Educational Robotics in a Systems Design Masters Program

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Abstract

This paper presents the concepts of our MoRob (Modular Educational Robotic Toolbox) project, which aims to provide a robot platform for university teaching and research. Characteristics are scalability, modularity, flexibility and ease of use. Within the context of this project, robots are used in student projects. Lego Mindstorms has been successfully applied at introductory level, and insights from this are incorporated into a new Masters degree in Systems Design, using other, higher-level platforms. With these, MSc. students will have the tools to tackle design tasks which are much more complex and sophisticated than the tasks that can be achieved with Lego. This also implies that, applying our concepts, a much broader range of engineering concepts can be taught. Our new system will be applicable as a vehicle for experimentation in a variety of courses. Therefore, a standardized teaching environment will emerge which will be easy to use in different applications.

1. Introduction

In recent years, autonomous mobile robots have developed into a very popular topic with high visibility in media like television, newspapers and the internet. Their use in research, entertainment and industrial applications is constantly rising. Going along with this development is an increasing number of robotics courses and dissertation projects at universities. The popularity of robotics in education comes as no surprise. It is an interdisciplinary topic involving mechanical, electrical, control, and computer engineering. Therefore, it offers an excellent basis for teaching a number of different engineering disciplines and their integration into systems. Experiences with courses utilizing robots have been reported e.g. on software engineering projects [7], hardware based vision [2], data structures courses [4]. Using robots, progress can be achieved in both theoretical knowledge and practical knowledge. Ahlgren [1] identified 17 fields in which considerable progress could be made while working on a robot contest.

Robots provide an interesting vehicle for demonstration of engineering problems, and practical exercises in student projects help to develop skills like creativity, teamwork, designing and problem solving. Motivation is improved when real world objects are included. In robotics projects this is the case as students can see, touch and play with their project [6]. Robots not only appeal to children [5], but are also very popular and stimulating for university students. Furthermore, they can be used as a motivational factor to attract high-school students to take engineering courses [9].

This paper describes the concepts of our MoRob (Modular Educational Robotic Toolbox) project, which aims to provide a flexible and modular robot platform aimed at university teaching and research. Within this context, robots are being used in student projects. Lego Mindstorms has been successfully used at introductory level, and insights from this will be incorporated into a new Masters course in Systems Design, using other, higher-level platforms.

2. Robot platforms in education

To accomplish courses and projects involving robots, universities need platforms which are flexible and modular, yet powerful, so they can be easily customized to the requirements of different subjects like automatic control, signal processing, real-time programming, hardware/software integration, artificial intelligence, etc. At present, no existing "off the shelf" robot meets all these requirements. While they provide an excellent basis for teaching such a variety of topics, a notorious problem is the lack of a suitable platform for such an effort. Often lecturers have to resort to “primitive" platforms with many limitations, or construct their own system, requiring many resources for implementation and maintenance over time.

The quality and properties of a robot platform determine which concepts can be conveyed to the students. At our lab, we are equipped with six different platforms which can be classified into three categories: 1. Introductory level, schools. 2. Undergraduate level. 3. Advanced robots for research. Our robots span the range from cheap and simple to sophisticated robots with a

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Figure 1. The ER1 robot platform

multitude of sensors and state-of-the-art processing power. At the lower end, we have a Rug Warrior and a number of Lego Mindstorms kits, which are both well established in education and widely used. In the next category we have a number of Evolution Robotics ER1 kits (Figure 1), and a scrabbling robot. While the ER1 is more powerful due to its use of a laptop with a robot development environment under MS-Windows, it is still very limited with respect to sensing facilities and flexibility of the software. The ER1 is a new platform launched in 2002 and, besides consumer use, also targeted at educational purposes. For research, we use Pioneer 2AT robots from ActiveMedia and RobuCar from Robosoft. Although considerably more expensive, Pioneer robots are state-of-the-art mobile platforms widely used in research. RobuCar is a more unusual platform, with the dimensions of a golf caddy and suitable to transport people, at the top end of the price scale. Our research robots are equipped with laser scanner, GPS, compass, gyroscope and wheel encoders. Processing is done by embedded PC boards running Linux with a real-time extension (RTAI). Open source approaches have been shown to be an important issue for Lego robots [8] and are increasingly becoming popular for higher-level platforms [10] [3].

3. The MoRob project

MoRob (Modular Educational Robotic Toolbox) is a new international project which started in October 2002. It intends to supply an educational robotic platform, to establish a standardized and easy to use teaching and research environment. The work reported in this paper is embedded into the interdisciplinary research in educational technology at the Learning Lab Lower Saxony (L3S) in Hanover (Germany). Project partners for MoRob are the Centre for Autonomous Systems, KTH Stockholm, and the Robotics Laboratory at Stanford University. The studies are carried out within the framework of the Wallenberg Global Learning Network (WGLN).

