What are the key features of future Remote Labs? A critical evaluation of an existing one

Was muss ein Remote Lab zukünftig leisten?

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Abstract — The authors are convinced that the upcoming fourth generation of Remote Labs has to adress the heterogeneity of the students especially. In support of this expectation we investigated an existing implementation and discuss the technical and didactical consequences.

Zusammenfassung — Die vierte Generation von Remote Labs wird sich in stärkerem Mae als bisher der Heterogenität der Studenten annehmen müssen. Zur Begründung dieser These wurde eine existierende Implementierung evaluiert und davon ausgehend die technischen und didaktischen Konsequenzen diskutiert.

I. Introduction

A key feature of the university program for engineering education is a systematic deepening of the theoretical knowledge by practical training sessions. Students have to design and to manufacture exemplary objects, to execute experiments in the laboratory or to implement small IT applications. These supplemental elements of the education process provide specific competencies (programming languages, usage of tools) and train the understanding of engineering concepts and strategies (i.e., divide and conquer). Larger student projects offer the opportunity to improve management skills and illustrate the challenges of interdisciplinary teams. It was shown that these experiences generate an additional motivation for students [1].

Nevertheless, the implementation of practical tasks is accompanied by technical and didactical challenges. First of all, the tasks have to be designed and prepared carefully to meet the capabilities and the prior knowledge of the students [2]. Additionally, the provision of the required hard- and software is often expensive and make a continuous monitoring and maintenance service necessary. Depending on the available number of instances an additional coordination effort for organizing the access to the devices is necessary.

A common approach to cope with these disadvantages is the concept of remote labs, an internet-based interface to educational hardware setups. Based on a camera stream, the student can control a machine, an experimental setup or a computer and evaluate the success of his/her commands. This position and time-independent access increases the utilization of the device and reduces the maintenance effort because the system avoids the error-prone direct access of the students. A remote lab combines the comfort of a simulation environment but provides a realistic experience by covering all situations that may occur in a real development process [3]. But of course, the preparatory overhead increases again, the lecturer has to implement an appropriate back- and front-end for a successful integration. To reduce this effort different frameworks were developed offering a generic and hardware independent devices access [4]. Based on the homogeneous interfaces universities started to offer common remote labs.

The working group Embbeded Smart Systems (ESS) of the OVGU implemented such a modular Remote Lab and integrated it within lectures for embedded systems since two years. Each season approximately 60 students participate in the course “Principals and Components of embedded Systems” that imparts the basics of software development for micro-controllers and peripherals. While analyzing the teaching evaluation report (a form that is filled by students at the end of each semester for every lecture), we got positive feedbacks but criticisms too. On the one hand, the students emphasized the possibility to access the hardware permanently and praised the availability of all data-sheets at one point. The first aspect is visible in Fig. 1. 26 percent of student’s activities are outside of the usual office time. Even though the evening and night hours are the least used periods, these hours make up about 20 Percent. Hence, it is obvious, that one of the main goals was reached, the students plan the tasks now according to individual working habits and personal timetables.

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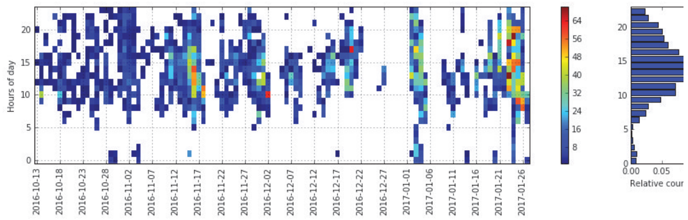


Fig. 1. Representation of log-ins to the system during the semester distributed about the hours of a day.

On the other hand, the participants were not completely convinced by the idea of the remote laboratory at all. They argued, that some of the tasks would require direct access to the hardware. In this situation, a real visit of the laboratory would be necessary to check the behavior of the system on-site. Additionally, the students addressed the susceptibility to errors of the system and asked for a closer interaction with the lectures. Consequently, we started a detailed investigation by evaluating the log files of the web front end and by aggregating additional information based on a questionnaire. This paper presents the main results of this analysis and derives resulting consequences for a further improvement of our setup.

