Merging Backgrounds – An Interdisciplinary Course Concept for a Robotic Laboratory

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Abstract. Interdisciplinary work is seen as an essential part in industrial development and scientific research projects. Modern education should address this skill. But integrating interdisciplinarity in a teaching curriculum is a demanding task. In this paper, we present a design of an introductory robotic laboratory, which is suitable for students in robotic related study programs, such as computer science, electrical engineering, mechatronics, and mechanical engineering. The course concept proposes the application of optional individual tasks to balance the different backgrounds and levels of the participants. Active participation and self-contained learning is identified as a key aspect in the proposed concept and therefore specifically addressed. Criteria for a suitable robot kit were formulated and a corresponding robot kit as an attractive teaching platform is presented. Results of a questionnaire provide an evaluation of the realized course concept.

Keywords: Interdisciplinary Learning, Teaching with Robots, Robot Kits

1 Introduction

Over the last years, interdisciplinarity has been highlighted as an important aspect in industry and research [1]. Interdisciplinary learning has become a growing trend in education resulting in combinations of related study subjects, such as computational biology, business informatics, or industrial engineering.

Accordingly, the University of Kassel has established a computer science curriculum closely coupled with the electrical engineering curriculum. Computer science students are taught the fundamental principles of electrical engineering. This cross-study connection in the computer science curriculum provides students with a broad technical background most useful in many industrial fields, for example in robotics to name one of the most interesting application areas. This application area is already addressed in a number of active research projects at the University of Kassel, such as IMPERA [2], ALICA [3], or the RoboCup team Carpe Noctem [4].

In order to foster these already established connections between the disciplines in the bachelor curriculum in computer science, a new application focus area “Robotics” has been created recently. In this focus area multiple subjects from different programs of study have been combined. Students are able to choose from subjects ranging from

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pp. 107-116

classic Artificial Intelligence (AI) theory in computer science to subjects from mechanical engineering. Besides lectures for teaching theoretical principles an essential design goal of the newly created focus area is the structural integration of practical experiences from the beginning, addressing the educational approach of constructionism [5].

In the new branch of study, we integrate an introductory robotic laboratory which focuses on practical first hand experiences for participants from different programs of study. With the philosophy of interdisciplinary education in mind and the background of already achieved combination of subjects from computer science to mechanical engineering in a robotic branch, specific requirements on the laboratory course concept have been identified:

- The interdisciplinary background of the course attendees should be addressed in the course concept.
- The course goals should be compatible with students in different levels of their studies without overwhelming or boring them.
- The course should be designed to allow numerous participants.
- The course objectives should be adjustable to the participating students' background.

In this paper we will present our approach to address these requirements in a course concept and introduce a suitable robot kit as the underlying course platform. The rest of the paper is organized as follows. As the presented course approach is based on a robot kit, Section 2 gives a short introduction of a suitable commercial robot kit and discusses the fitting in respect to the addressed course goals. On basis of the presented robot kit as the course hardware, Section 3 describes the course concept and realization. Then we present evaluation results obtained from a questionnaire for students in Section 4. Some final remarks on further experiences conclude the paper.

2 Robot Kit

Autonomous mobile robotics is a very active field in scientific research and subject of many different projects. Results therefrom are usually achieved with very specialized and most complex (and costly) robots, that are suitable for scientific research, but are usually not suitable for an introductory laboratory in robotics. Robots with the intended use as a teaching platform need to have a different focus and should satisfy different criteria, namely:

- Affordable: The laboratory is normally accessed by groups of students, so a large number of robots is needed to provide a proper hands-on experience. Due to our limited budgets for academic courses the costs for a robot have to be low.
- Robust: With respect to the inexperienced users operating the robot kit, the system should be as robust as possible.

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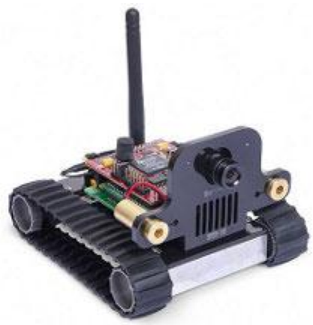
- Operable: Due to the number of students and especially the reoccurring restart of the laboratory the robot kit should be shipped completely functional and easy to reset to the original software and hardware configuration.
- Usable: The interaction should be as easy as possible without being limited in choice of possible in-depth lectures.
- Flexible: The robot kit should not be limited to one specific purpose, but should support multiple use cases with respect to different teaching subjects. Possible upgrades of sensors and actuators are desirable.
- Safe: Under no circumstances should working with the robot put course participants at risk of injuries.

