Teaching with open-source robotic manipulator

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Abstract. In this paper we present and evaluate the usage of an open-source robotic manipulator platform, that we have developed, in the context of various educational scenarios that we have conducted. The system was tested in multiple diverse learning scenarios, ranging from a summer school for primary-school students, to the course at the university level study. We show that the introduction of the system in the educational process improves the motivation as well as acquired knowledge of the participants.

Keywords: robotic manipulator, education, open-source, open-hardware, evaluation

1 Introduction

Robotics is a very attractive and increasingly important research and engineering discipline. Besides a growing commercial interest, it has also a lot of potential in education because of the engagement factor due to the hands-on experience; the students operate a real robots acting in a real world causing real effects in the environment. This is the main reason why robots can play an important role in STEM education in general and motivate students in fields other than robotics itself.

Another property of robotics is that, similar to biological systems, it is very diverse, the most well known categories being robot manipulators, mobile ground robots, and drones. Especially the mobile robots are very popular in education [1–3] because they are reasonably cheap to manufacture and easy to control. Price is a crucial factor in educational robotics, industry-grade robots remain very expensive equipment that only a few educational institutions can afford. This is most clearly shown in the case of robot manipulators that have to be quite complex to ensure a sufficient level of accuracy and reliability. The high price of robot manipulators has resulted in multiple attempts to build a low-cost manipulators [4–8] with varying levels of reliability. These works have focused primarily on the mechanical engineering side of the production such as type and cost of the building material (mostly alloys) and low-level control, leaving a huge gap in functionality that is required for using the robot in educational scenarios that focus on high-level control, programming and artificial intelligence.

This gap was addressed in our past work [9] where we have presented an open-source robotic manipulator that embraces the recent trend in manufacture of physical objects using the 3D printing technology. Our primary focus in the aforementioned work was a low-cost robot manipulator that is extended into an advanced robotics sensory platform that supports various educational scenarios. In this paper we present our experience with this platform in the context of various educational scenarios that we have conducted in the past year. The system was tested in multiple diverse learning environments, its effects were also evaluated where the evaluation was possible. We show that using the system in the educational process improves the motivation and obtained knowledge of the participants.

In the rest of the paper we first present the platform in Section 2, where we summarize its hardware characteristics as well as describe the different programming interfaces that we have implemented. In Section 3 we present and discuss the use-cases together with evaluation of their success. We conclude in Section 4 with concluding remarks and some ideas for future work.

2 Robotic manipulator

The main challenge of developing a robotics platform for educational purposes was to design a sufficiently reliable, but still a reasonably low-cost manipulation platform. Our robotic manipulator was initially presented in [9], but we have since then made several improvements towards a more flexible and reliable platform for various educational and research purposes based on our classroom experience. We have also invested a lot of efforts into making the manipulator usable at different skill levels, making it useful for teaching different STEM topics at various levels of education.

2.1 Hardware platform

The current hardware platform, presented in Figure 1, is a 5-DOF robot manipulator, based on an improved frame published in [10] and an upgraded open-hardware motor controller, proposed in [11]. The manipulator is supported by a Raspberry Pi 3 computer as the central processing unit and a web camera. We estimate the cost of the entire hardware platform (including 3D printer material, a Raspberry Pi 3 and a USB camera) to approximately 250-300€.

In comparison to the original platform, presented in [9], we have, based on the experience, improved the hardware platform by replacing a simple wooden base for Raspberry Pi 3 computer and a power supply with a custom 3D-printed base and re-designed power supply. This change simplified manipulator setup for users and made the manipulator units easily maintainable allowing easy access to all the components.

