Integration of Robotic Arm Manipulator with Computer Vision in a Project-Based Learning Environment

Krystian Radlak
Institute of Automatic Control
Silesian University of Technology
Akademicka 16, 44-100 Gliwice, Poland
Email: krystian.radlak@polsl.pl

Marcin Fojcik
Sogn og Fjordane University College
Svanehaugvegen 1, 6812 Førde, Norway
Email: marcin.fojcik@hisf.no

***Abstract*—This work-in-progress paper describes our experience in introduction of a Project-Based Learning environment in teaching of undergraduate students in the field of electrical engineering at Sogn og Fjordane University College in Norway. In the scope of this work, a robot capable of playing the tic-tac-toe game with a human and an additional laboratory exercise in robotic manipulation with computer vision has been developed. In this lab, the students integrated the robotic manipulator with computer vision in order to prepare a fully autonomous robot navigation using a prepared library that provides the functions for robot control and image processing. The project can be an interesting tool for learning some advanced topics such as robot vision, robot mechanics and autonomous robot navigation. The results show that students with strong motivation start to carry out an advanced project without any theoretical background in robotics and image processing. Another advantage is that the students can test in practice the influence of all stages of image processing on final robot navigation and understand that we may control robotic manipulators by using the vision information.**

I. Introduction

Robotics is one of the most important and exciting fields of technological advancements of our age. The first industrial robots have been introduced to the factories in early 1960s and we still observe the strong growth of new applications in recent years. The evolution of the technical needs of society and the technological advances achieved cause that robots are widely used in many areas such as agriculture, surgery assistance, rehabilitation, automatic refueling, automotive assembly line, etc. [1]–[3].

Robotic arms are one of the most important industrial robots, but they are typically designed to repeat tasks. Integration of the robot with the information coming from the camera can extend the functionality of their in automatic industrial process [4], [5]. However, in order to ensure the continued development and meet the future challenges in service robotics, it is important to train engineers, who will cover those necessities.

In recent years, an increased interest in robotics is also observed from the industry in the Sogn og Fjordane region in Norway. In order to respond to demands for skillful engineers Sogn og Fjordane University College (SFUC) cooperates with the regional industries in the realization of bachelor's projects. Within this cooperation almost all projects are conducted in such a way that the students receive the fragments of tasks that should be implemented under supervision of teachers from SFUC and employers. The result of this work is a bachelor's thesis connected with real-world problem and an industrial deployment of a technology. This work is the only way to conduct the projects connected with robotics. However, due to the fact that there are no courses as introduction to the robotics and image processing in the undergraduate curriculum, the students avoid the topics related to computer vision and robotics.

During a three-month visit of one of the authors (KR) under Erasmus internship program to SFUC, there appeared an idea to design an advanced application that can be presented as a spectacular demo of the robot's capabilities for visitors of the university and encourage the students to choose the robot-related tasks. As the result of this internship, a robot capable of playing the tic-tac-toe game was developed.

The laboratory in SFUC is equipped with Universal Robots UR5 and KUKA KR3 robot manipulators, but in this work we will focus on the UR5 robot, as we received many positives opinions from Norwegian companies, which successfully deployed this robot in their business. This robot was also used in many research projects [3], [6]. The UR5 robot with the control panel is presented in Fig. 1.

Fig. 1. The UR5 robot from Universal Robots.

978-1-4799-8454-1/15/$31.00 ©2015 IEEE

The second idea under this internship was to design and introduce an optional laboratory exercise that would give the students an opportunity to design, develop, evaluate, integrate and manage projects, in which they will use a robotic arm and computer vision algorithms in real-life applications. However, due to the fact that this internship took place during summer vacation, there was no possibility carrying this laboratory with the students and the laboratory stand was prepared to control it via Internet. To achieve this goal for all devices the public IP addresses were assigned, the web-camera was mounted near the robot and a free app TeamViewer for remote access to the system was used. The final workshops with the students were conducted by both authors, but one of the authors (KR) supervised the work of the students via Skype and TeamViewer applications.

