SOFTWARE FOR THE CONTROL AND MONITORING OF WORK OF A COLLABORATIVE ROBOT

Submitted: 15th July 2021; accepted: 10th December 2021

Wojciech Łabuński, Andrzej Burghardt

DOI: 10.14313/JAMRIS/3-2021/16

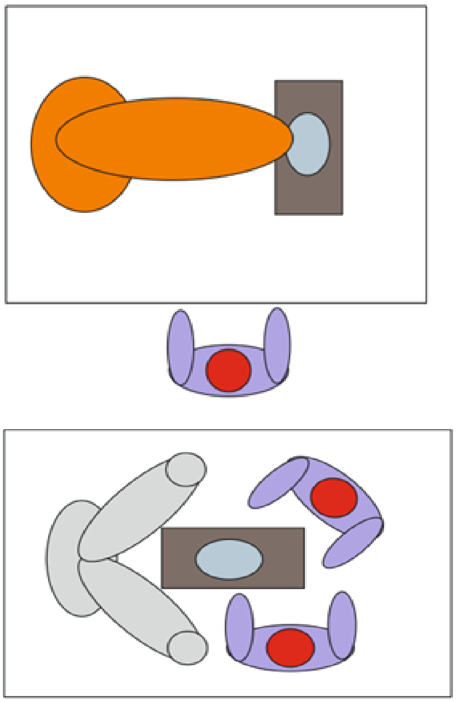
Abstract:
The development of robotic systems is correlated with the development of their software. Expanding robot implementation areas and attempts to replace more and more groups of activities carried out by people requires increasing the degrees of freedom, introducing robot interaction with the environment, and preparing software that manages over six degrees of freedom in a friendly, understandable, ergonomic, and functional manner. The authors proposed a method of programming a collaborative robot with the use of a joystick, created the necessary software, constructed elements of the system, obtaining an original, flexible, and intuitive solution. As part of the work, the proposed solution has been simulated and verified. Verification of the proposed solution was carried out on a real bench equipped with a cobot, Kawasaki duAro.

Keywords: *robotics, collaborative robot, python, joystick, cobot, Kawasaki, duAro*

1. Introduction

As the idea of Industry 4.0 develops, the concept of human-robot collaboration in a production environment is becoming more and more popular. The first and basic criterion that must be met for a robot to be allowed to work with a human is having safety systems that will allow reduction or limitation of the number and degree of dangers that may threaten the operator during cooperation with the machine. A mechanical unit designed for direct interaction with humans in a common workspace can be called a cooperating robot [17]. In the literature we can find the terms "collaborative robot", " cooperating robot" [17, 22, 23] or "cobot" [10]. All these terms are synonyms or abbreviations of the term Collaborative Robot. In this publication, the above terms will be used interchangeably. The growing expansion of collaborative robots in industry creates a growing need to provide appropriate systems that allow planning of the paths of a robot tool and implementation of its movement without hindrance. Allowing robots to work closely with people without using external safety systems, such as fencing, motion sensors, safety mats, magnetic bolts, carries risks for operators and programmers. Unlike working with conventional robots, it is not necessary for the collaborative robot to be located in a space with limited access for the operator. (Fig. 1)

In this work the Kawasaki collaborative robot was used because it was available to the authors and high level of safety can be easily used in teaching programming of industrial robots. The proposed solution is dedicated mainly for educational and presentational purpose.



a)

b)

Fig. 1. Ways of working with robots: a) conventional robot, b) collaborative robot

According to the ISO/TS 15066 technical specification, it should be possible to limit the velocity and power of a robot's drives. Also, the shape and material of the machine have an impact on work safety, some manufacturers install special foam on the robot arms to reduce the impact of the machine on the environment in the event of a collision. Five levels of robot-human cooperation can be distinguished [5, 17]: monitored stop (the robot does not move when the operator is in the cooperation space), manual guidance (the operator manually guides the robot tool), monitoring velocity and distance (the robot moves only when the operator is at a certain distance from it), limiting the power and forces of machine movements (system restrictions introduced in accordance with applicable guidelines). Fig. 2 shows an operator (3) and a collaborative robot (1) working together in a workplace (4) in a space described as (2).

