Open-source robotic manipulator and sensory platform

Luka Čehovin Zajc, Anže Rezelj, and Danijel Skočaj

University of Ljubljana, Faculty of Computer and Information Science,
Večna pot 113, Ljubljana, Slovenia,
{luka.cehovin,anze.rezelj,danijel.skocaj}@fri.uni-lj.si

Abstract. We present an open-source robotic platform for educational use that integrates multiple levels of interaction through the use of additional vision sensor. The environment can be used in virtual, augmented-reality and real-robot modes, enabling smooth transition from a virtual robot manipulator to a real one. We describe the main aspects of our platform that ensure low production costs and encourage openness of both its hardware and software. The main goal of of our work was to create a viable low-cost robotic manipulator platform alternative for the university level courses in intelligent robotics, however, the application domain is very broad.

Keywords: robotic manipulator, education, open-source, open-hardware, computer vision, augmented reality

1 Introduction

Robotics is a very attractive and increasingly important research and engineering discipline. With the growing robotics market and very bright outlooks for the future, it is to be expected that the demand for educated roboticists will even grow. Moreover, it is very advisable that also other engineers as well as young people in general become more familiarized with the robotics technology to cope with the challenges of the future. In addition, due to its attractiveness, robotics plays an important role in STEM education in general. Therefore, it is very important to develop teaching equipment and methodology that would enable efficient and generally accessible educational process in the field of robotics.

Robotics is also very engaging due to its hands-on experience; the students operate with real robots acting in a real world causing real effects in the environment. The robots are usually equipped with sensors to enable them to perceive the environment in order to act accordingly, therefore to close the perception-action loop. It is crucial that the students are exposed to real robots, yet industry-grade like robotic manipulators remain expensive equipment that only a few educational institutions can afford. Many educators are instead resorting to simulation-based solutions [1] which are cheaper and easier to set up and maintain, but do not offer the real experience and are more difficult to interact with. The high price of robot manipulators has resulted in multiple attempts to build medium [2] and low-cost [3–7] alternatives with varying level of reliability. Aforementioned works have focused primarily on the engineering side of the challenge such as type and cost of the building material (mostly alloys) and low-level control. The price of such systems spans from 4000$ to 50$ where the low-end systems have severely limited functionality, required for university-level courses on robotics.

In our work we embrace the recent trend in manufacture of physical objects using the 3D printing technology. Our primary focus is not in the assembly of the physical components, what sets our system apart from the rest in the educational aspect is the extension of our manipulator in a robotics sensory platform. Using these extensions we enable smooth transition between the simulated environment which is much more convenient in the early learning and development stage and the real world which is important for later stages because of the information richness and realism. We believe that a smooth transition between the simulated environment and the real world is crucial for teaching high-level robotics concepts. Using the combination of hardware and software, we have developed a system that can be used at three different levels:

1. *Simulated environment*: The robot manipulator operates in a simulated software environment, however the students can control it using the same interface as the real one.
2. *Augmented environment*: The students use the real camera to perceive the environment and to detect objects in the scene; however, they still operate the simulated robot manipulator. The robot manipulator is virtually positioned in the real world image stream using augmented reality technique.
3. *Real-world environment*: The system consists of the real camera as well as of the real robot manipulator. The robot performs both, perception and action in the real world environment.

The students are first trained using the simulated robot manipulator that enables convenient learning and experimentation. Since they do not need the physical robot manipulator, they can also use the simulated system at home. Moreover, by adding a (widely accessible) web-camera, the students can learn computer vision techniques using real images and observe the operation of the robot manipulator in an augmented environment.

In this paper we briefly describe the hardware and software components of our platform (Section 2), describe where it has been used and tested so far (Section 3) and conclude with our vision for the future (Section 4).

2 Platform

In order to make the system even accessible to the as broadest interested public as possible, we wave designed the platform to be open from the hardware up. We plan to open-source the blueprints, build instructions and software so that in principle, the platform could be produced and/or assembled by the students (or hobbyist), which increases their involvement even more and broadens the range of potential users.

