06251 Abstracts Collection
Multi-Robot Systems: Perception, Behaviors, Learning, and Action
— Dagstuhl Seminar —

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Abstract. From 19.06.06 to 23.06.06, the Dagstuhl Seminar 06251 "Multi-Robot Systems: Perception, Behaviors, Learning, and Action" was held in the International Conference and Research Center (IBFI), Schloss Dagstuhl. During the seminar, several participants presented their current research, and ongoing work and open problems were discussed. Abstracts of the presentations given during the seminar as well as abstracts of seminar results and ideas are put together in this paper. The first section describes the seminar topics and goals in general. Links to extended abstracts or full papers are provided, if available.

Keywords. Autonomous robots, multi-robot systems, object recognition, robot-human interaction, modeling, robot simulation

06251 Executive Summary – Multi-Robot Systems: Perception, Behaviors, Learning, and Action

The Dagstuhl Seminar on Multi-Robot Systems (06251) was held in June 20-23, 2006. It had the goal to bring researchers together from different areas of robotics to discuss current research topics on autonomous and interacting robots. The technical focus was on perception, behaviors, learning, and action. The seminar took directly place after the RoboCup robot soccer competitions and the subsequent symposium in Bremen. Thus researchers from many different countries were able to join the seminar and address issues without taking into account upcoming competitions or events.

Keywords: Summary

Joint work of: Schwiegelshohn, Uwe; Nistico, Walter; Hebbel, Matthias

Extended Abstract: http://drops.dagstuhl.de/opus/volltexte/2006/843

Humanoid Soccer Robots

Sven Behnke (Universität Freiburg, D)

In the talk, I will explain the rules of the RoboCup Humanoid League and discuss the different approaches for the design of the robot hardware and the software for perception and behavior control. I will cover the robots of my team NimbRo in detail, review the results of the 2006 competition in Bremen and give an outlook to the research issues that must be addressed in the future.

Keywords: RoboCup Humanoid League soccer robots

Will ever autonomous robots reach the market? Will ever autonomous robots reach the market? Modularity as one of the keys for cheap and effective autonomous robot development

Andrea Bonarini (Politecnico di Milano, I)

We are expecting that autonomous robots will become part of our everyday life like PCs and mobile phones. Somebody is arguing that this will never happen, others that it is already happening. The near future market for autonomous robots needs cheaper, more reliable and more useful (powerful) robots. After some discussion about this, the presentation will focus on one of the key issues for reliable and efficient development of autonomous robots, namely modular development of robot software. A general architecture including the main functionalities needed to develop an autonomous robot will be presented and a specific implementation (the Modular Robotic Toolkit - MRT) will be introduced. Finally, we will see how the presented approach has been effectively adopted in three different applications, where module resuse has improved quality and reduced development time.

Keywords: Autonomous robots, robot architecture, behaviors, robotic architecture, fuzzy behaviors, localization

Development of a New Standard Platform for The Four-Legged League of RoboCup

Stephan K. Chalup (University of Newcastle, AU)

The Sony Four-Legged League was run from 1998 to 2006 as software focused league using the Sony Aibo robot as standard platform. Early in 2006 Sony announced that production of the Aibo robot will be discontinued.

The Aibo robot was a very popular and sophisticated quadruped robot. Its friendly and aesthetic design contributed significantly to the success and high popularity of the Four-Legged League and associated robot projects.

This presentation includes a proposal of a prototype robot kit which could be used as a new standard platform for the Four-Legged League. The aims for development of the new platform can be summarized as follows:

- Continue and improve the concepts behind the Aibo.
- Allow research into sophisticated quadruped soccer skills.
- Achieve faster and more exciting soccer games.
- Contribute to progress of the four-legged league which has been a very successful league.
- Build an open systems robot to advance low level features and to support high level strategy planning and learning.
- Determine kit style hardware for year to year upgrades of selected modules

The robot kit will allow for substantial new flexibility in hardware design in associated technical/scientific challenges and research projects. A new task will arise for the technical committee of the league which would have to discuss and define the standard platform and possibly incremental upgrades for each year.

Stepping up to a new hardware platform provides the opportunity for significant advancements of skill standard and research achieved so far in this very successful and popular league.