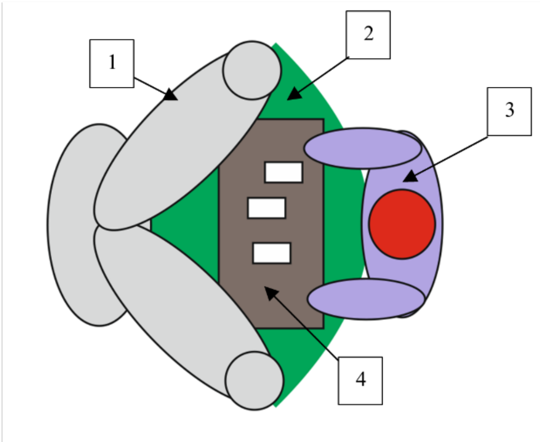


Fig. 2. Collaborative robot cooperation space

An example of cooperation between people and robots in the context of the stability of performed operations and the impact of interaction on stability has been described in [1]. Factors affecting robot-human interaction as well as problems and challenges related to it are described in [6, 7, 8, 10, 11, 14, 23, 27]. Papers [6, 7] describe issues and ways of implementing collaborative robots s in Czech Republic and African industry. Paper [8] presents the results of research on key factors that affect the organization of cooperation between a robot and a human being. One example of using the capabilities of a collaborative robot to facilitate human work is a robotic station for assembling homokinetic joints [10]. An analysis of universally understood physical interaction in tasks requiring cooperation between a robot and an employee was presented in [11]. Paper [14] concerns the problem of ethics in manufacturing stations equipped with industrial robots and collaborative robots. In contrast, paper [23] presents an analysis of robotization problems of small and medium enterprises. The safety of the operator working together with a collaborative robot is analysed in [4, 17, 18, 22, 26, 35]. In paper [17], the author analyses the issue of safety in systems equipped with cooperating robots in the context of industrial standards, among others PN-EN ISO 10218-1, PN-EN ISO 10218-2. Paper [35] presents the provisions of the technical specification ISO/TS 15066. The strategy for the correct assessment of the safety of a robotic system with a cooperating robot, as well as guidelines for the construction of such workstations are included in paper [18]. Analysis of current trends in industry in the context of the safety of robot-human cooperation was carried in paper [22]. The authors of [26] presented two risk analysis paths regarding safety issues for stations with cooperating robots. The use of collaborative robots in an industrial environment is discussed in papers [2, 3, 7, 12, 13, 16, 20, 21, 25, 30, 31, 32, 37, 38]. An example of the use of a robot cooperating with a triangulation sensor for determining the TCP of the robot and the calibration of the tool was presented in [12]. In paper [20], an example system was proposed in which human cooperation with many robots and an algorithm for controlling such a station would occur. Examples of collaborative robots used for assembly lines were presented and analysed in paper [21]. A review of applications for monitoring velocity and separation of the robot from humans in the light of the technical specification ISO/TS 15066 was described in paper [25]. In paper [30], an approach was proposed to estimate the confidence interval for the duration of a robot movement for situations in which space sharing between human and robot is required. In paper [31], the authors analysed practical possibilities and limitations of introducing collaborative robots in various industrial environments. The authors of paper [36] discussed the possibility of introducing collaborative robots into welding applications. An example of symbiotic cooperation between a robot and a human in an environment with a proprietary interface was presented in paper [38]. The issues of employee confidence in industrial robots, especially collaborative robots, were described in paper [9]. In papers [19, 29] authors discussed problems and possibilities of analysing and monitoring parameters and operations of industrial robots – in standard [19] and virtual environment [29]. Trust has been identified as one of the key factors affecting proper robot-human cooperation. Research has been carried out to determine how and when employees and machine operators build trust in industrial robots. A mathematical model of robot-human cooperation can be found in paper [28], the use of Python language in robotic applications is presented in papers [24, 33], and paper [34] describes the use of the pygame module for communication with a joystick.

There are many solutions that allow programming of industrial robots in online mode. One of the most popular of these is the manual programmer that acts as a peripheral device. It allows control of movements as well as creation of programs and monitoring of the robot's work parameters. The manual programmer is available in the product range of most robot producers: ABB, Kuka, Fanuc. Alternative solutions that are worth paying attention to are, for example, a touch screen tablet from the company Universal Robots. Some manufacturers allow control of the movement of a robot from the level of their programming and simulation environments, for example ABB and Kawasaki. However, most often such control is unwieldy and inconvenient for the programmer. Kawasaki software enables this option from the HyperTerminal level. It only allows the setting of a defined point in space or a specific angle of rotation of the axis. The Kawasaki duAro robot does not have in its basic equipment any peripheral devices enabling manual control over the movement of the robot during manual steering. Hence the need to prepare a system that could act as a manual controller with simultaneous monitoring of some robot operating parameters. The article proposes a solution using a two-axis joystick and a window application to communicate with the joystick with a robot controller. Analysis of the available literature has shown that similar proprietary solutions used to control the movement of robots, especially cooperating robots, are not found, and the subject matter brings a new view on manual steering of industrial robots.

2. Description of Workstation

The workstation with a collaborative robot (Fig. 3) used in the work is intended for educational demonstrations and development of robot programming skills. To facilitate control of the robot and memorizing points, and thus enable simpler planning of algorithms and carrying out pick and place operations, it was decided to add a joystick to the station. It plays the role of a manual robot controller, enabling steering and control of the movement of the individual arms of the collaborative robot.