This laboratory was designed in the form of Project-Based Learning (PBL) [7], because many researchers note the positive influence of PBL on education process [8]–[12]. The main idea of PBL approach is to engage students in learning and stimulate their thinking by solving a real-world problems instead of traditionally lecture-based learning [13].

The aim of this exercise was to illustrate how to localize a simple objects using computer vision methods for preparation of an autonomous robot navigation and check if further one-semester course in robotics can be conducted without lectures in robotics and image processing as PBL.

To accomplish it, we developed a basic application, in which the students need to change a small part of code to solve two proposed problems: removing all predefined objects from the table and adjusting the proper values of thresholds to recognize other types of the items on the table.

In this work-in-progress paper, we present the preliminary results of applying the PBL approach in teaching programming of robots and integrating it with computer vision and designed environments. The main idea was to introduce an additional laboratory project for the undergraduate students of electrical engineering at SFUC in Norway and show the students that they are able in an easy way to control the robotic arm using the ready-made algorithms. The next Section provides a brief description of the developed laboratory stand and prepared applications. In Section 3 we discuss the results and the impact of the deployed robot on the learning process and finally we conclude the paper.

II. Laboratory Stand Description

The most challenging part of this work was to find an alternative way to motivate and capture the interest of students to obtain programming skills for solving robotic tasks. To realize it, we prepared two applications containing ready-made algorithms for robot motion planning using computer vision algorithms.

The first application is an implementation of a robot capable of playing tic-tac-toe (or Noughts and crosses) game that has been presented on student university open days, when the robot played with students and visitors to show the possibility of using robot. The tic-tac-toe is a simple and short game, in which two players take turns marking the spaces in a 3×3 grid. The player who succeeds in placing three respective marks in a horizontal, vertical, or diagonal row wins the game. Typically, it is a paper-and-pencil game, but in our solution, we used basic geometric figures (red rectangles and blue circles) as pawns in the game.

In order to find the optimal move in the tic-tac-toe game for the robot a Minimax algorithm has been applied [14]. The Minimax algorithm is simple recursive algorithm that performs a deep search strategy checking the possible game states and allows to select the best move for the robot. A similar robot capable of playing the tic-tac-toe game was developed by a group of engineering students at São Paulo State University in Brazil [15].

A robot is able to play with a human by analyzing the position of the pawns on the table and the free fields of the game board using the visual information gathered by the Basler Ace GigE camera mounted at the end-effector of the robot. The scheme of the laboratory stand has been presented in Fig. 2. To communicate with the camera, we used SDK of Basler camera, to control the UR5 robot, we used a Python urx library developed by Olivier Roulet-Dubonnet [16], OpenCV library [17] for image processing purposes and GUI has been developed in using Qt library [18]. The communications between the camera, the robotic arm and the PC was performed via TCP/IP protocol.

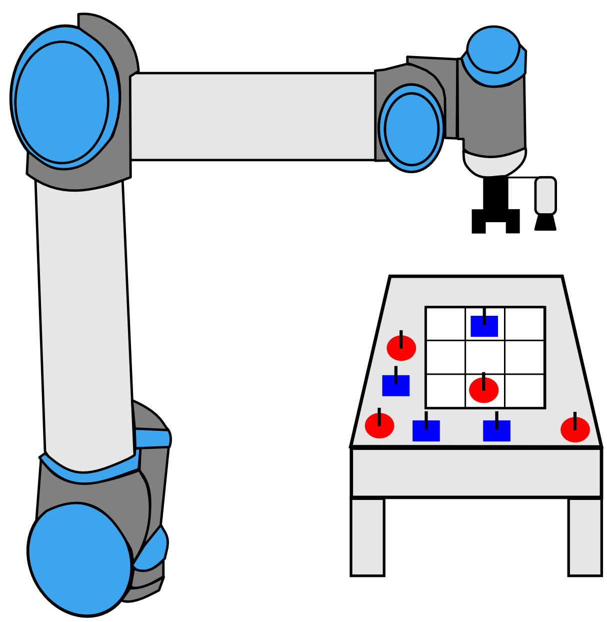

Fig. 2. A scheme of developed Tic-tac-toe playing UR5 robot manipulator.

