Solutions to Meet the Requirements of Educational Robotics

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KEYWORDS: *Educational Robotics, Robot Platforms, Robot Curricula, Problem-Based Learning, Autonomous Mobile Robots*

ABSTRACT: *Mobile robots are an excellent tool for teaching engineering concepts. Practical demonstrations and hands-on experience encourage students and increase motivation. Due to the interdisciplinary nature of robotics, involving electrical, mechanical and computer engineering as well as artificial intelligence, they can be employed in a variety of different subjects at undergraduate and postgraduate level, and in PhD research. To provide a suitable robotics environment for teaching and research, we have to meet the requirements of educators and students which differ from solutions offered for commercial robot applications. This paper examines these educational requirements of robots and shows a number of approaches to meet the requirements in practical systems. Within an international collaboration, we developed a modular platform for education with appropriate infrastructure. Curricula with guidelines how to use robots as well as available teaching materials facilitate initiation of robot usage. We show examples of our systems and how they can be used by teachers and students. Course evaluation proved popularity and merit to acquire engineering skills. Our robotics environment provides a valuable tool for engineering education which can be used in many different disciplines as a demonstrator to teach the topics of individual subjects, in lab classes and practical exercises, and as a platform for PhD research.*

1 INTRODUCTION

Robotics is the topic of constructing artefacts that couple perception to action to allow a system to carry out purposeful tasks for humans [1,2]. It is an interdisciplinary topic that involves components from electrical, mechanical and computer engineering as well as artificial intelligence. A key component of robotics is the need to integrate these disciplines in order to construct systems. Consequently mobile robots are an excellent tool for teaching engineering concepts which can be employed in a variety of different subjects at undergraduate and postgraduate level, and in PhD research. Practical demonstrations and hands-on experience encourage students and increase motivation. Besides learning engineering concepts, students performing robotic exercises develop valuable skills like creativity, teamwork, designing and problem solving. Furthermore, the popularity of robot "gadgets" with a high visibility in media like television, newspapers and the internet attracts students to engineering courses if such systems are included in the curriculum.

The benefits of using robots in education have been widely reported, e.g. [3-7], however, little has been said about the requirements robotic platforms have to meet to satisfy teachers as well as students.

2 REQUIREMENTS IN EDUCATIONAL ROBOTICS

To provide a suitable robotics environment for teaching and research studies, we have to meet the requirements of educators and students which differ from solutions offered for commercial robot applications: teachers without previous robotics experience should be able to introduce robots with only little effort. Students at different levels, with different backgrounds, will be users of the system.

Therefore, ease of use plays an important role as well as safety issues. Building own robots tailored to particular courses is a time-consuming issue, while financial constraints usually limit the number of platforms available at institutions. Therefore, appropriate platforms need to be flexible and modular so they can be adapted to different courses. Furthermore, an infrastructure is needed so that robot systems can be shared by a large number of students.

Simulators offer a cheap and safe way to get students started with issues involved in robotics. No physical hardware is necessary, instances of simulation software can run on different PCs so that a large number of individual student groups or teams can participate in classes. No moving robot parts can damage the lab environment or even students, therefore little supervision is necessary and students can work alone in computing labs or even at home. However, practical experimentation is an essential component and the key to success of teaching with robots. Therefore, simulators are useful tools to get started or evaluate new code written by students, but real robots are required to try out concepts in the real world.

While robots provide an excellent basis for teaching a variety of topics, a notorious problem is the lack of a suitable platform for such an effort. Often lecturers resort to “primitive” platforms such as LEGO Mindstorms, a well designed educational tool, however, too limited to really illustrate the key concepts of advanced courses. Another choice is constructing a custom system, however, the effort to set up a reasonable system by the lecturers on their own requires too many resources for implementation and maintenance over time. A suitable platform should meet the following requirements:

- A flexible architecture: mechanical, electrical and software interfaces must allow instructors to assemble systems into a variety of 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 behaviors. Consequently, a comprehensive API is required to accommodate this.
- 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 to be used for the construction of systems.
- Easy configuration: a standard set of components should allow for simple modular setup to facilitate tailoring to courses in the different disciplines.
- Scalable performance that allows the system to be used from simple setups to sophisticated platforms with complex behaviours.
- Flexible and diverse interfaces to accommodate different disciplines and allow a minimal learning curve. Interfaces to be used with standard educational tools such as MATLAB and Java are particularly desirable.
- A complementary software library of standard modules for navigation, detection of obstacles, basic trajectory following, … so as to allow different instructors to focus on different parts of the system.
- A comprehensive suite of documentation to allow simple use of the system and also a quick start to get it going.