Microsoft Robotics Studio

Ingo Dahm (Microsoft Deutschland GmbH - Unterschleissheim, D)

Today's improved processors and lower-cost sensors are fueling the development of robotics applications for a broad variety of devices, from household vacuums to unmanned vehicles for search and rescue missions. Microsoft Robotics Studio provides a common development platform for robotics innovators to overcome one of their biggest remaining hurdles: the fragmentation of the robotics industry caused by today's incompatible platforms.

Key features and benefits of the Microsoft Robotics Studio environment include these:

* End-to-end robotics development platform. Microsoft Robotics Studio includes a visual programming tool, making it easy to create and debug robot applications. Robotics Studio enables developers to generate modular services for hardware and software, allowing users to interact with robots through Web-based or Windows-based interfaces. Developers can also simulate robotic applications using realistic 3-D models; Microsoft has licensed the PhysX(tm) engine from AGEIA(tm), a pioneer in hardware-accelerated physics, enabling real-world physics simulations with robot models. The PhysX simulations can also be accelerated using AGEIA hardware.

* Lightweight services-oriented runtime. Microsoft Robotics Studio provides a lightweight services-oriented runtime. Using a .NET-based concurrency library, it makes asynchronous application development simple. The services-oriented, message-based architecture makes it simple to access the state of a robot's sensors and actuators with a Web browser, and its composable model enables the building of high-level functions using simple components and providing for reusability of code modules as well as better reliability and replaceability.

* Scalable, extensible platform. The Microsoft Robotics Studio programming model can be applied for a variety of robot hardware platforms, enabling users to transfer their learning skills across platforms. Third parties can also extend the functionality of the platform by providing additional libraries and services. Both remote (PC-based) and autonomous (robot-based) execution scenarios can be developed using a selection of programming languages, including those in Microsoft Visual Studio® and Microsoft Visual Studio Express languages (Visual C#® and Visual Basic® .NET), JScript® and Microsoft IronPython 1.0 Beta 1, and third-party languages that conform to its services-based architecture.

Thus, robotics studio provides a new architecture which is capable to unify existing approaches under one roof and make robotics research and development easier.

Distributed Task Assignment for Real World Environments

Alessandro Farinelli (Università di Roma "La Sapienza", I)

Task assignment is a very well known approach to address the problem of coordination both in Multi-Agent and Multi-Robot Systems.

In this talk we focus on particular scenarios for task assignment which we call real world scenario. In such scenarios robots are embedded in the environment, there are strict constraints on communication, and most importantly tasks that robots should execute are perceived by the robot itself during the mission execution, thus conflicts on the task assignment process might arise. The approach we present is based on token passing: each task is represented by a token that circulates among the agents. Only the agent which is currently holding the token can assign itself to that task. Since conflicting tokens might be created due to agent misaligned knowledge, we devised a distributed conflict detection algorithm which is able to detect and solve all conflicts present in the system. The method has been tested in several environments and was proved to give good performance and a very small communication overhead. We are currently working towards an extension of the approach to consider uncertainty in robot perception at coordination level. Robots attach to coordination messages their beliefs about interesting features The beliefs of different robots are merged and the robots revise their past actions according to their updated beliefs. The approach has been successfully evaluated on a simulated environment.

Keywords: Multi-Robot Systems, Task Assignment

Cooperation with Insecure Communication in Multi-Robot Systems

Birgit Koch (Universität Hamburg, D)

RoboCup has proven to be an interesting and challenging test bed for research in distributed artificial intelligence, multi-agent systems and robotics. Nowadays cooperation among robots is fundamental and social considerations get more and more important not only to match the best teams in RoboCup but also to industrial robots. Depending on the different RoboCup leagues, different issues in cooperation of a team of robots have been studied. The presented talk shows some approaches using cognitions from game theory, biology and socionics to foster cooperative behaviour in multi-robot systems with the focus on cooperation with insecure communication.

Discrete-Event-Based Modeling, Analysis and Design of Multi-Robot Systems

Pedro Lima (Instituto Superior Tecnico - Lisboa, P)

The overwhelming advances in developing multi-robot systems in recent years have significantly increased the knowledge about several relevant problems in Robotics, such as cooperative perception and localization, cooperative task planning and execution, cooperative learning, and functional+software architectures. It is now possible to start bridging the gap between the developed applications, usually based on empirical approaches, and the formalization of the methodologies adequate to solve general classes of multi-robot problems.