The second application illustrates how to localize simple objects (blue circles and red squares) on the table and move them to other locations. This application was used in an additional laboratory course, in which students needed to change some part of code and modify a basic image processing algorithm in order to teach a robot to recognize new items.

Similarly to the work [19], our software was divided into separate classes:

- class *Robot* for communication between the robot and the PC,
- class *FrameCapure* for images acquisition,
- class *ObjectDetection* for objects detection within the captured images,
- class *TableInterpreter* for transformation of visual information to appropriate robot's movements.
- class *MainWindow*, in which a user GUI was developed.

Within class *TableInterpreter* the functions were developed for automatic calibration of the distance between the robot's gripper and the table, the angle between camera and the robot coordinate system. Two different coordinate systems for the robot and the camera sensor are presented in Fig. 3.

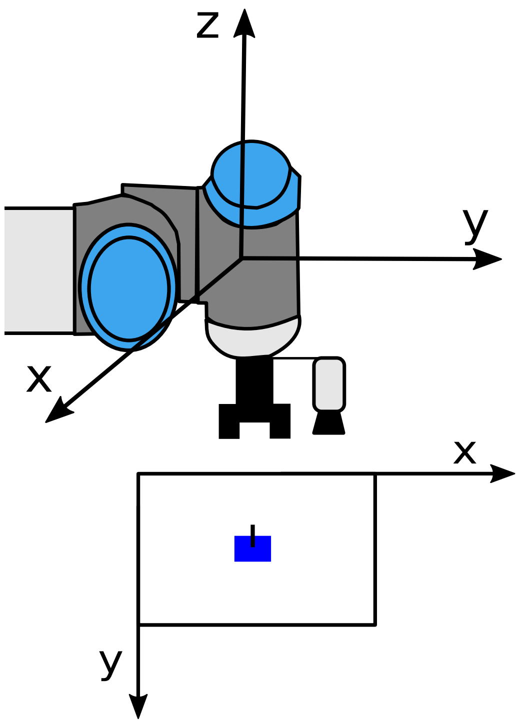

Fig. 3. A scheme of coordinate system of the camera and the robots.

In the proposed course there are not any advanced computer vision algorithms what allows for easy understanding of the whole objects detection process for the student with limited previous knowledge in image processing. In the applied algorithms all objects are detected based on the color properties of the objects using HSV color space by setting the proper thresholds. Then, morphological post-processing was applied to remove artifacts, which may have appear in the previous step and connected-component labeling was used to detect connected regions in obtained binary image. Finally, for each detected object the mass center has been calculated in order to move the robot arm through the desired position. The flow chart of the developed object localization method in presented in Fig. 4.

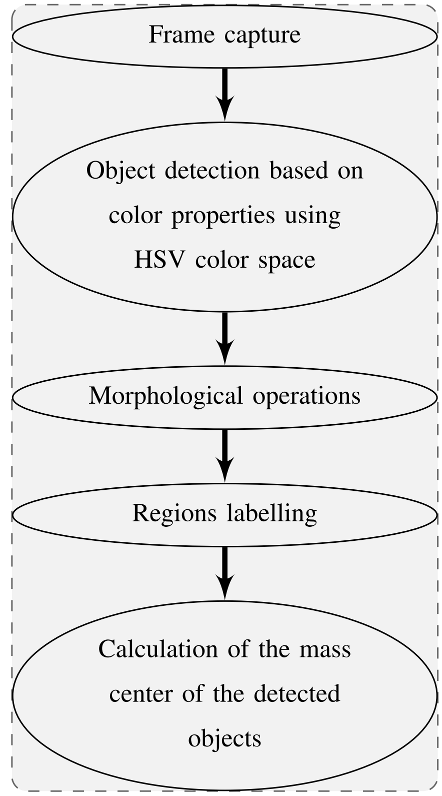

Fig. 4. Flow chart of the vision module used for object detection.