As has been demonstrated in many cases, Lego Mindstorms is a well designed and flexible educational kit. However, it has been designed for use in schools and, although applicable in some beginners courses (see Section 4 for an example), it is inappropriate for advanced classes at universities, e.g. in automatic control or real-time systems. For this reason, within MoRob we are designing and developing an advanced mobile robot platform for teaching undergraduate and graduate students as well as for PhD research.

Within the framework of educational robotics we have a number of requirements for a suitable platform and associated learning materials: 1. A flexible architecture, which has to consider mechanical, electrical and software interfaces to allow instructors to assemble systems into operational units. To allow use of the system in courses ranging from beginners to advanced and with different contents, there is a need for a layered architecture that allows interfacing to the system at all levels from motors to advanced behaviours. Consequently, a comprehensive API is required. 2. The system must have a variety of basic components to allow for construction of basic mobility systems, sensory modules such as odometers, ranging (sonar or laser), control computer system. There is thus a need for Lego like, but more flexible and powerful modules. 3. A library of standard modules for navigation, detection of obstacles, basic trajectory following, so as to allow different instructors to focus on different aspects. 4. A simple set of interfaces for Matlab and Java to enable a smooth learning curve when using the system. 5. A comprehensive suite of documentation to allow simple usage and also a quick start to get it going.

The aim of the MoRob project is to develop such a platform and to provide a standard set of control modules and teaching units. At the core of our system is the Scalable Processing Box (SPB), a standardized processing unit for easy experimentation with any kind of robotic platform. Key characteristics to fit the requirements of educational robotics are standardization, scalable performance, modularity to facilitate tailoring to courses in the different disciplines, flexible interfaces, robustness, simple handling and easy configuration. The SPB provides a real-time framework for simple usage of interfaces and algorithms. The basis is Linux/RTAI combined with a real-time API for common interfaces, e.g. CAN bus, Ethernet, serial, etc. (see Figure 2 for a schematic overview of the architecture). This base system can be booted from a compact flash card (CF-card) to ensure the flexibility needed in an environment where different users have to work with one hardware platform. Due to the limited memory of a CF-card, a suitable Linux distribution has been built. To keep the handling of the distribution as simple as possible, a combination of pre-compiled packages and easy to use installation scripts have been created. This way, the installation of an SPB can be done in the following modular steps: setup of the basic Linux structures, the development environment, Web support, real-time structures (RTAI), and real-time communication layer (RTNet [11], RTMailboxing, etc.). The modularity of the system achieved so far provides the option to set up only the required functionality of the SPB. After setup of this infrastructure, the API structures and device drivers can be implemented in additional packages.

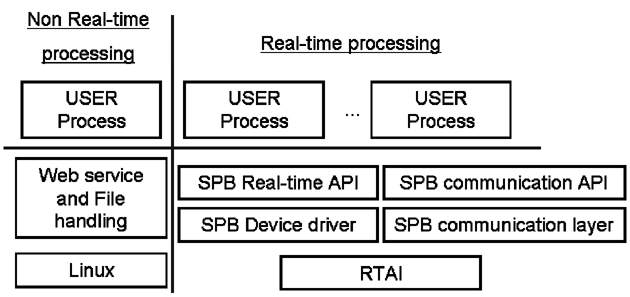

Figure 2. SPB architecture

To supplement the platform, the system will be accompanied by teaching units (course materials), which can be easily used and adapted to a variety of courses within the robotics and engineering curriculum. Furthermore, for practical exercises we need a standard set of control modules (toolboxes), for example for teaching navigation or introductory control. To share the system across a number of institutions, all accompanying materials will be made available in an internet repository, a WWW-portal which will integrate materials including lecture notes, slide presentations, exercises, software (toolboxes etc.), construction examples, curricula, etc.

A further MoRob workpackage is the evaluation of the new system and its educational impact: we intend to provide information as to the suitability for engineering education concerning robotics and using our MoRob system. Evaluation testbeds will be the new MSc. Systems Design at Hanover (Section 5), the new international MSc. Robotics at KTH and the Robotics Class 225 at Stanford. The main part of the evaluation of the MoRob system is scheduled for the 2nd project year. However, during this first year, a questionnaire will be used on existing courses at the three institutes to examine aspects of the current state of robotics education. This can then be used for comparison, and initial results can be reflected in further developments of MoRob. The questionnaire has been designed in Hanover and will be used on students from three different classes: 1. Mini-Project "mobile service robotics" in Hanover (Section 4). 2. Experimental robotics class at Stanford. 3. Introductory Control at KTH.