Such features allow teachers flexible use of robot platforms in their educational effort. Furthermore, research students benefit from such platforms: to carry out research, they need a system which is flexible and versatile so it can be adapted to their specific research needs. So far, many Ph.D. students face the burden to develop a robot system from scratch when they start on their project and have a research proposal ("re-inventing the wheel"). If they can quickly combine the modules that they need with little customization necessary, they can concentrate on their actual research task very quickly, rather than having to deal with creating their research tools.

3 MODULAR EDUCATIONAL ROBOTIC TOOLBOX

MoRob (Modular Educational Robotic Toolbox) is an international project which started in October 2002. The part of the work reported here is embedded into the interdisciplinary research in educational technology at the Learning Lab Lower Saxony (L3S) in Hanover (Germany) [8]. Project partners for MoRob are the Centre for Autonomous Systems, KTH Stockholm, and the Robotics Laboratory, Stanford

University. The aim of MoRob is to develop a framework for teaching/research with robotics, including the following issues:

- Project-based courses with robots
- Flexible and modular robotics kit for teaching and research
- Adaptive control architectures (Scalable Processing Box)
- Online provision of teaching materials, toolboxes and educational robotics resources
- Evaluation

3.1 Project-based courses with robots

Over the last two years we carried out a number of projects using 3 different robot platforms: Lego Mindstorms, Evolution ER1 and Pioneer 2 AT (see Figures 1-3). These proved to be quite successful, and experiences allowed us to evaluate advantages and disadvantages of the platforms used.

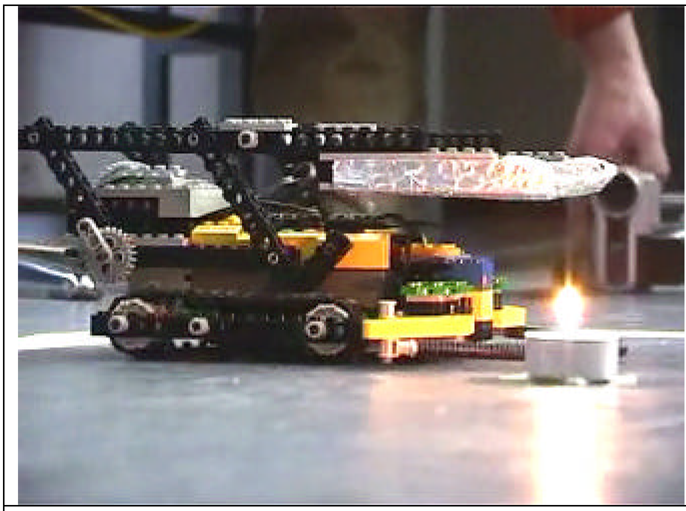

Figure 1: Lego Mindstorms robot built in a student project.

Figure 2: Evolution ER1.

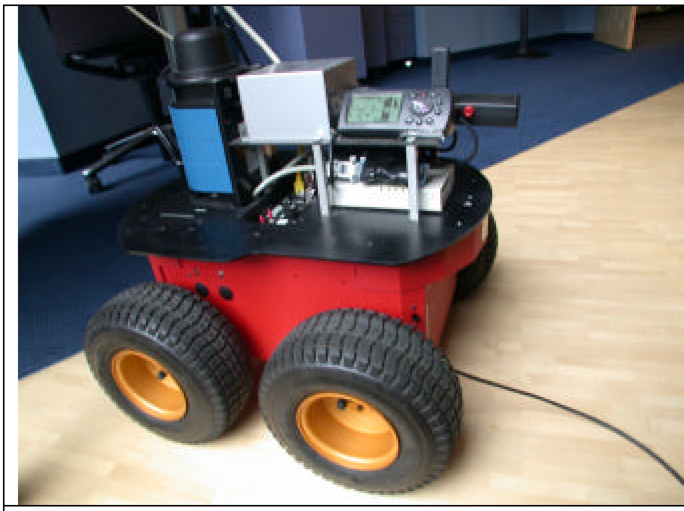

Figure 3: Pioneer 2AT with a variety of sensors.