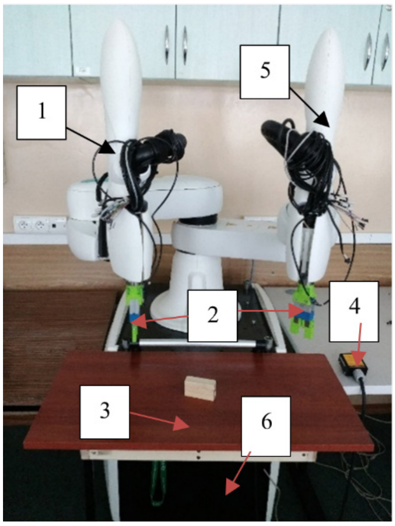


Fig. 3. Elements of a workstation with a collaborative robot

The workstation with a collaborative robot (Fig. 3) consists of a Kawasaki duAro robot and a test platform in the manipulator workspace. It is a two-armed robot designed to work with humans in industrial conditions. It consists of two arms (left - (1) and right - (5)) designed based on a SCARA robot. The parallel structure of the arms allows for high velocities of the mechanism. Each arm is equipped with a pneumatic gripper (2). The test platform (3) has been designed in such a way that it is connected to the robot base and rigid enough to maintain a constant level. The robot is controlled by means of a controller (6) equipped with the Cubic S option – a unit monitoring the movement of the robot and responsible for ensuring safety. The manufacturer equipped the robot with an external panel (4) that allows the brakes to be deactivated, which enables manual movement of the third axis of each arm.

Identical tools were mounted on both arms (Fig. 4). Each of them consists of a mounting (1), pneumatic gripper (2) and gripper fingers (3). Both the mounts and fingers were manufactured by the incremental method of ABS material.

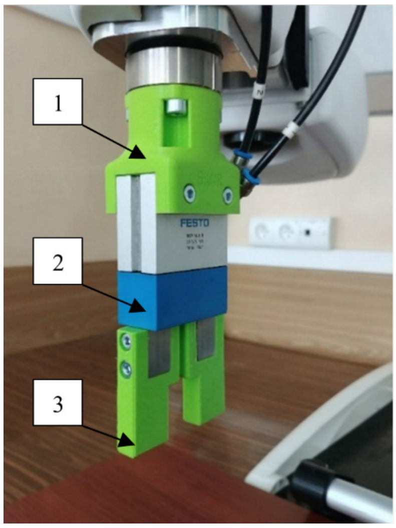


Fig. 4. Gripper

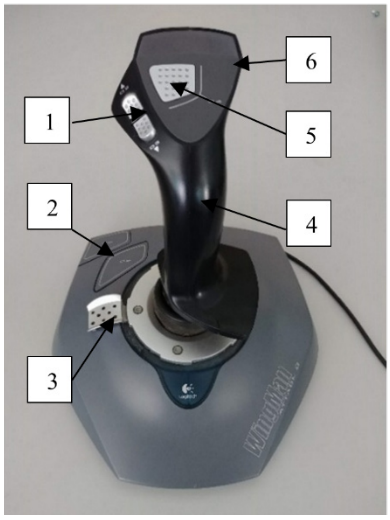
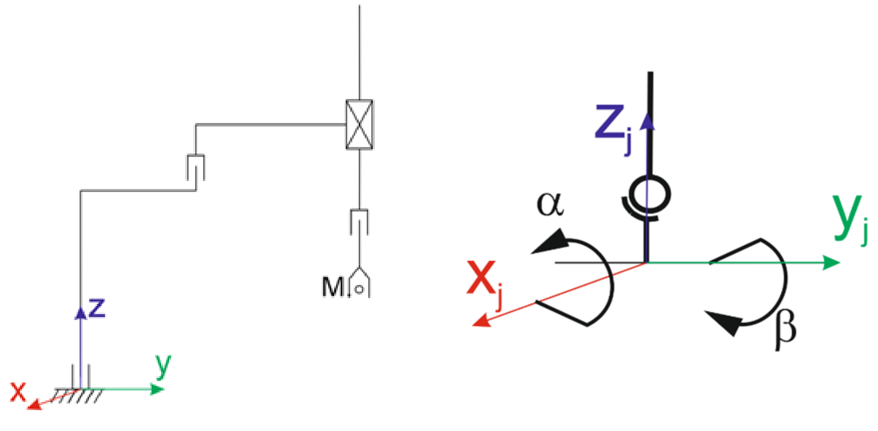


Fig. 5. Joystick

A joystick was used to control individual movements of the selected robot arm and to switch between selected motion control options (Fig. 5).