III. Evaluation of the Educational Effect

The primary objective of this study was to evaluate if an obligatory course in robotics with computer vision planned in the future can be conducted in the form of PBL without traditional lectures in this field. This is due to the fact that there is limited possibility to add novel courses in image processing and robotics to the current undergraduate curriculum in electrical engineering at SFUC.

For this laboratory we prepared two simple tasks, the first connected with planning the movement of the robot arm and the second focused on image processing problem. The first task required from students a modification of the function **PickCircleObject()** that picks up a single blue circle from the table and places all the circles detected by the function **DetectCircles()** on the line. The second task was to write a function to detect the black nails based on the HSV color space using the code of the function **DetectCircles()**. In this task a short introduction to the HSV color space was conducted and an additional function with the trackbar sliders that visualize the results of image thresholding in HSV color space.

In order to evaluate educational effects and determine the degree of interest, we observed students' attitude and reactions during the laboratory. In addition, in order to avoid subjective bias, we also prepared an anonymous questionnaire before and after exercise with questions about students' motivation, interests and expectations. 60% of students of the third year participated in this optional laboratory. We divided them in three groups.

Generally, all students in the survey reported that their knowledge about robotics and computer vision is minimal. Most students before the exercise expected to see the robot in action and acquire knowledge about the robotic arm programming and programming environment. Three persons were especially interested in the topic of workshop, because they would like to use this knowledge in their bachelor's project.

Due to the lack of earlier experience, most of the students considered computer vision and robotics as difficult and they thought that they would not even be able to start the project related to robotics. Almost half of the students noticed that they did not know that the camera sensor systems can extend the functionality of a robotic arm.

The answers from the questionnaire after exercise showed that 30% of the students were interested in both robotic arm programming and integration of the robot with camera sensors and application of image processing methods for autonomous robotic manipulation. On the other hand 40% of students were interested only in robotics without using computer vision.

The questionnaires also showed that the biggest problem for the students was the use of HSV color space, because they never heard about the Hue-Saturation-Value (HSV) color model. They were only familiar with RGB and CMYK color model and they were able to work with this novel color space only after a detailed explanation of the necessities of applying different color spaces. Another difficulty was caused by the different coordinate system for the robot and the camera and the fact that the robot axes were not directed perpendicular to the table with the items. Therefore, most students would like to receive learning materials and an instruction before the laboratory in order to prepare better for the upcoming exercise. This difficulties show that even in realization of PBL a detailed instruction is always required and it is not possible to treat the robot movement functions as "black boxes".

Contrary to our expectations, the students did not see any difficulties in conducting the laboratory exercise remotely using English by one of the lecturer. However, some concepts had to be explained by local lecturer in Norwegian language. Furthermore, all students have completed the tasks and they were satisfied with the exercise. This exercise was planned for 2-3 hours, but the students wanted an opportunity to learn for a longer period of time. Half of them outlined also the necessities of learning of some novel programming languages as they had only programming course in Java. All students will also recommend the participation in this laboratory to the other students.

IV. Conclusions and Future Work

In this work-in-progress paper, we provide a detailed description of prepared applications, especially our robot capable of playing the tic-tac-toe game and show preliminary results and experience in conduct of a small PBL workshop related to programming robotic arm and integrating it with computer vision for autonomous robotic manipulation. The students participation in this optional exercise gave us positive feedback on this activity and confirmed that they would like to take part in an obligatory course realized in this form.

Based on this experience, we are planning to introduce in the future an obligatory course of robotics with elements of computer vision for the students of electrical engineering at SFUC in the form of PBL.

Acknowledgment

The work of Krystian Radlak was supported as parts of the research project BKM/524/RAU1/2014/t.2b.

We would like to thank Mr. Mucsi Csaba for his advice and help in development of the tic-tac-toe playing robot.

