IOSUD - University Polytechnic Timisoara
Doctoral School of Engineering Studies

UNCONVENTIONAL SYSTEM TO CONTROL INDUSTRIAL ROBOTS

Doctoral Thesis - Abstract

for obtaining the scientific title of doctor at
Polytechnic University of Timisoara
in the field of mechanical engineering doctorate

author eng. Robert KRISTOF
scientific leader Prof. univ. dr. eng. Innocent MANIU

month 09 year 2023

CHAPTER 1 – INTRODUCTION

This chapter explores the concept of robots and robotics, beginning with the origin of the term "robot" in 1920, when the Czech writer Karel Čapek introduced it in the play "Rossumovi Univerzální Roboti (RUR)". The term "rabota" was used to describe fictional humanoid characters [1]. Although Karel Čapek is commonly associated with coining the term, the real inventor is believed to be his brother, Josef Čapek [2], [3]. Robots are defined as reprogrammable multifunctional manipulators, used in various fields, especially in production, due to the increase in productivity they bring [4]. Robotics is described as the art and knowledge associated with the design, application and use of robots in human endeavours, combining elements of mechanics, electronics and computer science [5]. Robotic systems are seen as complex production automation technologies with the advantage of eliminating manual labor and responding to market needs.[6]

Asimov's laws were introduced in fiction and influenced the development of ethics in the development of artificial intelligence, representing a starting point for research in this field.

The section also addresses the evolution of industrial robotic systems, highlighting advances in robot driving technology and their importance in manufacturing. The discussion extends to the classification of robots, covering the classification variants proposed by different authors and organizations. It then goes on to detail industrial robots, highlighting their advantages and disadvantages. Advantages include low production costs, superior product quality, space efficiency and work safety, while high initial investment and labor impact are considered disadvantages.

The chapter continues by presenting statistics on annual installations of industrial robots in different regions and fields of activity. A significant increase in installations is seen in the year 2021, with China dominating the top countries with the most industrial robot installations [7]. The COVID-19 pandemic has significantly influenced the deployment of robots, with some countries accelerating their adoption, while others have had negative developments.

This section provides a comprehensive overview of the evolution and impact of robots and robotics in various fields and regions.

CHAPTER 2 - THE CURRENT STAGE IN THE FIELD OF CONTROLLING INDUSTRIAL ROBOTS

This chapter focuses on analyzing and presenting the different ways in which industrial robots can be controlled using a variety of devices and technologies. In a world of ever-evolving technology, researchers and developers have explored more options to enable human operators to interact with industrial robots in a more intuitive and efficient way.

One of the control modes is through teach pendants (Fig. 1). These consoles are used to program and guide the robots. In recent years, teach pendants have evolved considerably, offering more user-friendly interfaces such as icon-based programming, color touch screens, and 3D joysticks. Industrial robot manufacturers have even developed projects aimed at using touchscreens and voice recognition to facilitate robot programming, allowing users to program robots without advanced programming or robotics knowledge.[8]

Fig. 1– KUKA KR15 mobile teach pendant

Another device under review is the Microsoft Kinect, which uses depth sensors and gesture recognition to detect the movements and actions of human operators. This device was originally created for the gaming industry, but has also been adapted to control industrial robots. The images captured by the Kinect can be processed to detect objects and determine their positioning, thus enabling precise control of robots [9], as shown in Fig. 2.

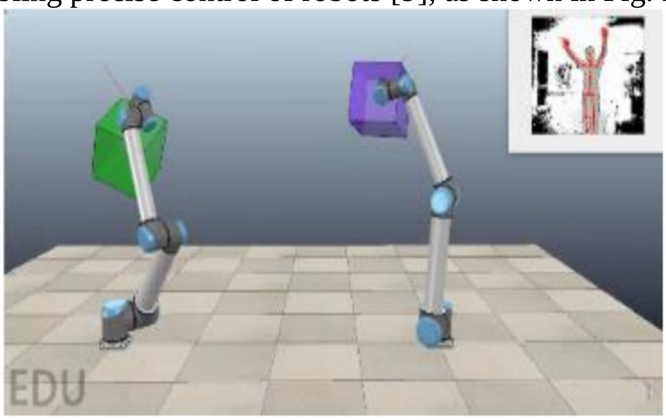

Fig. 2- Manipulation of cubes with the help of Microsoft Kinect v2[10]

Mobile phones have also become powerful devices for controlling industrial robots. With the accelerometers and touch screens of these devices, users can control the movements of the robots by moving the phone or via virtual buttons on the screen [11]. This approach has been successfully adapted for various industrial robot control applications as seen in Fig. 3.

