and scene analysis using function-based context as cues to aid in the recognition process.

It has been shown that function-based recognition successfully makes the association of function to structure when provided a complete 3-D description of an object. The next obvious step is to incorporate both the symbolic labeling of the potential functionality of an object and the steps to confirm said functionality through interaction. The subsystem, based on interaction with robotics, was developed and tested on a subset of objects from the categories chair and cup. Real-time evaluation was performed using real objects.

More recently, a second subsystem was developed, incorporating context-based reasoning to examine scenes of objects such as office spaces and meeting rooms. Function-based context provides cues to influence where geometric relations are relevant. The extension investigates how context, defined in terms of required functional properties for a task, can be used to focus the system on specific geometric relationships that can fulfill function.

25 Towards robust perception and sensor integration

Bernt Schiele
Department of Computer Science
ETH Zurich

Even though many of today's vision algorithms are very successful, they often lack robustness since they are typically limited to a particular situation. In this talk we argue that the principles of sensor and model integration can increase the robustness of today's computer vision algorithms substantially. In this talk we discuss two examples namely face tracking and face detection where the robustness of simple models is leveraged by sensor and model integration. The first example is multi-cue tracking of faces including the principles of self-organization of the integration mechanism and self-adaptation of the cue models during tracking. The second example shows how the maximization of mutual information can be used to combine object models without prior learning. The same principle can be used also for model selection.

26 Use of Robots in Computer Aided Surgery

Richard Bächler, PhD
M.E. Müller Institute for Biomechanics,
University of Bern

Computer aided surgery (CAS, also termed "Image Guided Surgery") has brought the computer not only into the operating room, but into the surgical site itself. By providing advanced planning and navigation aids to the surgeon, the accuracy and safety of surgical procedures can be improved significantly. This is especially valuable in surgeries where the anatomy deviates from the "normal" anatomy, as anatomical landmarks and known features might be missing, e.g., due to trauma or tumors. The main components of a CAS system are the therapeutical object (i.e., the patient respectively the anatomy operated on), the virtual object (i.e., an image of patient's anatomy), and the navigator that provides the link between the therapeutical and virtual objects.

In order to improve the surgeon's tactile abilities, a huge variety of instruments have been devised. The most recent addition to the conventional instrument sets has been the introduction of robots into the operating room. By taking advantage of a robots mechanical features (sub-millimetric positioning accuracy,

no tremor, repeatability of movements) the accuracy of the execution may be improved significantly. In the context of a CAS system, the surgical robot is often used as the navigator. Currently, different fields of application for surgical robots can be identified:

- Active robots perform cutting tasks thus replacing the surgeon. The first use of a robot in the operating room was the RoboDoc (developed at IBM), a surgical robot designed for total hip arthroplasty surgery. The RoboDoc system is capable of milling the cavity for the femoral implant in THA surgery with high precision. It performs the preparation for primary as well as for revision THA. Major drawbacks of the system are the use of fiducial pins for registration purposes, the larger and thus more invasive approach to the surgical site, and the prolonged surgery time. Current clinical studies are aimed at determining if the advantages outweigh the disadvantages. Other active robotic systems have been designed for total knee arthroplasty and maxillo-facial interventions.
- Another field of application is the use of robots as "intelligent" tool holders. A pilot application has been developed by the German space agency DLR that holds the laparoscopic camera in abdominal surgery. By tracking color labels on the surgeon's instruments, the robot is able to follow the movements of the surgeon. A study showed that the robotic assistant performed his task with less soft tissue contact than a human assistant (thus reducing the need to retract the camera and wipe the lens) and was able to guide the camera according to the surgeon's needs. This resulted in a shorter surgery time and reduced the stress in the operating room significantly, as the surgeon did not need to tell his assistant where to point the camera. Other systems that fall into this category have been developed, e.g., to hold a trochar along a planned trajectory to allow precise biopsies.
- Dexterity enhancement systems aim at providing the surgeon with an advanced instrument to carry out micro-surgical interventions with an accuracy and stability not possible with the human hand. One of the current research projects is the "steady hand" system developed at Johns Hopkins University.
- Telepresence surgery requires an effector on the patient's side of the system as well as a haptic feedback system on the surgeon's side. The effector is usually a robotic system adapted to the requirements of the planned surgery adding sensors for haptic feedback. The haptic feedback component may also be provided by using a robotic system. In this case, the system can then be used for simulation of surgery. This is currently one of the main research areas for computer aided surgery, as a controlled training and simulation

environment has a huge potential for the education of young surgeons, as well as for the planning of new surgical techniques or complex surgeries.

In conclusion, surgical robots have successfully entered the operating room, but the first generation systems still have a number of disadvantages that must be improved before surgical robots will really have a wide-spread use. Current requirements are less invasive approaches, “intelligent” and maybe even semi-autonomous behaviour, easy to use user interfaces. Advancements in these areas will make the surgical robot a standard “instrument” in the operating room of the 21st century.

27 Vision for the Disabled: Navigation and Recognition

Sven Dickinson
Dept. of Computer Science
University of Toronto

We address the problem of designing a mobile robot that can locate and retrieve generically defined objects in a disabled person’s home. In this talk, we address three of the many vision subproblems that define the task. In the first part of the talk, we present a method for determining the optimal set of visual landmarks for subsequent navigation. In the second part of the talk, we present an approach to object indexing and matching based on a hierarchical, tree-based representation of the silhouette structure of an object. The third, and final part of the talk addresses what we believe to be a critical, open problem in object recognition. Specifically, we address the problem of how, given a collection of images of exemplar objects from a single, known class, how can we automatically acquire a prototypical model for the class. We call this the problem of image abstraction, and consider its solution essential to the success of generic object recognition.