II. EXISTING REMOTE LAB FOR EMBEDDED SYSTEMS

The undergraduate lecture for "Principles and Components of Embedded Systems" (PKeS) is given for students of Computer Science and Electrical Engineering. It intends to close the gap between lectures in computer architectures, electrical basics and software engineering for embedded devices. For this purpose the lecture addresses topics as Analog to Digital Converter (ADC), Pulse Width Modulation (PWM) or Real Time Operation Systems (RTOSs). The theoretical knowledge is consolidated by a set of 6 practical exercises implemented on an 8-Bit-Micro-controller ATmega 2560 manufactured by Atmel.

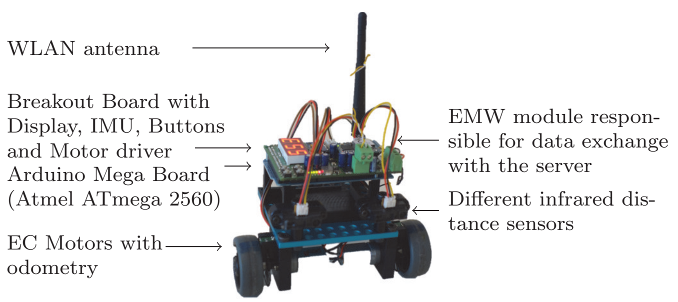


Fig. 2. One of the remote programmed robot systems with an AVR controller as a target

We integrated the controller (integrated into an open sources Arduino board) in a small robot system, containing different types of sensors (Infra-red distance sensors, buttons, and an Inertial Measurement Unit (IMU)), two motors, a 3x7 segment display, as visible in Fig. 2. The practical tasks range from a mandatory "Hello World Task" over a display driver up to robot's escape from a maze. Each task has to be implemented in assembly of c/c++ programs by single students or groups of two persons within two or three weeks. An experienced tutor evaluates the result and the quality of the code during the exercises.

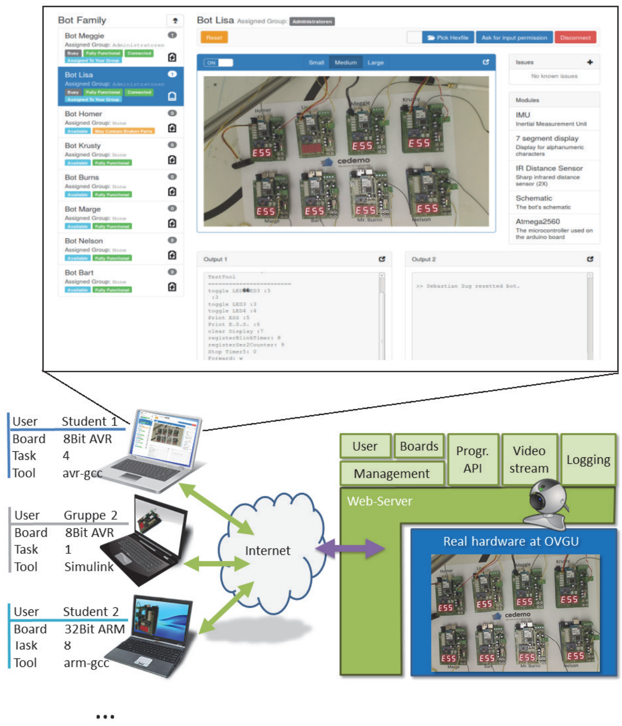


Fig. 3. Core elements of the existing implementation and screenshot of the web-frontend, it contains the video stream, management sections, textual interfaces for debugging purposes and a link collection to hardware data sheets

During the last decade, the robot platform was changed four times. For all implementations the reliability of the platforms was a challenging problem. When students worked directly with the systems, we missed a careful dealing with the setup. Robots crashed with the walls, were "adapted and improved" by students or left with low voltage batteries. Additionally, during the days before a deadline, the tutors have to manage the increased demand for robots.

Consequently, we decided to transform the project in a remote lab. Based on an extension of robots hardware and a self-implemented front- and back-end the robots offer a programming interface to a web-page. The server infrastructure contain robot and user management modules, the programming API, algorithms for video stream processing and encoding as well as a logging data base system.

The screenshot of the webpage is visible in the upper part of Fig. 3. On the left side, eight controllers are available at the moment. Their names and robot's current situation, like energy state or mentioned failures are visible. The students are free to choose one of the available devices. The system interrupts the connection automatically after 20min or if no actions are registered for 10min. One the right side the web page lists some links to the relevant datasheets and tutorials. The center of the page integrates the video stream. In this screenshot, taken during the implementation of the first task, we concentrate all controllers in front of one camera. For this task the access to the whole robot periphery is not needed. With the three buttons on the right side the students can upload their `.hex` file and activate the light in the laboratory.