The Lego Mindstorms mobile robot kit is well established in education, widely used and supported by a large user community [9,10]. Its modular composition and kit approach are perfectly suited for educational applications. The kit consists of Lego bricks, the RCX controller, a variety of sensors (light sensors, bumpers, etc.) and actuators/motors. As well as the many Lego parts, construction guidelines for custom-made parts are available. Besides the software provided with the Mindstorms kit, there is a large variety of third party and open source software available, for example LeJos (Java) and NQC (C-like) amongst others.

We used the Lego kit for 5th semester student groups from the BSc. course "Applied Computer Science" to carry out a project "Autonomous Service Robots". Tasks for the students are different every year. In 2003, they had to build fire-fighting robots, in 2004, two robots collaboratively had to solve pick-up and place tasks. 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.

The modular kit approach made Lego easily applicable in the educational setting. However, shortcomings of this platform were prominent, for example imprecise sensors, limited I/O capacity, limited processing power, small memory. These features limit the system to teach advanced engineering courses. However, here Lego was beneficial to introduce the students to problem-based exercises, working in teams, and apply previously acquired programming skills to a practical problem.

The ER1 is a new mobile robot platform launched in 2002 [11]. Besides consumer use it is also targeted at educational purposes. Robot bases of the ER1 are built from aluminium profiles which offers enough flexibility to build a variety of different robots. Sensing on the basic ER1 is achieved through a webcam and wheel encoders. Infrared sensors, as well as a gripper, are available as additional accessories. Processing is achieved by mounting a laptop on the robot base, therefore enough processing power can be provided to achieve complex tasks.

We used the ER1 in a new lab project in the summer semester 2003. Here, students of Communication Science at the University of Hanover had to solve a localization task using information from the signal strength from Bluetooth access points. Application scenario was a "smart house" where users can communicate with appliances and mobile service robots from a PDA. For the robots, in order to navigate according to the user's requests, and to find out where the user is, localization has to take place to identify the positions. A number of undergraduate student teams carried out this project-based task as a lab session of their degree course. The robots here were not used to teach robotics content, but as a vehicle for a practical task in Communication Science. To summarize experiences with the ER1, the proprietary development environment under MS-Windows supplied with the ER1 allows only simple programming via the ER1 GUI, or sending commands to the robot from other programs. Overall, this offers little to advanced programmers. Other development platforms are also available from Evolution, but at additional costs. However, benefits were that the students could practically implement their work, and an increase in motivation was visible.

For student research projects, we use Pioneer 2AT robots from ActivMedia [12]. Pioneer robots are state-of-the-art mobile platforms widely used in research. 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). A number of dissertation projects have been carried out in the area of mobile robot navigation. Although well suited for these tasks, the Pioneer platform lacks the modularity desired for a more general educational platform, and expert knowledge is required to reconfigure the current setup.

3.2 Flexible and modular robotics kit for teaching and research

Our experiences with the commercially available robot platforms described above showed that each had certain advantages, however, a number of shortcomings as well. It can be concluded that no existing platform which can be purchased "off-the-shelf" meets all desired requirements in education.

To get a more suitable robot platform for education, we designed a new kit which combines advantages of these 3 systems. With modular components, flexible platforms tailored to teaching and research can be build. The mechanical setup is easily customizable to the requirements of the users (like Lego, but much more robust). To equip the robot individually, the kit includes a selection of components, e.g. servo drives and sensor modules like odometry, laser scanner, ultrasound, inertial sensors, etc. Individual components (aluminium profiles, sensors, actuators, controllers) can be complemented to obtain reasonable kits which can be used in a variety of courses and lab exercises. A picture of the new kit can be found in Figure 4.

This robot system was designed at the Institute for Systems Engineering - Real Time Systems Group (RTS) at the University of Hanover. It was put together by combining a number of standard industrial components which are commercially available. Main features are:

- as flexible and modular as Lego
- containing state-of-the-art sensors as used with Pioneer and other commercial platforms
- software-independence through using SPBs