Fig. 6 presents kinematic diagrams and the way in which the movements of the robot in the appropriate coordinate systems were mapped using the joystick movement. The movement of the M point associated with the robot tool was implemented in the robot's base system - xyz. The coordinate system in the base of the joystick was adopted analogously and marked with xjy¬¬jzj. Tilting the controller in the direction of the selected axis resulted in the movement of point M along the corresponding axis of the robot system. For example, movement of the joystick by angle α in the positive direction of the y axis corresponded to the movement of point M in the positive direction of the y axis. Movement of point M in the direction of the z axis was transmitted using the slider (3) shown in Fig. 5.

Movement in the basic Cartesian system was implemented by means of tilts along two joy-stick axes (4) – axes xj and yj (Fig. 6b) and two buttons (1) responsible for the tool configuration (two-way rotation). In addition, it provides the ability to control the movement of the TCP point along the z axis (3) and arm selection (2). To operate the gripper, the trigger button on the back of the joystick (6) was used. It is also possible to select the currently used arm (2). Closing the connection between the joystick and the robot controller is ensured by means of a button (5). Thanks to this, the operator has full control over the movement of each of the robot arms.



a) b)

Fig. 6. Kinematic diagram: a) duAro robot arm, b) joystick

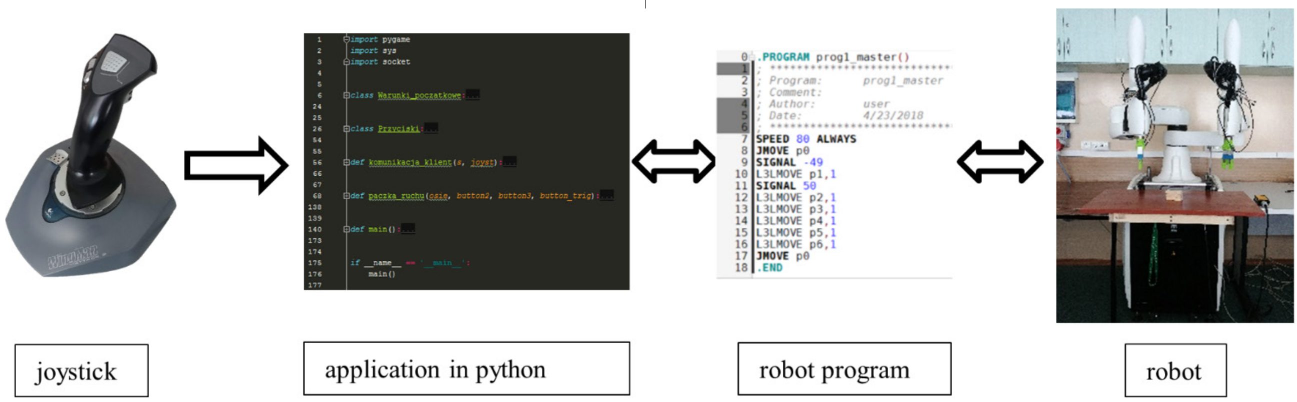


Fig. 7. Information flow in the cooperating robot control system

Tab. 1. Data frame elements

No.	Name of the variable	Number of characters	Value	Purpose
1.	robot_arm	2	"A1" or "A2"	arm number
2.	interpolation	1	"J" or "B"	junction and linear interpolation
3.	horizontal_direction	2	"-1" or "+1" or "+0"	horizontal joystick deflection
4.	vertical_direction	2	"-1" or "+1" or "+0"	vertical joystick deflection
5.	string_direction_z	3	from 000 to 100	tool vertical axis direction
6.	rotation	2	"-1" or "+1" or "+0"	tool orientation
7.	velocity	3	from 000 to 100	robot TCP velocity in the base system
8.	tool	1	"0" or "1"	gripper state – open / closed
9.	S	1	"S"	end of frame sign

3. Description

Using an existing robotized station equipped with a Kawasaki duAro collaborative robot, a work control system was prepared using the joystick to manipulate. The window application controlled and monitored the robot's operation, simultaneously recording information about the status of the joystick. The processed data were sent to the robot controller using the TCP/IP protocol, where, after interpretation by the robot software, they ensured movement of the selected robot arm. Despite the limited number of joystick buttons, control over the collaborative robot was obtained.

3.1. Communication

Communication between the joystick and the collaborative robot was prepared using the TCP/IP protocol and a PC. Data flow is from the joystick to the application, which forwards it to the robot controller. There, individual data is interpreted and translated into the appropriate robot motion. Part of the information is also passed the other way: from the robot to the application. The user can monitor and change the velocity of the TCP point of the currently operating arm (Fig. 7). The information was sent in the form of a data frame. This was a nine-element vector consisting of characters depicted in ASCII code. Each element of this structure had a clear interpretation. They are presented in Tab. 1. together with the function they perform, the values they can take, and the number of characters reserved for a given variable. The total number of characters sent from the application to the robot controller is 17. The data frame was transferred to the robot controller during the robot's operation. Fig. 7 schematically illustrates the flow of information in an industrial robot control system.