An important aspect of open-hardware is reproducibility. Since the designs for the manipulator are public, a new unit should be assembled easily by anyone with sufficient knowledge about 3D printing and electronics. Based on our internal evaluation conducted during the manufacture process of ten manipulators

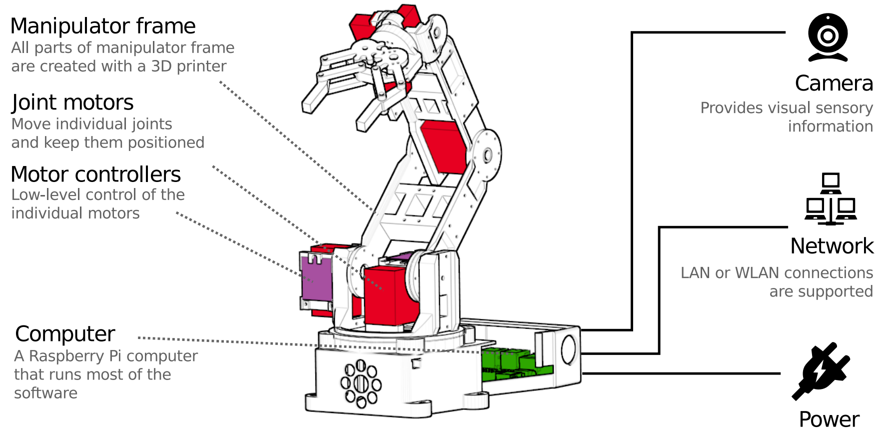

Fig. 1. Robotic manipulator and other components of the platform. The base of the robot contains a Raspberry Pi 3 computer and some additional components for power supply. The embedded computer serves as a central computational unit and a bridge between the manipulator and the user.

for the purpose of our educational activities we have estimated that a skilled engineer can assemble a single unit in less than 24 hours. One of the manipulators was even assembled by a keen primary-school student. While this demonstrates the reproducibility principle, we are continuously working on improving this experience in the future by providing written instructions.

2.2 Programming interfaces

Our system is designed to support multiple programming languages in different interaction scenarios aimed at different skill levels and use-cases. Users can write scripts that are executed directly on the embedded computer of the robotic manipulator or control the manipulator via the HTTP API. All types of interaction are accessible through the web interface running on the embedded computer. The advantage of this approach is that it supports working with the platform without the requirement of having a dedicated client computer with special software installed.

The possibilities of interaction with proposed robotic platform are shown in Figure 2. The user interacts with the robotic platform via a web-server that supports low-level primitive commands to move the manipulator or access the camera. This type of access is suitable for controlling and monitoring the manipulator directly, which is popular motivational approach for younger students, but can also be used to control the robot from a program executed on a client computer provided that a suitable environment is installed. Alternatively users can submit entire scripts that are executed on the server. This approach is additionally augmented by an in-browser editor and an ability to save scripts on the