Figure 4: The MoRob kit

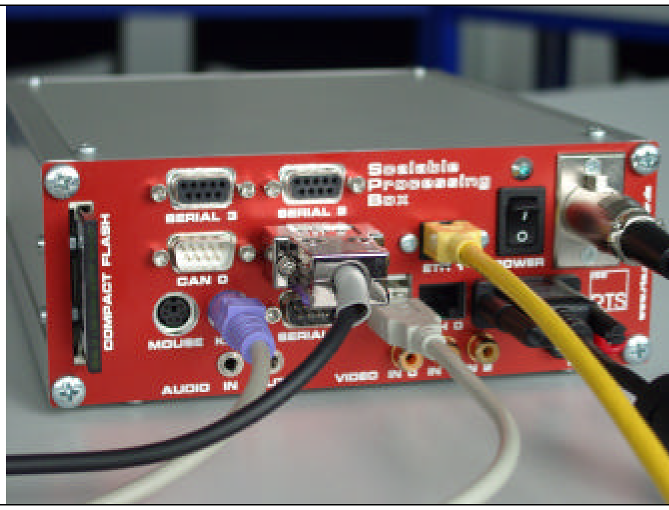

Figure 5: Scalable Processing Box

3.3 Adaptive control architectures (Scalable Processing Box)

As the core controller of the system described above, we developed the Scalable Processing Box (SPB) (see Figure 5), which provides a structured, flexible and easy-to-use processing platform with standardized hard- and software interfaces [13]. It is possible to rearrange SPBs in a similar way to Lego building blocks to fit different scenarios. The software architecture (Linux Real-time Environment - LiRE) offers a real time framework for easy use of interfaces and algorithms. All software is publicly available on a website (open source approach), therefore the toolbox is open for extensions and improvements by the educators and robotics community, as well as students.

Technical details are presented in [14] at this conference. With this system, students have the tools to tackle design tasks which are much more complex and sophisticated than the tasks that can be achieved with e.g. Lego. This also implies that a much broader range of engineering concepts can be taught.

3.4 Online provision of teaching materials and educational robotics resources

Besides suitable platforms, we believe that a framework providing relevant information and supporting materials is necessary to give teachers all necessary instruments for a straightforward start in teaching with robots. Therefore, to provide a complete framework for educational robotics, we not only supply hardware and software components, but also look at concepts to provide flexible teaching materials, toolboxes and documentation in a common learning platform.

Amongst the MoRob project partners, the aim is to have all developed materials online in an internet repository [8] by the end of the project. This includes:

- software
- hardware descriptions
- technical documentation
- lecture notes and slides
- videos
- exercises, solutions
- toolboxes
- curricula

This way, materials can be shared not only by the project partners, but also by the community. This supports the Open Source idea behind the project, which we do not only apply to software, but also to teaching materials ("open tutorials") and hardware (provision of description to re-build components). We are currently developing two tutorials particularly tailored to our components: a hardware tutorial focussing on the features of the SPB, and a software development tutorial tailored to RTAI and LIRE.

The idea of online materials is also supported by the European Robotics Network (EURON) [15], a Network of Excellence funded by the European Union. Here we are currently active in the Education &

Training key area, an international collaboration with members from different EU countries, which works, amongst other things, on the following topics:

- Robotics WEBook, an online encyclopaedia comprising articles in robotics and related areas in tutorial or reference style. Official launch of this WEBook is planned for spring 2004, keep checking [8][15] for links to this initiative.
- Educational robotics resource pages. This has started as a WiKi platform (see [8] for a link) to provide robotics related educational information to teachers. Besides information on summer schools and sample videos for teaching with robots, we have started pages describing different robotics platforms and their use in education. These are meant to enable teachers to judge on different platforms through relevant information, examples in educational use and links to other sources of information. The whole community is invited to provide entries for new platforms, or add information to existing ones. There is no required format, and contributions can include information on hardware, including sensors and actuators; software (including third party and open source); educational levels and target groups; educational support of the platform; modularity; price range; number of systems used; institutions using platform in education and PhD projects; examples; images; links.

4 CONCLUSION

Robotics is perfectly suited to teach basic principles of automatic control, signal processing, intelligent sensing, real-time programming, hardware/software integration, artificial intelligence, world modelling and a lot more important content out of traditional engineering and computer sciences courses. To use robots efficiently in education, a number of requirements have to be met to satisfy both teachers' and students' needs. The MoRob project addresses these issues and evaluates educational robotic platforms as well as designing both hardware and software frameworks for such an effort. Provision of suitable information and supporting materials raises the awareness about this educational tool and increases information exchange within the community. Furthermore, it encourages in particular teachers with little previous robotics knowledge to apply this new technology in their courses.

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