2.1 Hardware

The main challenge of developing the robotics platform was to design a robot manipulator, which is reliable, but also low-cost to produce. Our manipulator is shown in Fig. 1. It has 5 DOF and is quite robust but also lightweight and easy to use. It is safe enough to be operated by the kids, while on the other hand realistic enough to be useful for the students of robotics. The key factor in openness is that most of the structural components can be printed by a 3D printer. The first iteration of our manipulator is based on the work from [8][1] that was adapted to our needs, while other components can mostly be bought in a hobby store. The only notable exception that is not readily available are the motor controllers which are based on the OpenServo designs [9] that we have further improved. Those controllers are replacing original controller in servo motors. For servo motors we used Hitec HS-311, HS-645MG, HS-485HB and three Emax ES08A II which are used in base, shoulder, elbow, wrist and gripper respectively. Maximum payload is about 100g. Power for motors is supplied using 5V 10A power supply for better voltage stability in high current cases.

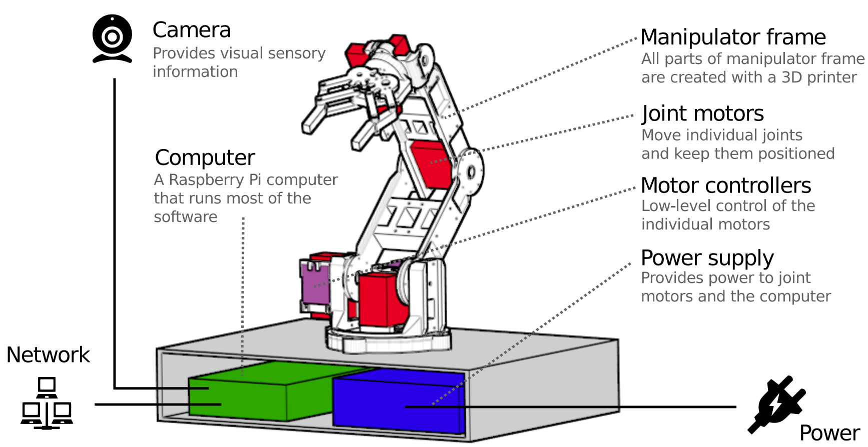

Fig. 1. Robotic manipulator and other components of the platform

While the robot manipulator can be connected to an arbitrary computer, our platform is designed to be used with low-cost single-board computers, like Raspberry Pi. The Raspberry Pi computer and the power supply unit are enclosed in the base of the platform. The camera can be positioned above the manipulator and is registered with the working surface using special markers.

We estimate the cost of the entire system (including 3D printer material, a Raspberry Pi computer and a camera) to be around 250€ which makes it really

[1] The model is available at Thingiverse (`http://www.thingiverse.com/thing:30163`) under a permissive Creative Commons license.

affordable. We would also like to point out that this is the small quantity price which may be further reduced by bulk orders of certain components.

2.2 Software

The software stack that was developed for our platform follows several design goals: (1) it has to be lightweight so that it can be deployed on low-cost embedded devices, like Raspberry Pi, (2) it has to be flexible and modular so that it can be adjusted to different educational scenarios, (3) it has to be robust to withstand long-term usage, (4) it has to be accessible from without complicated installations, and (5) it has to rely only on open-source technologies to reduce cost of the system and to retain its openness.

To address these constraints we have developed a multi-process architecture, similar to the one of more complex robotic middlewares, e.g. ROS [10], but more optimized in terms of memory and processing requirements. The components run on Linux-based system and communicate between each other using a message bus based on system sockets as shown in Fig. 2. Individual components take care of image acquisition, image processing, low-level robot control, trajectory planning and interaction with the user.