This criteria are met by the robot kit SRV-1 [6] from Surveyor (see Subsection 2.3), which we like to present in the rest of this section.

2.1 Hardware Setup of the SRV-1

Designed for research [7], and education [8], Surveyor's SRV-1 robot kit is a robust mobile robot with a quad-motor tracked base for motion, as shown in Fig. 1. Communication with the robot is realized using a wireless module, which provides additional features like a simple embedded web server.



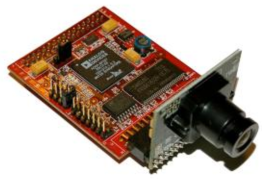


Fig. 1. Left: the Surveyors SRV-1 robot in default configuration. Right: the SRV-1 Blackfin Camera Board includes a digital video camera and a processor

Information processing is integrated in the camera board (Fig. 1 right side) and employs a Blackfin processor by Analog Devices, which provides enough onboard processing power for a variety of course experiments. Additionally, a digital video camera is mounted in front of the camera board. The robot is equipped with laser pointers, which are used for distance measurements. Though experiments have shown imprecise distance values, the quality of the results is satisfactory for a laboratory that aims at basic robotic understanding. For more demanding applications a set of optional modules is available, such as an ultrasonic range module, a GPS module, or a stereovision. The robot is extendable according to the provided open system information [6], such as the open source firmware, schematics, etc.

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2.2 Software Setup of the SRV1

In order to operate the robot remotely or autonomously, the robot provides multiple ways to realize robot programs. The robot features an onboard interpreter for a simplified C dialect with embedded robot specific commands. This is an intuitive way to realize robot behaviors, suitable for a laboratory with a focus other than programming. For more advanced course subjects, such as hardware integration, the interpreter is too limited. Therefore, the robot provides an open source firmware and a command protocol for remote control. The firmware and the compiler tool chain are free and easily installed. Individual modified firmware could be flashed wireless to the processor with a user-friendly web interface or by using basic firmware commands. Moreover, the firmware includes extensive machine vision features. This provides the possibility to introduce machine vision concepts to an introductory laboratory without having to cover all the low level details. Besides directly programming the robot platform, a command protocol is used to control the robot from an extern computer. In this case, the robot can be abstracted to an agent that acts in the real world. High-level AI concepts, like intelligent agents or multi agent cooperation could be taught without concerns about the underlying hardware. For a quick start a ready to use Java-based console is available for remote control.

2.3 Overview

The presented robot hardware assembles a robust, ready to use mobile robot, which can flexibly be extended. For first hands-on experiences, software for remote control is included. Depending on the course focus, the robot kit supports multiple ways of programming, ranging from hardware oriented programming up to server-client interaction through the command protocol. In order to increase the usability of the robot kit in a non-programming focused course an easy to use built-in C interpreter is provided. With a price of 525 USD per robot in standard configuration (at the time of writing) we believe that the presented robot kit is a suitable and affordable platform. Table 1. summarizes the presented characteristics of the robot kit with respect to the identified criteria for a usage in an introductory robotic course.

Table 1. Comparison of the presented robot kit in respect to identified criteria.

Criteria	Robot kit characteristic	Result
Affordable	525 USD plus add-ons as needed	Acceptable
Robust	Robust design but no housing	Meet
Operable	Fully assembled and ready to use	Fully meet
Usable	Multiple ways of programming	Fully meet
Flexible	Full open source design	Fully meet
Safe	Small robot size, moderate velocity, low supply voltage	Fully meet

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3 Course Concept

The SRV-1 robot kit, as described in the previous chapter, is used as the underlying hardware platform for the proposed laboratory course concept. In this section, the course design with respect to the requirements, stated in Section 1, and the used robot platform is presented. The design of the application focus "Robotics" is geared to an interdisciplinary group of students, resulting in course participants with different backgrounds. Hence, a course concept is developed that addresses the different backgrounds and levels of study while still providing individual learning progress.