III. Evaluation

A. Objectives and procedures

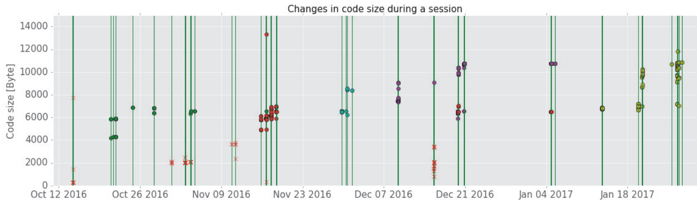
With an empirical study we want to examine the heterogeneity of our students concerning previous knowledge on embedded systems, the behavior of the students in the system and attitudes towards the Remote Lab in comparison with a Hands-on Lab. Accordingly, our research questions were:

- Are there any correlations between the previous knowledge and the learning performance?
- Is there a relation between user behavior and learning performance?
- How do students evaluate the Remote Lab in comparison with a Hands-on Lab? Are there any challenges we should consider for further versions of the Remote Lab or in further research?

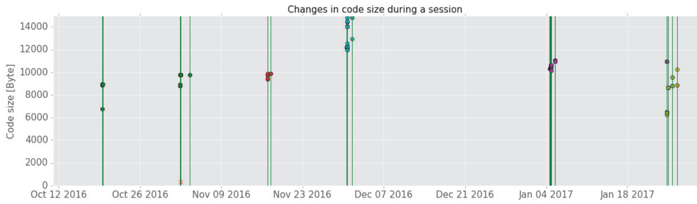
To examine our research questions, we carried out an evaluation with 34 participants of the course PKeS. Therefore we used the log-files of the practical exercises in the Remote Lab and a digital survey, administered after the end of the semester. In the log-files students' interactions with the system were recorded, for example the logins and the upload and size of the code. In the survey the students could rate there prior knowledge concerning embedded controllers/boards and robot applications on rating scales from 1 (very low) to 5 (very high). Furthermore, they were asked to evaluate the Remote Lab in comparison to a Hands-on Lab. On the one hand, they could rate advantages or disadvantages of Remote Labs on a rating scale. On the other hand, they had the possibility to write down opinions and remarks as elaborated text.

B. Evaluation of the Log-Files

In this paper we focus the evaluation part on the heterogeneity of the students related to prior knowledge and coding experience. Fig. 4 and 5 illustrate this aspect based on two exemplary data sets. The first one contrasts the programming activities based on the flash operations by a student with a low prior knowledge and an experienced one. While the x-axis represents the time window of the semester the y-axis displays the size of the executable code transferred to the robot. The student of the development progress visible in (b) implements the task in fewer sessions than the student of (a). Additionally, the spread of the code size in lower in the second case. The style of programming of both students



(a) Student with very low prior knowledge



(b) Experienced Student

Fig. 4. Comparison of the individual progress of different students for tasks 1-5

was investigated in Fig 5 more in detail. The diagrams depict the change of the code size related to the duration this step. The second student developed the program in small steps, while the first had obviously copied a lot of lines. We cannot analyze the source of this operation, but we recognized that many students prefer to search for existing implementations from previous semesters as to write their own code.

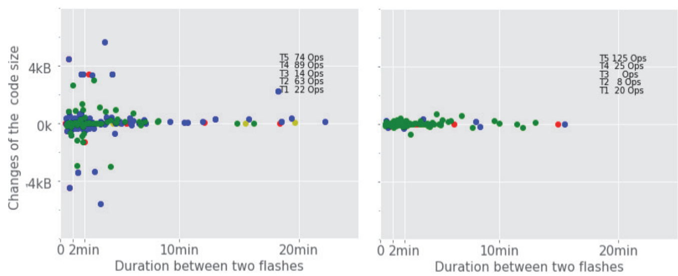


Fig. 5. Number of flash operations vs. corresponding code size changes for the exemplary students