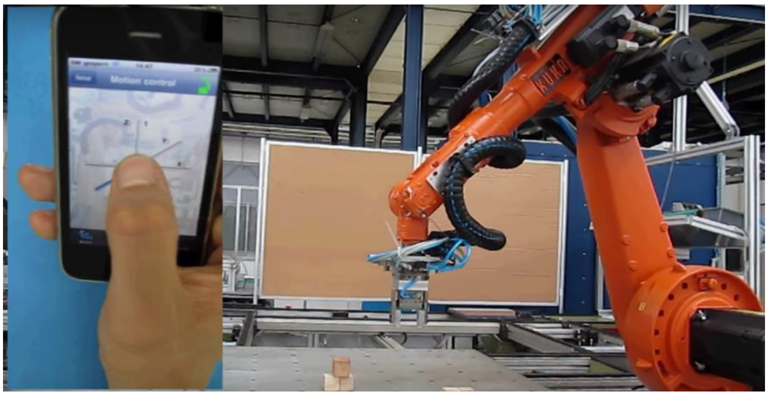

Fig. 3- Industrial robot controlled with the mobile phone accelerometer[12]

Joysticks and gamepads, common in computer games, are other devices analyzed for controlling robots. They can provide precise control over robot movements, giving human operators a game-like experience as can be seen in Fig. 4.

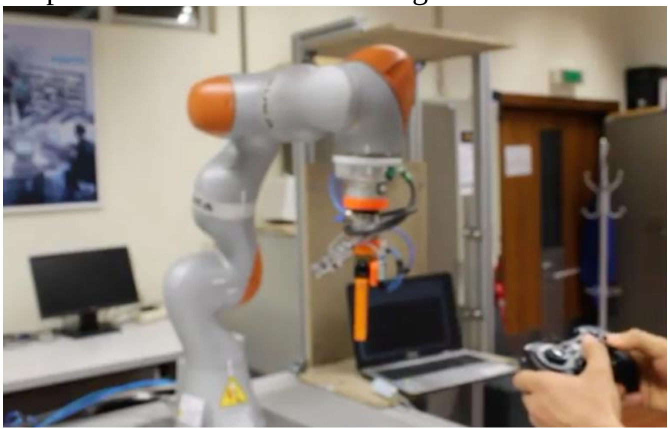

Fig. 4- Industrial robot controlled by means of a gamepad[13], [14]

Leap Motion (Fig. 5) is a device specialized in gesture recognition. It can detect hand and finger movements, allowing operators to control industrial robots through a series of predefined gestures.[15]

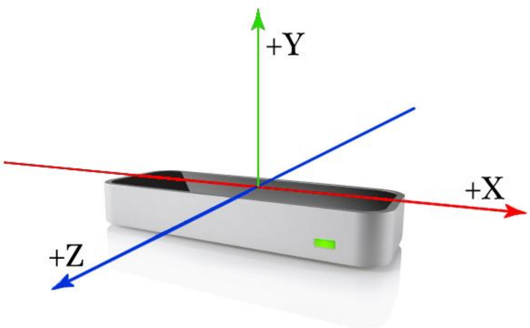

Fig. 5– Leap Motion [15]

Finally, the Myo Armband (Fig. 6) is another interesting device that uses muscle activity to control robots. By wearing the Myo wristband on the forearm, operators can generate gestures and commands through electromyography signals.[16]

Fig. 6- Myo Armband

Thus, this chapter explores a wide range of methods and technologies for industrial robot control, providing insight into the diversity and innovations in this field.

CHAPTER 3 - THE PROPOSED SOLUTION AND RESEARCH STAGES

This chapter focuses on the proposed solution for controlling an industrial robot using the Myo Armband, as well as the research steps associated with this process.

Devices used:

3.1. KUKA KR15 industrial robot (Fig. 7): This is a robot with 6 axes and an articulated structure with a payload of 15 kg. Capable of performing a variety of movements within a defined workspace, the KUKA KR15 robot has various applications in fields such as aerospace, automotive, electronics, food and metalworking.[17]

Fig. 7– KUKA KR15

3.2. Myo Armband (Fig. 8): Made by Thalmic Labs, this armband allows for gesture control of various objects. It detects electrical impulses in the muscles of the forearm to interpret movements and gestures. With a variety of sensors and processors, the armband can be used to control various devices and applications, being compatible with PCs and games.[18]

Fig. 8- Myo Armband

3.3. Universal Robots UR10e (Fig. 9): This is a collaborative robot (cobot) developed by Universal Robots. The UR10e model has a payload of 12.5 kg and focuses on human assistance in industrial processes.[19]

Fig. 9- Universal Robots UR10e

The proposed solution involves the development of a control system for an industrial robot using the Myo Armband. This brings significant innovation by being able to save positions and generate programs for the robot, all through wrist gestures. This opens up extensive possibilities for using industrial robots without requiring advanced programming knowledge.