3.1 Conceptual Design

Interdisciplinary course design, especially the design of introductory laboratories, faces the general problem of small common prior knowledge of the course attendees. Nevertheless the course design should still provide a constant learning success, independent of the study background of the participants. The amount of minimal learning success is referred to as *course base line* in the following. In order to handle the different backgrounds while pursuing a constant course base line, two strategies seem reasonable at first glance: Build on a common but small knowledge base that every participant should possess while reducing the resulting course base line and hence risking to bore some students. Alternatively, build on the super set of all study backgrounds achieving a high course level but risking to overwhelm students. More adjusted settings of assumed prior knowledge and acquired course objectives could be found, but there is still a trade-off involved. In the following, we like to propose a dynamic teaching concept to weaken this trade-off.

The proposed concept of an interdisciplinary robot laboratory is based on the assumption that motivation and active participation is the key to an efficient individual learning process. This understanding leads to a central challenge in the proposed concept: how to motivate students to further explore the course objective individually after having reached the minimal requirements. Following that conceptual question, a reduction in mandatory exercises of the course base line is proposed to free the time for the students to explore the lessons' subject on their own. Given the needed high motivation, this results in students, who set up their own individual learning goals and with it optimize their individual learning process. With the reduction of the course base line, the definition of the common prior knowledge for the interdisciplinary course is facilitated, while at the same time each special study background is individually fostered with the optional exploration tasks.

In order to trigger the desired behavior, the course concept has to specifically assure the needed conditions. The course has to take place in a relaxed, motivating, and challenging learning environment. Additionally, the personal tasks for exploring on top of the course base line should not consist of predefined, already solved, standard exercises, but should encourage creative solutions. By providing such a stimulating environment students are highly motivated and start to have fun and start to play (as evaluated in Section 4), because they are excited to learn and experiment with the robot. Playing combined with guidance, given by the teacher, results in an

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pp. 107-116

individually adjusted level of complexity of the attended subject and therefore a most effective learning experience.

3.2 Concept Realization

The stated conceptual considerations are realized in an introductory robotic laboratory embedded in the interdisciplinary application focus “Robotics” of the computer science curriculum of the University of Kassel. The previously presented robot kit SRV-1 from Surveyor is used as the teaching platform.

The extend of work for the course curriculum is set to 3 ECTS credits, meaning one lesson per week with a duration of 90 min. Additionally to the official laboratory, an optional lesson is scheduled weekly. Participation is voluntary and provides the opportunity to work with the robot in a self-contained way. To further increase independent work, a software simulator for home experiments is provided as well. In order to increase participants and simultaneously foster team work, students are asked to group in teams of maximal three persons. Teamwork and mutual knowledge sharing are an envisioned result of it. In the case of a small number of course participants the concept fits equally well to a one person one robot situation. The course does not require any special environmental conditions and could be held in nearly every location. The students are encouraged to use their own laptops and operating systems as well as their preferred tools (terminal programs, editors, etc.) for robot software development. In the rare case that none of the students in a group possesses a private laptop, a laptop is provided by the instructor. The course curriculum is split in three parts: the embedded part which aims at hardware related aspects, the software part which concentrates on remote robot interaction and control, and the individual project at the end of the laboratory. The basic topics provide the student with an understanding of the principle problems in robotics, like uncertainty of environmental information, imprecise actuators, and autonomous behavior in dynamic environments. In the course of the laboratory practical approaches for these challenges are discussed and realized, such as an integration of additional sensors to improve the environmental information using competitive sensor fusion, or simple robot behaviors using a reactive agent. Each lesson consists of exercises which cover the basic subject of the lesson (base line). These easy to accomplish exercises are combined with more challenging suggestions of optional tasks calling on the creativity of the participants. Students are encouraged to suggest, discuss, and follow their own ideas. After completing the laboratory the gained competences are a basic understanding and first-hand experience in practical realization of essential robot capabilities, like sensor data processing, robot control, and decision making.