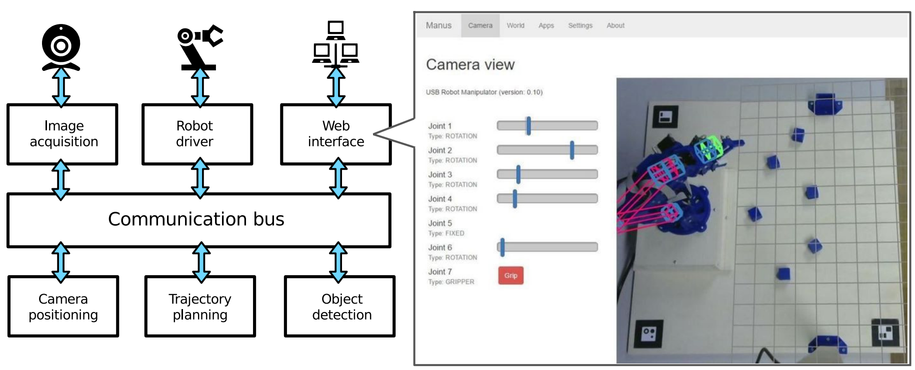

Fig. 2. Software architecture of the system and a screenshot of the web-interface

Since the platform is designed to be used at different levels of educational process, the interaction also varies a lot. At the higher levels the interaction is done using web interface which alleviates operating system and compatibility constraints. We have created a web front-end (Fig. 2) that enables monitoring of the current status and we plan to extend it with rudimentary programming facilities aimed at younger audience. More advanced usage scenarios involve remote control using web API (e.g. from Matlab) or direct integration of code into the local ecosystem by interacting with components via the message bus.

3 Use cases

The developed platform was so far used in two different educational scenarios. We have introduced it into curriculum of a course on robotics and computer vision at the university level and used it in educational events that promote the field of computer science, the target audience in this case being potential future students and other tech-savvy youth.

University-level course: During the course on robotics and machine perception 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. The teaching process involves the stages presented in Table 1:

Table 1. Gradual teaching stages.

	perception	action	activity
1	simulated	none	Learning basic computer vision algorithms by processing stored images.
2	real	none	Learning more advanced computer vision algorithms by capturing and processing live images.
3	none	simulated	Learning the basics of robot manipulation in simulated environment.
4	none	real	Learning to operate the robot manipulator in the real world.
5	real	simulated	Detecting the objects in the scene and pointing at them with the virtual robot manipulator.
6	real	real	Detecting and grasping the objects in the scene with the physical robot manipulator.

The separation to these different stages is not strict, they are also intertwined with the goal to achieve a maximal motivation of the students and speed up learning. We have began with the introduction of the proposed platform into a robotics and machine perception course in year 2017 to replace a simple simulation solution. We have discovered that our multi-level system scales extremely well as students were able to accomplish most of the tasks already at home using the provided simulated and augmented environment and finalize the given assignments in time on a limited number of real platforms available at the university. Moreover, due to the open-source design and low-cost components, some students have also decided to build a robot manipulator by themselves to even deepen their knowledge and to use it for other projects.

Educational events: During the educational events organized to promote computer science the contact of the audience with the platform is usually very brief, therefore the message has to be more focused. We have designed a demonstration in which a robot is sorting boxes of two colors. In some cases the robot may fail to grasp the box correctly and the audience members are invited to help the robot by guiding it using simple forward-kinematic control to demonstrate that the task is more difficult than it seems. The demo attracted great interest of the participants (mostly primary school pupils) and it was very well accepted.

4 Conclusion

In this paper we have presented a low-cost open-source robotic manipulator extended with the vision sensor. We have described the hardware and software aspects of the platform as well as our current use cases in educational activities. At the moment we have produced an initial batch of six robot manipulators and have tested the system at the university level course on robotics and machine vision as well as in several educational activities. The platform is robust and stable. In the future we would like to upgrade the manipulator to 6 DOF for additional flexibility. We are also preparing to organize a summer school for kids in primary school where we will be able to evaluate the system in different conditions. After improving the production process we plan to release all the plans and the software for the platform so that it may be used as well as contributed to by the community.

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