3.2. Control of Robot Arm – Kawasaki Program

Kawasaki the manufacturer of duAro robot enables programming of its devices using the AS language dedicated for this purpose. It is robot programming language consisting of two groups of instructions – one for motion of the arms and another for other purposes like operating signals, for and while loops etc. All commands and functions are entered using the terminal from a computer (Fig. 8a). It allows, among others, for access to the robot controller memory and data stored on it, as well as for direct control and monitoring of arm movement. Robot communication with the terminal is carried out using the TCP/IP protocol using commands in the ASCII code. The application that facilitates writing programs for Kawasaki robots is KIDE (Kawasaki Robotics Integrated Development Environment) (Fig. 8b). It is additional application which can help with controlling a robot and its programs. It is not necessary for creating and realizing robot programs, but it is helpful when comes to management of larger portions of code and more complex schemes of action.

The graphic interface allows for simpler management of programs, variables in the controller's memory, and a text editor adapted to the AS language syntax allows faster writing of programs and debugging of prepared code. It can also help to create motion programs and robot points in a workspace, define motion and process parameters and manage program variables, databases, and input/output signals. The software helps also with monitoring performance of a machine and saving and analysing error logs.

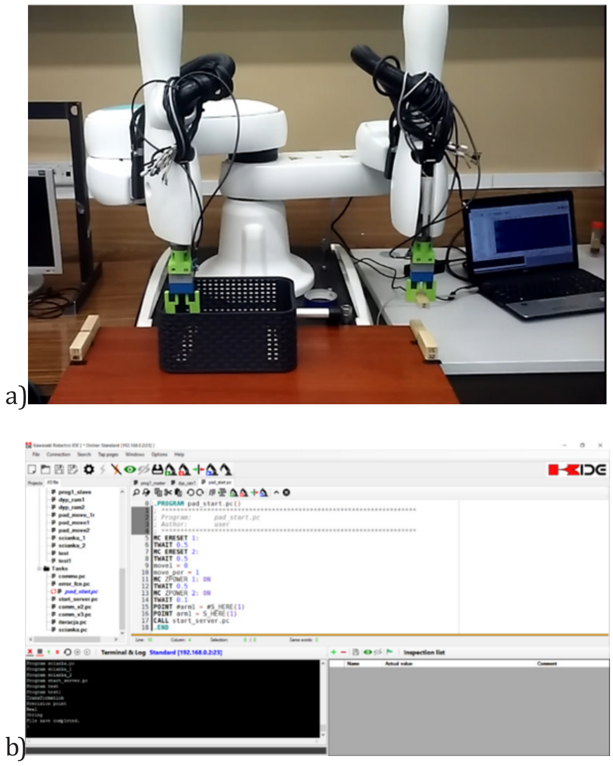


Fig. 8. The robot program was prepared on the workstation (a) using the KIDE application (b)

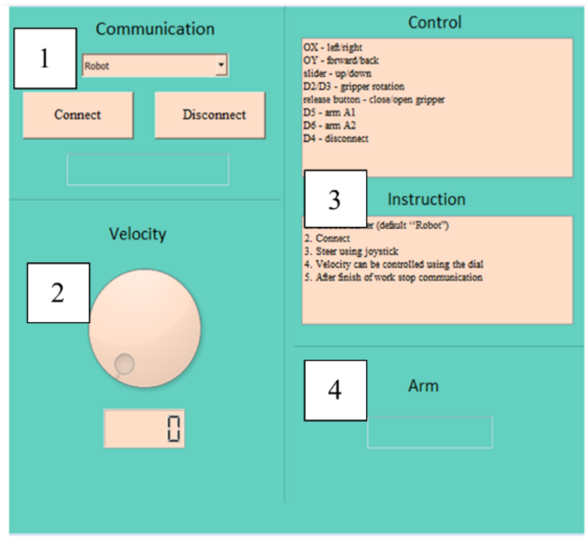


Fig. 9. Application for robot control using a joystick

3.3. Application for Joystick – Robot and Communication

To solve the problem of control over robot movements, a joystick connected to a PC was used. A window application was prepared to act as a joystick controller and a server that supports data exchange between the joystick and the collaborative robot. Full use of the joystick functionality was possible thanks to the Python language and the pygame library available to it.