The approach to formal modeling, analysis and design I will present is based on discrete event systems theory. Using examples of applications to real and simulated robots, I will show how we use finite state automata and Petri nets to represent multi-robot plans, their execution, analysis and synthesis. Different views of the models enable qualitative (e.g., existence of deadlocks, liveness) and quantitative (e.g. plan success probability) analysis, and subsequent synthesis, of multi-robot plans. Systematic approaches to cooperative behavior modeling, based on commitments and synchronization signals, are made possible, and can abstract apparently different approaches, such as cooperation relying on implicit vs explicit communication. Using this approach leads quite naturally to a formulation of a planning problem as a Markov Decision Process (MDP), possibly Partially Observable (POMDP), whose solution, using reinforcement learning or other related techniques that approximate the optinal solution of stochastic decision-making problems, is currently a hot topic in the literature. The resulting advantage is that discrete event models constrain the number of possible plans, reducing the complexity of the (PO)MDP solving algorithms.

Keywords: Multi-Robot Systems, Discrete Event Systems, Petri nets, Finite State Automata, Reinforcement Learning

Decision-Theoretic Planning for Playing Table Soccer

Bernhard Nebel (Universität Freiburg, D)

Table soccer (also called "foosball") is much simpler than real soccer. Nevertheless, one faces the same challenges as in all other robotics domains. Sensors are noisy, actions must be selected under time pressure and the execution of actions is often less than perfect. One approach to solve the action selection problem in such a context is decision-theoretic planning, i.e., identifying the action that gives the maximum expected utility. In this talk we present a decision-theoretic planning system suited for controlling the behavior of a table soccer robot. The system employs forward-simulation for estimating the expected utility of alternative action sequences. As demonstrated in experiments, this system outperforms a purely reactive approach in simulation.

However, this superiority of the approach did not extend to the real soccer table.

Joint work of: Tacke, Moritz; Weigel, Thilo; Nebel, Bernhard

Fast, Neat, and Under Control: Inverse Steering Behaviors

Oliver Obst (Universität Bremen, D)

Steering behaviors are a set of reactive algorithms used for navigating autonomous agents in their environment. Combinations of steering behaviors can be used to create complex, interesting and lifelike movement. However, special care has to be given to their arbitration.

If done the wrong way, the arbitration can lead to suboptimal, undesired, or even catastrophic results in certain situations. This presentation presents a solution to these problems by introducing inverse steering behaviors (ISBs) for controlling physical agents.

Inverse steering behaviors change the original concept of steering behaviors and facilitate improved arbitration between different options by using cost based heuristics.

Object Recognition by Autonomous Vehicles

Günther Palm (Universität Ulm, D)

Visual object detection in itself is a difficult task, but when it is done on autonomous vehicles, a lot more difficulties arise. Real-time constraints, limited computational ressources, noisy movement measurements or blurred images due to fast ego motion to name just a few of them. In this talk, I want to demonstrate, how even under these circumstances sophisticated object detection systems can be built, which are beyond the (in RoboCup) usual color blob detection methods.

Our solution uses a hierarchical approach to feature computation: region of interest selection, feature extraction and neural networks for classification.

Combining this together with an interwoven tracking of selected regions and temporal information fusion, this results not only in a robust and stable detection system, but also has some other advantages like e.g. the possibility of fine-grained certainty vs. effort consideration or task-dependend evaluation strategies.

Multi-Robot System Specification and Analysis with Hybrid State Machines

Frieder Stolzenburg (HS Harz - Wernigerode, D)

In multi-robot systems as in the RoboCup, the need for precise modeling or specification of agent behaviors arises due to the high complexity of the robot agent interactions and the dynamics of the environment. Since the behavior of agents usually can be understood as driven by external events and internal states, it is obvious to model multiagent systems by state transition diagrams. Here, a combination of UML statecharts and hybrid automata is proposed, allowing formal system specification on different levels of abstraction on the one hand, and expressing real-time system behavior with continuous variables on the other hand. It is shown how multi-robot systems with homogeneous and/or heterogeneous agents can be modeled by hybrid and hierarchichical state machines and how model checking techniques for hybrid automata can be applied.