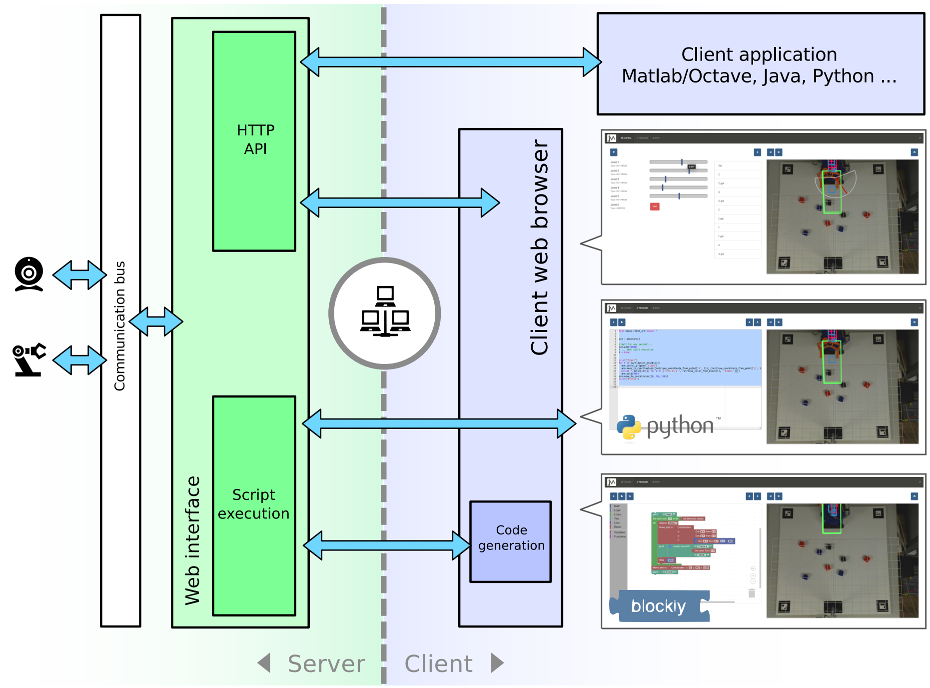

Fig. 2. Programming interfaces overview for the robotics platform. The server side on the left is connected to the client (user) via the local network. The system supports HTTP API for basic manipulator commands as well as execution of entire scripts for more complex use cases.

robot itself, which essentially turns the client computer into a simple dummy terminal that only provides a web browser. This functionality is important in case of shorter events where participants do not have time to set up their computers or in case where their computer skills are limited. In-browser editor currently supports Python scripts as well as Blockly diagrams that are converted to Python within the browser. In both cases the system provides special commands to move the manipulator as well as other hardware-related tasks. We have added support for these two languages because they are frequently used in computer science education. Especially Blockly (as well as its ancestor Scratch) has been used extensively in robotic education and introduction to programming [12–14]. Support for additional languages can be added easily as the system is very modular.

3 Teaching use-cases

The developed platform was so far used in several educational scenarios for the audience of various age and pre-knowledge. In the past two years we have gradually introduced it into curriculum of a course on robotics and computer vision at the university level, we have also organized a summer-school on programming and robotics for primary-school students, as well as use it in educational events that promote the field of computer science. In this section we review these scenarios in more detail and present a motivation for using the developed platform.

3.1 University course on robotics and computer vision

The initial motivation for development of the described manipulator was a university-level course on robotics and computer vision (RMP). During the course it is important that the students acquire a suitable level of knowledge about both, perception and action part of the robot manipulation. Using the developed robotic platform, we introduce the students to the different topics in a gradual manner. Because the students use the manipulators for the laboratory exercises through the entire semester, we have created a multi-level hierarchy that enables running the same system in three modes. In *simulated environment* the robot manipulator operates in a simulation, while in *augmented environment* the system uses a real camera to perceive the environment but the robot manipulator is simulated and shown superimposed on the top of the camera image. These two environments allow students to deploy the system at home. In the final, *Real-world environment*, the system works with a real manipulator and a camera, using the system that students use in the laboratory.

At the end of the course the students were given an anonymous questionnaire that measured four concepts: (i) how the use of the robotic manipulator influenced their *motivation* for working with robots, (ii) how was it useful to better learn new concepts about *robotics*, (iii) how were they satisfied with the *hardware*, i.e., with the provided platform, and (iv) how useful they found to be the *multi-level* paradigm. Each of the four concepts was measured with four claims, for each of the claims the students provided their attitude on a 5-level Likert scale. Additionally, the students were asked two open questions about the problems with the manipulator and ideas for improvement.

The processed results for the four concepts are summarized in Figure 3. We can see that the students evaluated the usefulness of the robot manipulator for motivating their work and fostering learning very positively, with an average score of 4.22 and 4.47 respectively, on the scale from 1 to 5. The hardware platform was also positively accepted, with an average score 3.78, although also certain shortcomings of the robot manipulator were exposed. The multi-level paradigm was on average also moderately positively accepted (with an average score of 3.36), however it was not universally accepted by the students, as can be seen in a high variance (1.48) of the answers. This is to some degree understandable as the simulator is not a real substitute for a real manipulator.