4. Project-based student labs with Lego

In the fifth semester of the BSc. course "Applied Computer Science" at the University of Hanover, students take a hardware laboratory course. They work in groups of 4, and after a number of set practical exercises they have to undertake a "mini-project" running over a period of 4 weeks. They can choose between 4 different projects, however, places are limited on each project and filled up on a first come first served basis.

One of the projects offered is "mobile service robotics" in which the students have to solve a task using the Lego Mindstorms kit. This project offered the largest number of places; however, it was the first one to be filled, proving the popularity of the subject. This year, the application scenario was an area with burning oil springs generating so much heat that humans cannot get close due to the high temperatures. Therefore, the task was to build a fire-fighting robot to extinguish the springs, which were simulated by putting a number of burning candles in an unenclosed area on the floor (for a similar task, see [1])

The teams were equipped with a Lego Mindstorms kit each, with the LeJos Java environment provided. Within the groups, the students had to solve the task self-organized with little interference by the tutor.

The project was carried out by 4 groups, all achieving the goal successfully, with only one group missing a small number of candles during the final presentation of results. Three of the groups tackled the task by integrating a fan to blow out the candles. One group built a "flap" onto the robot which would cover the candle to extinguish it (see Figure 3 for one of the robots, a video of the presentation can be found under www.learninglab.de/morob).

For the first phase of evaluation within MoRob, our hardware lab was one of the courses to be looked at. The other two courses will take place in spring 2003, and presentation of full results will be presented elsewhere. However, a few insights can be reported after a first look at this part of the evaluation with our Lego participants: within the problem-based learning task, students could bring in their own ideas to a large extent and had to acquire new knowledge on their own. The tutor only had to give little directions and students could organize their work freely. Teamwork and communication skills were felt to be among the most important things learned during this project. Overall, the students judged the Lego

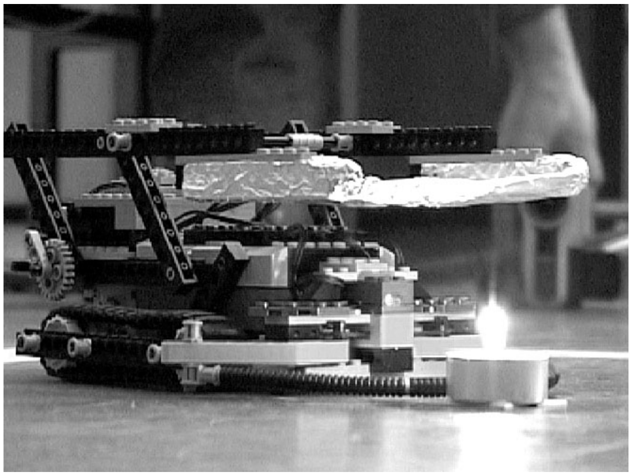

Figure 3. A Lego robot built in the mini-project

platform and its environment as positive and appropriate. However, there were a large number of individual comments highlighting the shortcomings of this platform, for example: imprecise sensors, limited software, small memory, problems with multithreading and arithmetic.

5. A series of robotics projects within an MSc

This section describes a new Masters program at the University of Hanover which incorporates a series of robotics projects as an essential part of the degree. It takes the concept of robots in a project-based scenario further, using it in far more sophisticated settings. MoRob concepts, in particular the Scalable Processing Box, allow carrying out such projects with other platforms and tackling much more complex and complicated tasks. In this context, the MSc. also offers an excellent testbed for pedagogical and didactic evaluation of our project: the building blocks and technology can be tested during a complete course sequence of four semesters.

The new Masters program in Systems Design at Hanover University will start in autumn 2003. Here, robotics is integrated for motivation and as a core part for understanding systems analysis and design. A "system" can range from mobile phones to engine controllers etc.; in the MoRob context we consider a mobile service robot. The course is targeted at computer science graduates with strong software experience. Within this course, one of the main learning targets is to deal with software not as an isolated product, but embedded into real world systems with electronics, sensors and mechanical characteristics.