References

[1] F. Sistler, "Robotics and intelligent machines in agriculture," *IEEE Journal of Robotics and Automation*, vol. 3, no. 1, pp. 3–6, 1987.
[2] E. Garcia, M. Jimenez, P. De Santos, and M. Armada, "The evolution of robotics research," *IEEE Robotics Automation Magazine*, vol. 14, no. 1, pp. 90–103, 2007.
[3] R. Müller, M. Vette, and M. Scholer, "Inspector robot a new collaborative testing system designed for the automotive final assembly line," *Procedia* {*CIRP*}, vol. 23, no. 0, pp. 59 – 64, 2014, 5th {CIRP} Conference on Assembly Technologies and Systems.
[4] D. Guo, H. Ju, and Y. Yao, "Research of manipulator motion planning algorithm based on vision," in *Sixth International Conference on Fuzzy Systems and Knowledge Discovery*, vol. 5, 2009, pp. 420–425.
[5] J. Rendon-Mancha, A. Cardenas, M. Garcia, E. Gonzalez-Galvan, and B. Lara, "Robot positioning using camera-space manipulation with a linear camera model," *IEEE Transactions on Robotics*, vol. 26, no. 4, pp. 726–733, 2010.
[6] M. Lind, L. Tingelstad, and J. Schrimpf, "Real-time robot trajectory generation with python," in *Workshop on Robot Motion Planning: Online, Reactive and in Real-Time*, 2012, pp. 7–12.
[7] H. A. Hadim and S. K. Esche, "Enhancing the engineering curriculum through project-based learning," in *32nd Annual Frontiers in Education*, vol. 2. IEEE, 2002, pp. F3F–1–F3F–6.
[8] P. K. Hansen, "Does productivity apply to pbl methods in engineering education," *International Journal for Engineering Education*, vol. 19, no. 1, pp. 177–182, 2003.
[9] C. L. Dym, A. M. Agogino, O. Eris, D. D. Frey, and L. J. Leifer, "Engineering design thinking, teaching, and learning," *Journal of Engineering Education*, vol. 94, no. 1, pp. 103–120, 2005.
[10] R. Alba-Flores, F. Rios-Gutierrez, and C. Jeanniton, "Project-based learning approach in a senior level course in autonomous mobile robots," in *Proceedings of IEEE Southeastcon*, 2012, pp. 1–8.
[11] K. Sugimoto, "An approach for engineering education at an early stage," in *Frontiers in Education Conference*, 2014, pp. 1–3.
[12] A. Kokosy, M. Micea, and P. Saey, "A professional project based learning method in mobile robotics," in *Frontiers in Education Conference*, 2014, pp. 1–7.
[13] D. R. Woods, A. N. Hrymak, and H. M. Wright, "Approaches to learning and learning environments in problem-based versus lecture-based learning," in *Proceedings of the 2001 ASEE Annual Conference and Exposition*, 2001, pp. 24–27.
[14] P. Borovska and M. Lazarova, "Efficiency of parallel minimax algorithm for game tree search," in *Proceedings of the 2007 International Conference on Computer Systems and Technologies*, ser. CompSysTech '07. ACM, 2007, pp. 14:1–14:6.
[15] M. Antunes de Lemos and E. Verri Liberado, "Industrial robotics applied to education," in *International Conference on Computer Science and Network Technology*, vol. 4, 2011, pp. 2843–2846.
[16] python-urx library. (Visited on 04/24/2015). [Online]. Available: https://github.com/oroulet/python-urx
[17] Opencv library. (Visited on 04/24/2015). [Online]. Available: opencv.org
[18] Qt library. (Visited on 04/24/2015). [Online]. Available: qt.io
[19] K. Palenta and A. Babiarz, "Kuka robot motion planning using the 1742 ni smart camera," in *Man-Machine Interactions 3*, ser. Advances in Intelligent Systems and Computing. Springer International Publishing, 2014, vol. 242, pp. 115–122.