Embedded Part. The first part is concerned with robot platform related topics, like hardware integration and embedded programming. The primary aim of this part is to familiarize the students with the potential of the SRV-1 robot kit. The first lesson is spent on connecting and using the robot with the given control software. The students quickly achieve results, and gain first impressions of the challenge of autonomous robot control. This provides the essential initial course motivation. After having completed the initial setup and gaining confidence in basic robot handling, the

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pp. 107-116

students are asked to implement a simple standard exercise of driving a square with the robot. This simple exercise provides a direct physical observable result visualizing key issues in robotics, like imprecise actuator outputs, while enforcing the hands-on learning experience. This standard exercise is implemented in different possible ways. The students have to teach the use of the online C interpreter as well as firmware manipulation themselves. In learning to adapt the robots' firmware the students improve their C programming skills. The provided standard exercises are easy to handle, even by students inexperienced in C programming, but the provided optional tasks are challenging even for more experienced students. On this basis more advanced topics in robotics are touched, like sensor integration, sensor fusion, and application of machine vision concepts. E.g. the exercise in the latter is the detection of a colored object. Thereby the students learn about color representations, detection methods, and experience the influence of dynamic light conditions on machine vision. After completing this base line exercise the students could optionally combine their results with a robot search behavior or enhance their detection methods with additional features, like size heuristics. Similar suggestions for advanced tasks are provided continuously during the course. Due to the scope of this paper no further details on course subjects are given but can be found at the course page [9].

Software Part. The second part is concerned with interfacing the robot hardware with an external computer and realizing autonomous control. The aim of these laboratory activities is to have the course participants study practical implementations of network programming and software control architectures. The realization is proposed to be done in a high level language. Therefore, Java is suggested, but not mandatory. In order to provide a real world development environment, the students are asked to set up their own individual software tools, like terminal programs, IDEs, version control systems, etc. Following, interfacing with the robot is done. Therefore, an introduction to network communication is presented. As the base line task, the students are asked to establish a network connection and manually send robot protocol commands. Optionally sequences of protocol commands could be used to realize an arbitrary robot behavior, like an object detection task.
After finishing this essential task, an architecture for a robot control program is discussed and implemented. Therefore an introduction to agent models is given to provide the theoretical foundation. Again, the students are encouraged to follow their individual ideas of software architecture design and control structure implementation. During the implementation a variety of topics are addressed, like graphical user interface programming, agent models, information/knowledge representation, and sensor/actor modeling. Each of these topics possesses rich possibilities for challenging additional objectives. The completed lessons result in a software program able to control simple autonomous robot actions.

Individual Project. After completing both parts, the students have gained basic understanding in robotics and a fairly good knowledge of the robot platform. The course base line is completed at this stage of the laboratory. The final part of the course exclusively consists of an individual project allowing the students to fully put their creativity to play. The participants can choose from two project ideas presented by the instructor, i.e. a team project with individual sub tasks for each group, and a competitive project, where each team competes in the same task. No step by step instructions are provided and as far as possible no predefined way is set for achieving the task. For example, we present here the competitive project of the winter term 2011/2012. The students choose the competitive project in form of a game, where two robots are placed in an unknown play ground with static obstacles and try to find and mark each other. The team that marks first the other 5 times wins the game. All possible adjustments of the robot platform are allowed. Nearly no regulations are set, except a colored housing to facilitate the opponent detection as seen in the Figure 2.

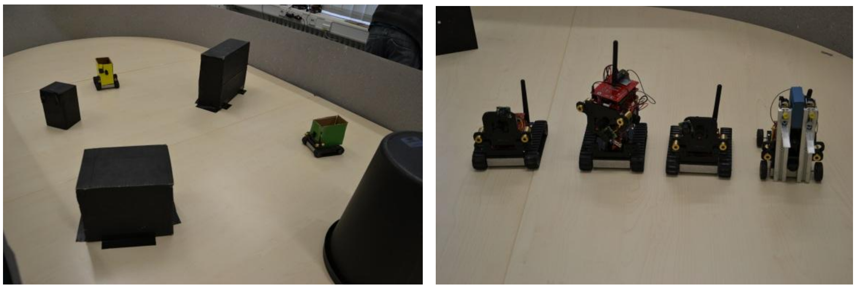

Fig. 2. In the left picture the game ground of the competition is shown, while the right one presents the modified participating robots of each group.

This clearly structured task consists of a set of general robotic problems that have to be solved, like obstacle detection and avoidance, opponent detection, navigation, path planning, strategy planning and execution, etc. A game behavior can be achieved with a simple approach but can be reasonable improved by implementing more sophisticated software approaches focusing on a more intelligent game strategy. Alternatively, the robot strategies can be kept simple but extended with advanced hardware capabilities of the robot. Both approaches are equally reasonable and have been pursued (as shown in the project video [10]).