The course is organized into a number of modules totalling in 120 Credit Points (CPs). Out of these, 12 CPs are devoted to fundamental subjects like mathematics,

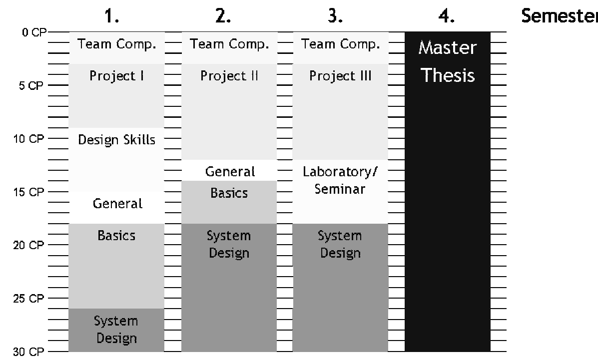

Figure 4. Building blocks of the MSc. program

electrical engineering and computer science topics ("basics"), to fill the gaps of students with different backgrounds (compare Figure 4). 14 CPs are for the development of soft skills like team competence and other general studies (business management, law, cost estimation, patents, ...), 28 CPs are for specialized systems design courses (system theory, system design, simulation techniques, requirements engineering, human-computer interfaces, mechatronics) and system integration, e.g. in robotics. The final thesis occupies 30 CPs. The biggest module with 36 CPs is practical work, which subdivides according to Table 1

Project I	Analysis/Modelling	6 CPs
Project II	Synthesis 1 (Design)	9 CPs
Project III	Synthesis 2 (Implementation)	9 CPs
Design Skills		6 CPs
Labs/Seminars		6 CPs

Table 1: Practical work on the MSc. course

As we can see, a large part of the practical work is devoted to projects. We have a series of 3 projects, building on each other over the first three semesters of the course. They are undertaken in teams of 4 individual students. Project I has the task of analysis and modelling of a system. The students have to use Matlab/Simulink to create a simulation model of an existing system with all its software, electrical and mechanical components, with static and dynamic properties. Potential systems are the Evolution robot and the Pioneer robot. Project II will take the students to the design phase. Here, the aim is to create a prototype as a virtual model, with the same tools from project I (Matlab). Finally, project III is concerned with integration. Here, no Matlab is used but the system will be implemented in the real world. This will focus on software development and electrical devices (sensors), considering the mechanical construction of the system. It has to be realized taking into account all concerns of the real world, including noise and real-time constraints. A key issue is the interaction between the different disciplines involved.

Altogether there will be 6 student teams with tasks for specific systems. Service robotics scenarios could be to develop a vacuum-cleaning robot or a robotic watchman to secure buildings. Alternatively, teams could work on a common task, each concentrating on a different aspect of the system. An overall task could be to develop a new mini-robot from scratch, one team focussing on the chip design, one on the mechanical design, etc.

The concept of the course is to be independent of the robot platform. This could be the Pioneer robot with our SPB, the Evolution robot with our SPB, or any available robot augmented with the SPB. Here, the platform independence of the SPB will come to great use as it allows flexible usage. Furthermore, as the software of the box runs from a CF-card, it is easy to organize different groups working on the same platform while developing software on independent workstations. Therefore, all resources can be exploited most advantageously.

6. Conclusion

This paper introduced the concepts of MoRob, which aims to supply an educational robotic platform for teaching undergraduate and graduate students as well as for PhD research. Characteristics are scalability, modularity, flexibility and ease of use. In student projects, exercises to realize robots offer exciting and challenging tasks which help to develop engineering skills like creativity, teamwork, designing and problem solving. Teaching can take place in student teams through problem-based learning. This improves and increases the attractiveness of learning, particularly in robotics, mechatronics, autonomous systems and computer science.

At the core of our system is the SPB, designed to become a standardized and powerful processing platform for easy experimentation with any kind of robotic platform. Because of the modular and well structured design it will be possible to rearrange SPBs in a similar way to Lego building blocks to fit different scenarios. All software will be publicly available on a website (open source approach), therefore the toolbox will be open for extensions and improvements by the robotics community.

A Lego project carried out at our institution has shown to be successful. Students were highly motivated and completed the project-based task in a self-directed manner without much intervention by the tutor. Lego proved to be a popular and useful tool which is flexible and easy to use. However, this platform reaches its limitations very easily (programming power, sensors, scalability, mechanical robustness, etc.). Therefore, it is not the best platform for advanced courses. Simple tasks like in the scenario here can be solved, however, for more complex tasks this system will be inappropriate and we need a more sophisticated robot platform. The newly designed MSc. in Systems Design will also use problem-based learning in robotics student projects. This will have the same benefits of using robots in education. However, within this MSc. students have the tools to tackle design tasks which are much more complex and sophisticated than the tasks that can be achieved with Lego. This also implies that, applying the concepts of MoRob, a much broader range of engineering concepts can be taught.

Further work will concentrate on extending the functionality of the SPB, application in different learning scenarios, and provision of an internet repository.

7. Acknowledgements

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