The proposed research consists of several stages:

- Myo Armband integration testing: Checking the connection of the armband with other devices and testing its functionality.
- Controlling the KUKA KR15 robot: The possibility of controlling the KUKA KR15 robot using the Myo Armband on Cartesian coordinates is explored.
- UR10e Robot Control: Extends research to control Universal Robots' UR10e robot using the Myo wristband.
- Analysis and Experiments: The behavior of the two robots in terms of control with the Myo Armband is compared and the results are analyzed to determine the effectiveness and usefulness of the solution.

The objectives of the research are:

O1. Making an efficient control system: Creating a control system for industrial robots that enables smooth and seamless movements using the Myo Armband.
O2. Time and accuracy evaluation: Testing the system to evaluate how quickly and accurately the robot can be controlled using the Myo Armband compared to traditional methods.
O3. Collecting feedback from users: Surveying users to collect opinions and impressions about the efficiency and ease of use of the solution.
O4. Analysis of Results: Examination of data obtained from tests and questionnaires to determine which of the two control devices (Myo Armband or teach pendant) is more effective in controlling industrial robots.

This chapter provides a detailed insight into the proposed solution and how the research was structured and implemented to achieve the stated objectives.

CHAPTER 4 – EVALUATION OF THE OPTIMAL SOLUTION

This chapter deals with the evaluation of the optimal solution for connecting the Myo Armband with industrial robots, highlighting the application of this technology in the control of robotic movements. The chapter focuses on three different applications of the Myo Armband technology: connecting with a mobile robot, connecting with a KUKA KR15 industrial robot, and connecting with a Universal Robots UR10e collaborative robot.

4.1 Myo Armband application with Arduino (Fig. 10):

In this application, a solution was developed to test the capabilities of the Myo wristband by controlling a mobile robot on the Arduino platform. The system includes a mobile robot, an Arduino Uno board, and an L298 motor driver. Through the Bluetooth connection between the Myo Armband and a laptop computer, the gesture signals are interpreted and transmitted to the Arduino. It commands the motor driver to control the movement of the robot according to the function by the detected gestures.[20]

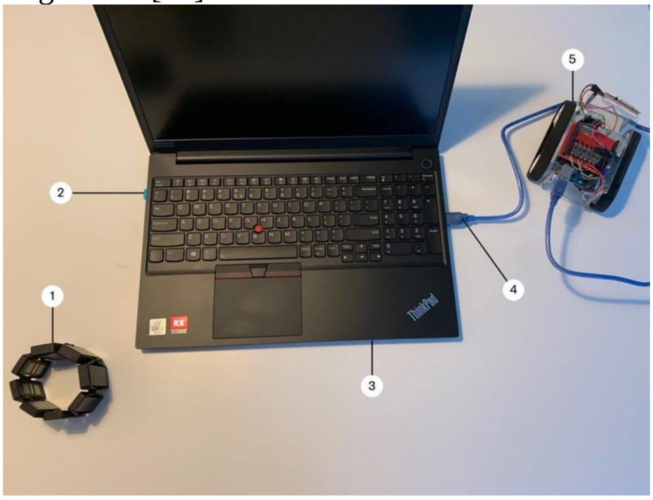

Fig. 10- Myo Armband application with Arduino[20]

4.2. Myo application with KUKA KR15 industrial robot (Fig. 11):

This app explores connecting the Myo Armband to a KUKA KR15 industrial robot. The Myo Armband is connected to a handheld computer via Bluetooth, and the computer transmits positioning and orientation commands to the KUKA KR15 robot via a serial cable. Through the gestures interpreted by the Myo wristband, the operator controls the industrial robot in a series of movements.[21]