C. Analysis of a Questionnaire

The prior knowledge of our students on embedded controllers/boards (M: 1.92, SD: 1.10) as well as robot applications (M: 1.68, SD: 1.02) is rather low. However, there is also a quarter of students which state that their prior knowledge is rather high or very high. There is a correlation between prior knowledge on embedded controllers and robot application (r = .56, $p < .001$). Someone who has high knowledge on robot applications has high knowledge on embedded controllers as well and vice versa. Both items also correlate with the learning performance. The better the knowledge about robot applications (r = -.34, $p < .05$) and embedded controllers/boards (r = -.39, $p < .05$) before the course, the better the grade in the exam afterwards. The results of a rating scale comparing the working experience in the Remote Lab to a regular Laboratory (Figure 6) exhibit perceived advan-

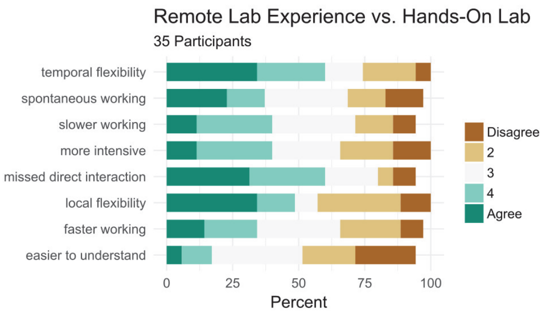


Fig. 6. Students compare their Remote Lab experience to regular Laboratories

tages of the Remote Lab setting, as gained temporal and local flexibility. At the same time problems are highlighted that pose hurdles to overcome in the upcoming iterations of the Remote Lab, such as bridging the missing direct contact to the robots by improving their reliability and extending the didactic integration in order to better the learning experience in the Remote Lab.

These outcomes are also supported by open text answers given by the participants. The answers offer some additional insights into the the perceived advantages and disadvantages of the Remote Lab. They repeatedly include the additional flexibility and improved interaction with the robots due to the the Remote Lab situation. Technical problems are specifically named in these answers, for example the instability of the video stream, reliability of the robots and missing debugging capabilities in the code editor. These answers are particularly useful, as they highlight the importance of improvements that are already prepared in the upcoming implementation of the Remote Lab.

IV. Conclusions and Future Requirements

The results of our evaluation implicate that students are willing to learn with Remote Labs and do not particularly miss the hands-on approach. However, the students mentioned some disadvantages of Remote Labs, especially aspects of usability. If the system is not working properly decreasing motivation and low technology acceptance might be the result. Therefore, the usability of the Remote Lab should be as high as possible.

Our results also indicate a relation between prior knowledge and learning. To overcome the determined heterogeneity, the Remote Lab has to provide additional learning material tailored for the specific needs. This may include an extended documentation, instructional videos or tutorials. As part of the ongoing project the feasibility of multiple adaptive alternatives will be tested and implemented. In the upcoming iteration of the Remote Lab students will be classified into groups of beginner and more-skilled students. Both of these groups receive the same set of exercises, but the beginners will start of with more pre-populated clues about how to solve the tasks. The more advanced students on the other hand get the chance to start from scratch, allowing them to put their established competences to use [5]. Extended forms of adaptive learning, as the automatic detection of students that are stuck and the administration of tailored assistance will be studied on the basis of the use logs and further questionnaires. Another vector for adaptation that will be tested in future implementations are Learning Analytic Dashboards that allow the teachers and students to reflect upon the learning experience and (self-)adapt accordingly.

In order to establish an infrastructure that motivates the re-usability in other contexts the integration of the Remote Lab interface into e-Learning platforms (e.g. Moodle) is another ambition of this project. If the Remote Lab interface was available as a plugin for popular e-Learning environments this would allow for a better didactic integration into the topical context of the respective course. The existing structural support of these platforms could be used as well, for example the time tabling functions could be used in order to reserve time slots in the laboratory, communication with the teachers and within the group could rely on the existing capabilities and forums and wikis could aid in the cooperative development and exchange of knowledge and competences.

To sum up, we would like to make some suggestions for implementing Remote Labs in the future:

- To increase learning performance it is suitable to implement adaptive Remote Labs for tailored instruction.
- The usability of Remote Labs is of particular importance to sustain motivation.
- An integration of a Remote Lab into a learning management system provide additional benefit for learner and teacher.

However, our research is still at the beginning. In further research we have to gain much more detailed information on challenges as well as advantages of Remote Labs and an optimal instructional design for specific objectives and learners.

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