We have also analyzed the student surveys of the course for the academic years 2015/16 and 2016/17. The questionnaire is given to the students at the end of the semester by the faculty administration. We are comparing these two years because we have introduced the robotic manipulators in year 2016/17 and the results for year 2017/18 are not available yet. In year 2015/16 9 students

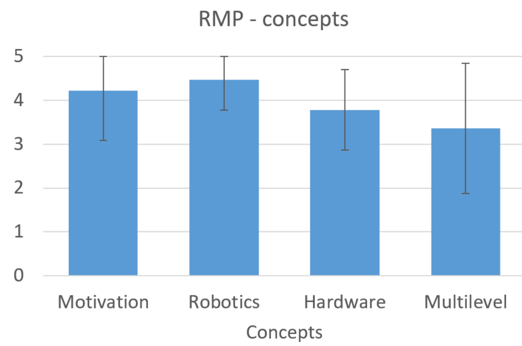

Fig. 3. Results of the survey at the university level course on robotics and computer vision.

provided the answers to the questionnaire, while in the year 2016/17 15 students answered exactly the same questionnaire.

We present here the results of the answers to four questions related to the introduction of the manipulator platform: the *Total* grade, *Overall* satisfaction with the course, encouragement towards independent *Thinking*, and obtained *Competences*. The 5-level Likert scale was used in this case as well.

The results are presented in Figure 4. We can see that the answers on all four questions improved after the introduction of the robot manipulator in the pedagogical work. The students' positive attitude towards the introduced platform is therefore also reflected in better evaluation of the course.

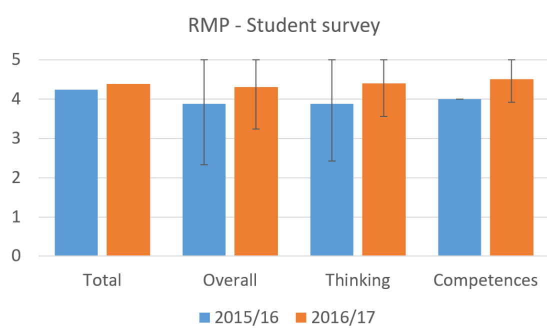

Fig. 4. Comparison of the course grade over years 2015/16 and 2016/17.

3.2 Summer school for primary-school level children

In summer of 2017 we organized a summer school on programming, robotics and computer vision. The summer school was one week long and it was attended by 18 children aged between 12 and 14 years (14 boys and 4 girls). Some children had basic experience in visual programming languages, like Scratch, none of them have worked with robots before. The main goal of the event was to excite children for STEM subjects, and to teach them basic principles of programming (e.g., if-statements, for-loops, etc.), robotics, and computer vision. Because of different backgrounds we have used Blockly as the language of choice. The children were working in pairs, each of them operating a single robot manipulator via the web interface. This way both students were able to solve problems together or individually. Some photos, showing the activity during the summer school, are shown in Figure 5.

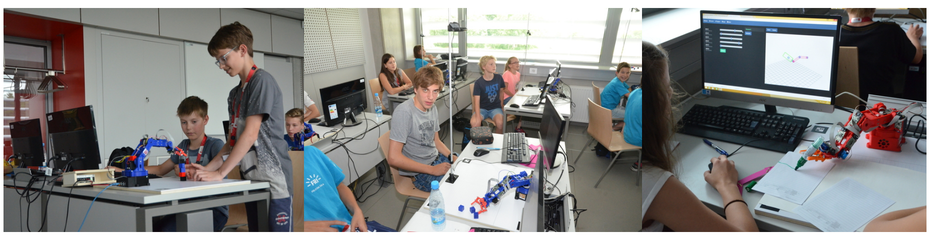

Fig. 5. Photos from the summer school on programming and robotics.

The motivation of children and their attained knowledge was measured with a questionnaire that was given to them before and after the summer school. Motivation was measured with a set of 10 claims, each of them recorded participants attitude towards them on a 5-level Likert scale. The knowledge was measured in terms of self-evaluation with a set of 10 claims. We verified their knowledge also by giving them to solve three assignments related to the basics of programming, robotics and computer vision.