To improve the programming process implemented in Python, the option of creating function definitions and saving them in a separate file was used. Such a file is called a module. Its content can be loaded into another module or into a program. One of the useful Python modules is pygame. It allows the programmer to access peripheral devices (such as joystick, pad, speakers etc.) from the Python language, which can be used, for example, as a computer game control. The pygame module is based on the cross-platform SDL (Simple DirectMedia Layer) library, which gives access to hardware thanks to OpenGL and DirectX technologies. The graphic interface of the collaborative robot control application was prepared using Qt libraries available for the Python language. These are libraries for designing graphical user interfaces. They were created for C++ and Java, but it is possible to create applications using other popular languages such as Ruby, C# or Python.

The application window was divided into four parts (Fig. 9). In the first part (1), the user has the option to choose how the application will communicate with external devices. Real workstation control is enabled by the "Robot" option, while the "Computer" option using a local connection can be used for offline testing. The limited number of buttons and joystick sliders caused the necessity to add a robot velocity control option in a second area (2). Due to the assumption that the robot arm will be moved in linear interpolation, in the base coordinate system the robot velocity is the TCP velocity of the selected arm expressed in the range from 0% to 100%. The current percentage value was displayed below the dial. Part three (3) contains user information and operating instructions for the joystick-robot system. In contrast, part 4 provided information on which robot arm is currently being controlled.

The use of the pygame library made it easy to implement joystick control and combine its individual elements with specific robot features. The socket library made it easy to use the TCP/IP protocol to receive and transfer data between the computer and the robot. Appropriate variables in the program were assigned to individual degrees of freedom of the controller and its buttons.

4. Validation Tests

Validation tests (Fig. 10) were carried out on a real object confirming the correct operation of the system. The workstation was prepared by combining a collaborative robot, a computer, and a joystick. As expected, the TCP/IP protocol proved to be a sufficient means of communication for exchanging information between individual station elements. The software of individual robot functions and enabling them to be associated with joystick movements and its buttons significantly facilitated the programming of robot movements. In further work, the proposed solution can be expanded with the option of remembering the position of the tool. In addition, the presented solution is universal and easily adaptable to the robots of other manufacturers. After applying additional safety measures, such as fencing, they can also be used in work with industrial robots not adapted to work with humans.

Fig. 10. Verification of the prepared application

5. Conclusion

The paper presents a proposal for software intended for controlling a collaborative robot implemented using a joystick. Analysis of the available literature allows us to state that similar solutions are not used. As part of the work, a Kawasaki duAro collaborative robot controller was connect-ed to a joystick using the TCP/IP protocol. Python language and available modules were used, which greatly facilitated the operation of individual joystick functions. A window application was developed using the Qt library. The graphical user interface allows easy connection of the joystick and robot with simultaneous monitoring of operating parameters. The solution prepared in this way fulfilled its task and allowed control of the robot's movements with the help of a joystick. The next stage of the work will be connecting an external vision system to carry out an assembly operation.

AUTHORS

Wojciech Łabuński* – Faculty of Mechanical Engineering and Aeronautics, Rzeszow University of Technology, Poland, e-mail: w.labunski@prz.edu.pl.

Andrzej Burghardt* – Faculty of Mechanical Engineering and Aeronautics, Rzeszow University of Technology, Poland, e-mail: andrzejb@prz.edu.pl.

*Corresponding author

REFERENCES

[1] A. Ajoudani, A. M. Zanchettin, S. Ivaldi, A. Albu-Schäffer, K. Kosuge and O. Khatib, "Progress and prospects of the human–robot collaboration", *Autonomous Robots*, vol. 42, no. 5, 2018, 957–975, 10.1007/s10514-017-9677-2.

[2] Y. Aydin, D. Sirintuna and C. Basdogan, "Towards collaborative drilling with a cobot using admittance controller", *Transactions of the Institute of Measurement and Control*, vol. 43, no. 8, 2021, 1760–1773, 10.1177/0142331220934643.

[3] R. Bejarano, B. R. Ferrer, W. M. Mohammed and J. L. Martinez Lastra, "Implementing a Human-Robot Collaborative Assembly Workstation". In: *2019 IEEE 17th International Conference on Industrial Informatics (INDIN)*, 2019, 557–564, 10.1109/INDIN41052.2019.8972158.

[4] Z. M. Bi, C. Luo, Z. Miao, B. Zhang, W. J. Zhang and L. Wang, "Safety assurance mechanisms of collaborative robotic systems in manufacturing", *Robotics and Computer-Integrated Manufacturing*, vol. 67, 2021, 10.1016/j.rcim.2020.102022.

[5] B. Matthias, "ISO/TS 15066 - Collaborative Robots - Present Status", https://www.researchgate.net/publication/282809861_ISOTS_15066_-_Collaborative_Robots_-_Present_Status. Accessed on: 2022-03-28.

[6] T. Broum and M. Šimon, "Preparation of Collaborative Robot Implementation in the Czech Republic". In: *Proc. of the International Conference on Industrial Engineering and Operations Management*, 2019.