Table 2. Presentation of the team design goals of the project robots. The teams are numbered from left to right in respect to Fig. 2.

	Design goals
Team 1	Improved perception: sensor detection through regression methods
Team 2	Hardware extension: rotatable robot head with multi side ultrasonic ranging modules
Team 3	Improved perception: size heuristics to gain depth information
Team 4	Mechanical extension: lift mechanism and wheel-based motion

4 Evaluation of the Concept

In order to measure the effects of the proposed concept and the realized introductory robot laboratory the students were asked to fill an anonymous questionnaire after the

ISBN 978-88-95872-05-6
pp. 107-116

final test. We wanted to verify if the proposed course principles we were aiming at were achieved from the perception of the course participants. The average study background of the course participants since the beginning in 2010 are: computer science 73.9%, electrical engineering 4.3%, mechanical engineering 13% and mechatronics 8.6%, with a total number of course participants of 23 students in two runs. Due to space restriction, only an excerpt of the evaluation is presented in the following. Course improvements resulting from the first evaluation causes a number of new questions added in the current evaluation form. Only questions marked with an asterisk have been evaluated in both laboratories. The students have been asked to judge each statement by choosing one of five possible grades: 1. *fully fits*, 2. *fits*, 3. *partially fits*, 4. *does not fit*, and 5. *does not fit at all*. Table 3 presents the averaged results of the most relevant questions.

Table 3. Presentation of an excerpt of relevant question and results of the evaluation questionnaire. (* indicates questions that were asked in both evaluations, see the explanations in the text.)

	Question	Result
12*	The free choice of means, like operating system, IDE, programming language etc. should be kept.	1.46
17*	The splitting of the laboratory in base line exercises, optional tasks, and final project is reasonable.	1.72
18	The level of the base line exercise is suitable.	1.00
19	The final project in form of a competition was motivating.	1.00
20*	The occasionally theory introductions have been a suitable extension of the laboratory	1.27
24*	The usage of personal laptops in the laboratory is acceptable.	1.27
25	The offer of a free lesson for self-contained work with the robots is suitable.	1.00
26	I used the offered free lesson often (state the estimated number of hours).	2.33
27	The offered simulator for independent work is suitable.	2.00
28	I used the offered simulator often (state the estimated number of hours).	4.66
29*	The practical work contributes to the general understanding in the field of robotics.	1.33

Results of the questionnaire are discussed in the following. Statements 12 and 24 address the free choice of an individual working setup during the laboratory. The student reacted very positively with averaged results 1.46 and 1.27. Statements 25 to 28 address the topic of providing additional working opportunities with the robots, independent of the official laboratory. The established free lesson have been found very suitable and used often (averaged number of hours: 5.25 h). However, the result regarding the provided simulator is negative. Usage of the simulator was very limited (less than one hour). Students did not give any specific reasons for this. We assume that problems in the simulators' usability cause this result. The proposed course concept of splitting the laboratory in easy base line exercises, optional challenging tasks, and a final competitive group project is seen positively. Statements 17 to 20 are answered very positively with a combined result of 1.25. Finally the students are

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queried on the contribution of practical hands-on work with the robots kit in understanding the course objectives. We can assert a clearly positive response with 1.33. Overall, the course concept is judged very positive.

5 Conclusion

In this paper we have presented a course concept for an introductory robot laboratory with the special focus on interdisciplinary groups of students. The proposed course design splits the course objectives in basic exercises, more challenging optional tasks, and an individual group project. The combination of easy to accomplish basic exercises and additional optional, motivating tasks calling on the creativity of the participants, results in an individually balanced work load for each student, independent of the study background and level. In that manner satisfactory course objectives are achieved, while individually supporting students' educational development. Evaluation results are presented and showed encouraging results of the proposed concept. Moreover, the SRV-1 robot kit is introduced and found suitable in teaching an introductory robot laboratory for interdisciplinary participants.

Currently, we realize a control architecture for the robot kit based on the Robot Operating System (ROS) [11] in order to introduce a state of the art robot development framework to future course participants. Additionally, we are planning to run a comparison between two student groups, one following the presented course concept the other a more traditional lecture/exercise approach and evaluate the results.

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