Keywords: Cooperative robotics, robot behavior engineering, formal specification methods

Multi-Robot Learning for Continuous Area Sweeping Tasks (and other Multi-Robot topics)

Peter Stone (Univ. of Texas at Austin, USA)

As mobile robots become increasingly autonomous over extended periods of time, opportunities arise for their use on repetitive tasks. We define and implement behaviors for a class of such tasks that we call continuous area sweeping tasks. A continuous area sweeping task is one in which a group of robots must repeatedly visit all points in a fixed area, possibly with non-uniform frequency, as specified by a task-dependent performance criterion. Examples of problems that need continuous area sweeping are trash removal in a large building and routine surveillance.

In our research, we begin with a single-robot approach to this problem. We then extend the approach to multi-robot scenarios with a focus on adaptive and decentralized task assignment in continuous area sweeping problems. The proposed method is stable in environments with dynamic factors, such as robot malfunctions or the addition of new robots to the team. The approach is fully implemented and tested both in simulation and on physical robots.

I also briefly touched upon other multi-robot research directions in my lab, including: - autonomous intersection management - distributed reinforcement learning for simulated robot soccer keepaway and half-field offense - distributed learning of a fast quadruped gait

Technical details are avaiable in my papers at:

http://www.cs.utexas.edu/ pstone/papers.html

Keywords: Multi-robot learning; continuous area sweeping

Joint work of: Stone, Peter; Ahmadi, Mazda

Full Paper:
http://www.cs.utexas.edu/~pstone/Papers/bib2html/b2hd-ICRA06.html

Reactive Behavior Organization

Hans Utz (USA)

Behavior-based approaches are usually associated with having severe scalability problems. Yet, autonomous mobile robots in highly dynamic scenarios, such as RoboCup, are required to have a rich set of reactive repertoire. In most behavior-based approaches, implementing a broad set of different behavioral skills and coordinating them to achieve coherent complex behavior is therefore an error-prone and very tedious task.

Concepts for organizing reactive behavior in a hierarchical manner are rarely found. In consequence, reuse of behaviors for different application scenarios or even on different robots is very rare.

In this talk the design a a behavior architecture that addresses some of these issues is discussed within the context of behavior-based and hybrid robot control. The approach presents a step towards more systematic software engineering of behavior-based robot systems.

A Deliberative Layer for Multi-Robot Systems

Vittorio Ziparo (Università di Roma I, I)

The design of deliberative layers is one of the most challenging tasks when building Multi-Robot Systems. In this talk we show how combining synchronized plans and task assignment allows to effectively tackle this issue.

Keywords: Multi-Robot, Coordination

Visually tracking football games based on TV broadcasts

Nicolai Baron von Hoyningen-Huene (TU München, D)

The topic of the talk was to describe CAESAR, a visual tracking system that determines the coordinates and trajectories of football players in camera view based on TV broadcasts. To do so, CAESAR solves a complex probabilistic estimation problem that consists of three subproblems that interact in subtle ways: the estimation of the camera direction and zoom factor, the tracking and smoothing of player routes, and the disambiguation of tracked players after occlusions. CAESAR handles multi camera views to increase accuracy and completeness of the observations. We report on results obtained in a public demonstration performed during RoboCup 2006 where we conducted extensive experiments with real data from live coverages of World Cup 2006 games in Germany. The system is operating under unconstrained conditions and in (almost) realtime.

Optimal dynamic role assignment and trajectory planning for multi-robot teams: A hybrid dynamical systems approach

Oskar von Stryk (TU Darmstadt, D)

Based on a nonlinear hybrid dynamical systems model a new method for optimal coordination and control of multiple unmanned vehicles is investigated. The time dependent hybrid state of the overall system consists of discrete (roles, actions) and continuous (e.g., position, orientation, velocity) state variables of the vehicles involved. The evolution in time of the system.s state is described by a hybrid state automaton. The presented approach enables a tight and formal coupling of discrete and continuous state dynamics, i.e., of dynamic role and action assignment and sequencing as well as of the physical motion behavior of a single vehicle modeled by nonlinear differential equations of motion. The problem of optimal hybrid state trajectories that minimize a merit function as time or energy for optimal multi-vehicle cooperation subject to further constraints is transformed to a mixed-binary dynamic optimization problem being solved numerically.

The approach presented in this talk is applied, e.g., to the scenario of optimal simultaneous target allocation and dynamic trajectory planning for a team of unmanned aerial vehicles in a plane.