[7] A. P. Calitz, P. Poisat and M. Cullen, "The future African workplace: The use of collaborative robots in manufacturing", *SA Journal of Human Resource Management*, vol. 1, no. 2, 2017, 10.4102/sajhrm.v15i0.901.

[8] G. Charalambous, S. Fletcher and P. Webb, "Identifying the key organisational human factors for introducing human-robot collaboration in industry: an exploratory study", *The International Journal of Advanced Manufacturing Technology*, vol. 81, 2015, 2143–2155, 10.1007/s00170-015-7335-4.

[9] G. Charalambous, S. Fletcher and P. Webb, "The Development of a Scale to Evaluate Trust in Industrial Human-robot Collaboration", *International Journal of Social Robotics*, vol. 8, no. 2, 2016, 193–209, 10.1007/s12369-015-0333-8.

[10] A. Cherubini, R. Passama, A. Crosnier, A. Lasnier and P. Fraisse, "Collaborative manufacturing with physical human–robot interaction", *Robotics and Computer-Integrated Manufacturing*, vol. 40, 2016, 1–13, 10.1016/j.rcim.2015.12.007.

[11] A. De Santis, B. Siciliano, A. De Luca and A. Bicchi, "An atlas of physical human–robot interaction", *Mechanism and Machine Theory*, vol. 43, no. 3, 2008, 253–270, 10.1016/j.mechmachtheory.2007.03.003.

[12] G. B. de Sousa, A. Olabi, J. Palos and O. Gibaru, "3D Metrology Using a Collaborative Robot with a Laser Triangulation Sensor", *Procedia Manufacturing*, vol. 11, 2017, 132–140, 10.1016/j.promfg.2017.07.211.

[13] S. El Zaatari, M. Marei, W. Li and Z. Usman, "Cobot programming for collaborative industrial tasks: An overview", *Robotics and Autonomous Systems*, vol. 116, 2019, 162–180, 10.1016/j.robot.2019.03.003.

[14] S. R. Fletcher and P. Webb, "Industrial Robot Ethics: The Challenges of Closer Human Collaboration in Future Manufacturing Systems". In: M. I. Aldinhas Ferreira, J. Silva Sequeira, M. O. Tokhi, E. E. Kadar and G. S. Virk (eds.), *A World with Robots: International Conference on Robot Ethics: ICRE 2015*, 2017, 159–169, 10.1007/978-3-319-46667-5_12.

[15] J. Fryman and B. Matthias, *Safety of Industrial Robots: From Conventional to Collaborative Applications*, ROBOTIK 7th German Conference on Robotics. VDE, 2012.

[16] F. Gil-Vilda, A. Sune, J. A. Yagüe-Fabra, C. Crespo and H. Serrano, "Integration of a collaborative robot in a U-shaped production line: a real case study", *Procedia Manufacturing*, vol. 13, 2017, 109–115, 10.1016/j.promfg.2017.09.015.

[17] M. Głowicki, "Coboty – zagadnienia bezpieczeństwa przy integracji robotów współpracujących", *Napędy i Sterowanie*, vol. 19, no. 4, 2017, (in Polish).

[18] S. Grahn, K. Johansson and Y. Eriksson, "Safety Assessment Strategy for Collaborative Robot Installations". In: H. Canbolat (eds.), *Robots Operating in Hazardous Environments*, 2017, 10.5772/intechopen.69375.

[19] B. Jakubiec, "Virtual environment as a tool for analysing the operation of an industrial robot", *PRZEGLĄD ELEKTROTECHNICZNY*, vol. 1, no. 2, 2020, 100–103, 10.15199/48.2020.02.23.

[20] K. Kosuge, H. Yoshida, D. Taguchi, T. Fukuda, K. Hariki, K. Kanitani and M. Sakai, "Robot-human collaboration for new robotic applications". In: *Proc. of IECON'94 - 20th Annual Conference of IEEE Industrial Electronics, Control and Instrumentation*, 1994, 713–718, 10.1109/IECON.1994.397872.

[21] J. Krüger, T. K. Lien and A. Verl, "Cooperation of human and machines in assembly lines", *CIRP Annals*, vol. 58, no. 2, 2009, 628–646, 10.1016/j.cirp.2009.09.009.

[22] J. Kulik and Ł. Wojtczak, "Safe human-robot interaction - a real need or a temporary trend among domestic SMEs", *Pomiary Automatyka Robotyka*, vol. 22, no. 1, 2018, 67–74, 10.14313/PAR_227/67, (in Polish).

[23] J. Kulik and Ł. Wojtczak, "World Trends in Robotics and Technical Challenges of Polish SME's", *Pomiary Automatyka Robotyka*, vol. 19, no. 4, 2015, 79–86, 10.14313/PAR_218/79, (in Polish).