Results of the questionnaire are summarized in Figure 6. Based on the results we can conclude that the knowledge, both the self-assessed and objective, significantly improved after the summer school. The motivation also improved slightly (the change in all three cases is statistically significant). A reasonably modest improvement in motivation can be attributed to the fact that the students who applied to the summer school were already highly interested in robotics. Several students were also able to program in visual programming languages before the summer school, however they further improved their knowledge (the average percentage of correctly solved programming assignment raised from 61% to 72%). Since the students didn't have almost any pre-knowledge in robotics and computer vision, the improvement in understanding basic concepts in these two research fields is very large (from 22% to 61% and from 11% to 61% respectively).

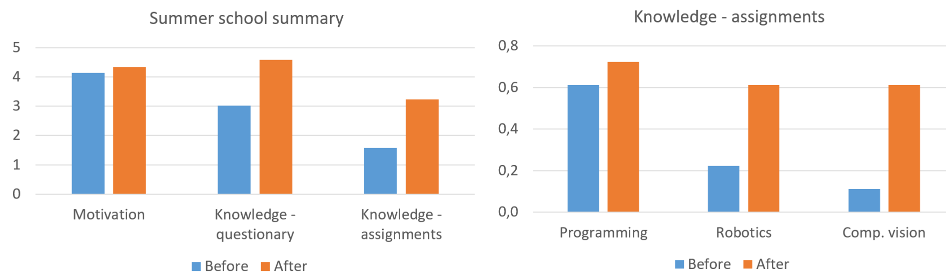

Fig. 6. Results of the questionnaire at summer-school.

3.3 Shorter educational events

Our robot platform is also utilized in shorter educational events where one or more robots are used to promote science and robotics. Because the interaction time of visitors is short in this case, their experiences cannot be measured systematically, however, we list the most significant events in this section for completeness together with our findings. In all cases the robots were used to run pre-made Python demos to attract visitors who were able to control the robot manually. Photos from the events are shown in Figure 7.

Fig. 7. Photos from different short educational events where the robot platform was utilized.

1. **Day of computer science -** In this event several groups of primary school students visited our faculty where multiple short (20-30 minute) interactive workshops were held for them. At the workshop the students were introduced to the platform and modified some pre-made Blockly programs. Despite the short turn-around of the groups the system was very stable. Moreover, it sparked a lot of interest in students and in teachers who accompanied them.

2. **The European Researchers' Night** - Our aim at this event was to popularize computer science and robotics research. The visitors (mainly children) were able to see the robotic manipulator at work (performing simple predefined tasks) and also to try to control it. Although they were just weakly supervised by the instructors, they were very quickly able to learn how to operate the robotic manipulator and perform simple tasks. The robot manipulator attracted a lot of attention and brought a lot of fun to the visitors, who also learned something new about the robotics and computer science.
3. ***Informativa* fair** - The fair is aimed at students who are enrolling to universities to help them decide on the field of study. The event was an important test for the platform because it was the first time that the entire event was handled completely by the computer science students who did not have any prior experience with the robot platform and has demonstrated that the setup of the robot is easy enough for someone without an in-depth knowledge about the system's internals.

4 Conclusion

In this paper we have presented our experience with using our open-source robotic manipulator platform at various educational activities that we have organized in the past year. The system was tested in multiple diverse learning environments, from the summer school for primary school students to the university level course. The effects of using the platform were evaluated. We have shown that using the system in the educational process improves the motivation and obtained knowledge of the participants. We have also demonstrated that the platform can indeed be replicated over several units which is a good starting point for an open-hardware project.

We are already in the gradual process of releasing all the plans for hardware as well as the software for the platform so that it may be used by as well as built upon by the community. We are also striving to continuously improve the platform. Based on the results of the evaluations we have also identified several potential improvements. As reported by the students, the accuracy of the robot is insufficient for fine object manipulation tasks. The reason for this are slight differences between the individual units. We are investigating an automatic or semi-automatic manipulator calibration process that would improve the accuracy across all manipulator units. We are also working on improving the simulator that would provide a more realistic testing environment with rigid-body physics simulation. This will hopefully make the simulator a suitable temporary substitute for a real manipulator.

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