[24] K. Kurc, A. Burghardt, D. Szybicki, P. Gierlak, W. Łabuński, M. Muszyńska and J. Giergiel, "Robotic machining in correlation with a 3D scanner", *Mechanics and Mechanical Engineering*, vol. 24, no. 1, 2020, 36–41, 10.2478/mme-2020-0003.

[25] J. A. Marvel and R. Norcross, "Implementing speed and separation monitoring in collaborative robot workcells", *Robotics and Computer-Integrated Manufacturing*, vol. 44, 2017, 144–155, 10.1016/j.rcim.2016.08.001.

[26] B. Matthias, S. Kock, H. Jerregard, M. Kallman and I. Lundberg, "Safety of collaborative industrial robots: Certification possibilities for a collaborative assembly robot concept". In: *2011 IEEE International Symposium on Assembly and Manufacturing (ISAM)*, 2011, 1–6, 10.1109/ISAM.2011.5942307.

[27] J. E. Michaelis, A. Siebert-Evenstone, D. W. Shaffer and B. Mutlu, "Collaborative or Simply Uncaged? Understanding Human-Cobot Interactions in Automation". In: *Proc. of the 2020 CHI Conference on Human Factors in Computing Systems*, 2020, 1–12, 10.1145/3313831.3376547.

[28] S. Nikolaidis, J. Forlizzi, D. Hsu, J. Shah and S. Srinivasa, "Mathematical Models of Adaptation in Human-Robot Collaboration", *arXiv:1707.02586 [cs]*, 2017, 10.48550/arXiv.1707.02586.

[29] P. Obal, A. Burghardt, K. Kurc, D. Szybicki and P. Gierlak, "Monitoring the Parameters of Industrial Robots". In: R. Hanus, D. Mazur and C. Kreischer (eds.), *Methods and Techniques of Signal Processing in Physical Measurements*, vol. 548, 2019, 230–238, 10.1007/978-3-030-11187-8_19.

[30] S. Pellegrinelli, F. L. Moro, N. Pedrocchi, L. Molinari Tosatti and T. Tolio, "A probabilistic approach to workspace sharing for human–robot cooperation in assembly tasks", *CIRP Annals*, vol. 65, no. 1, 2016, 57–60, 10.1016/j.cirp.2016.04.035.

[31] Z. Pilat, W. Klimasara, M. Pachuta, M. Słowikowski, M. Smater and J. Zieliński, "Possibilities of practical introduction of colaborative robots in various manufacturing technologies implemented in an industrial environment", *Pomiary Automatyka Robotyka*, vol. 22, no. 1, 2018, 59–65, 10.14313/PAR_227/59, (in Polish).

[32] Z. Pilat, W. Klimasara, M. Pachuta and M. Słowikowski, "Some New Robotization Problems Related to the Introduction of Collaborative Robots into Industrial Practice", *Journal of Automation, Mobile Robotics and Intelligent Systems*, 2019, 91–97, 10.14313/JAMRIS/4-2019/42.

[33] A. Piotrowski, "An Analysis of the use of the Python Language in Robot Applications", *Applied Computer Science*, vol. 12, no. 2, 2016, 5–21.

[34] K. A. Radhika, B. L. Raksha, B. R. Sujatha, U. Pruthviraj and K. V. Gangadharan, "IoT Based Joystick Controlled Pibot Using Socket Communication". In: *2018 IEEE Distributed Computing, VLSI, Electrical Circuits and Robotics (DISCOVER)*, 2018, 121–125, 10.1109/DISCOVER.2018.8674130.

[35] M. J. Rosenstrauch and J. Kruger, "Safe human-robot-collaboration-introduction and experiment using ISO/TS 15066". In: *2017 3rd International Conference on Control, Automation and Robotics (ICCAR)*, 2017, 740–744, 10.1109/ICCAR.2017.7942795.

[36] M. Safeea, R. Bearee and P. Neto, "End-Effector Precise Hand-Guiding for Collaborative Robots". In: A. Ollero, A. Sanfeliu, L. Montano, N. Lau and C. Cardeira (eds.), *ROBOT 2017: Third Iberian Robotics Conference*, 2018, 595–605, 10.1007/978-3-319-70836-2_49.

[37] P. Skrobek and A. Rogowski, "Direct human-robot collaboration in welding", *Welding Technology Review*, vol. 90, no. 1, 2018, 10.26628/wtr.v90i1.847, (in Polish).

[38] X. V. Wang, Z. Kemény, J. Váncza and L. Wang, "Human–robot collaborative assembly in cyber-physical production: Classification framework and implementation", *CIRP Annals*, vol. 66, no. 1, 2017, 5–8, 10.1016/j.cirp.2017.04.101.