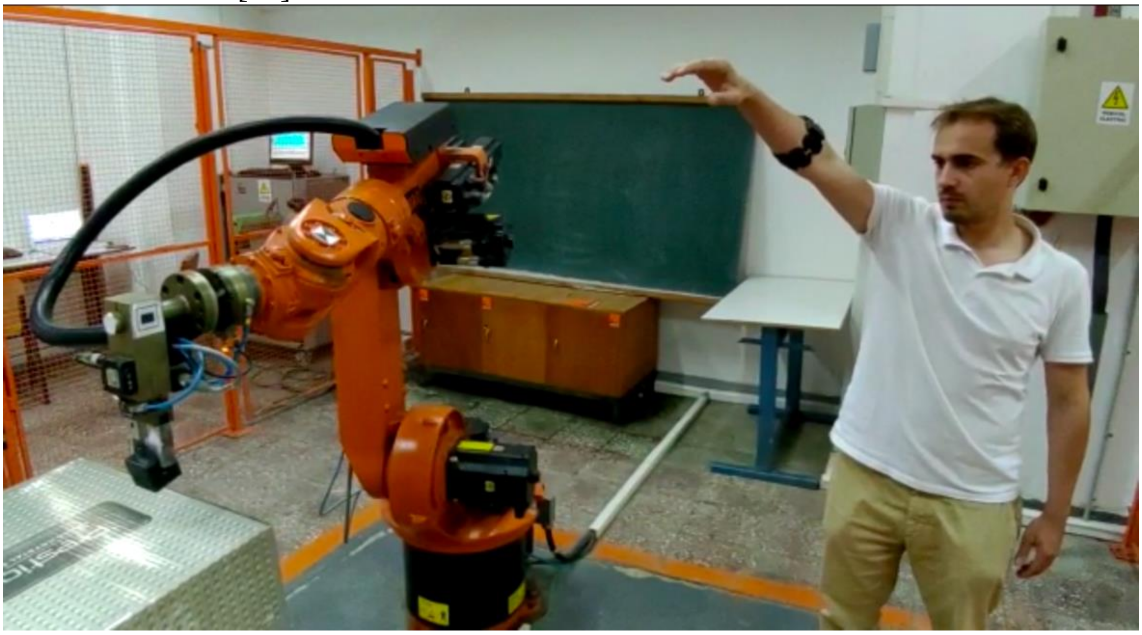

Fig. 11- Myo Armband application on KUKA KR15[21]

4.3 Dual Myo application – KUKA KR15 (Fig. 12):

This app adds another dimension of control by using two Myo Armbands in connection with the KUKA KR15 industrial robot. The first armband is responsible for the positioning coordinates, while the second armband handles the orientation of the robot. However, the experiment highlighted the difficulties of controlling six coordinates at the same time and the problems associated with bodily connections between arms.

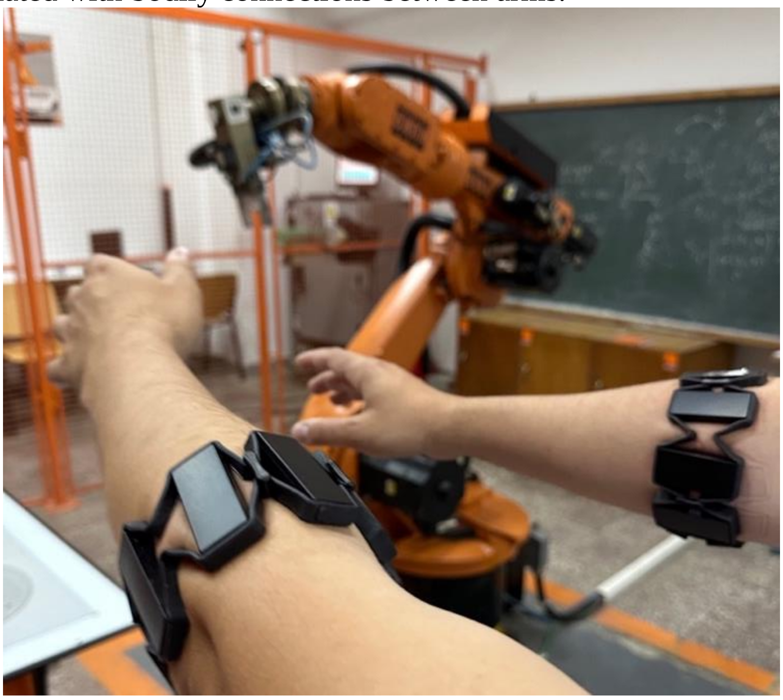

Fig. 12- Dual Myo application on KUKA KR15

4.4. Myo Armband – Universal Robots UR10e application (Fig. 13):

In this last application, the connection of the Myo Armband with a collaborative robot Universal Robots UR10e was realized. Via a desktop system, Myo's gesture signals are interpreted into C# and Python programs. These programs transmit positioning and orientation commands to the UR10e robot via the Ethernet communication protocol. The experiment enabled continuous and precise movements of the collaborative robot.

Fig. 13- Myo Armband application on Universal Robots UR10e

In conclusion, these applications demonstrate the potential and limitations of using the Myo Armband to control industrial robots. Even though promising results have been obtained in terms of gesture control, there are challenges related to calibration, communication, and movement coordination. The optimal solution is given by the Myo Armband – Universal Robots UR10e application.

CHAPTER 5 – RESEARCH METHODOLOGY AND TESTING OF THE OPTIMAL SOLUTION

The research and testing methodology for finding the optimal solution involved conducting experiments on a group of users, who performed three types of tests. The main goal was to compare the performance of the optimal solution as measured by similar experiments using the Myo Armband device and a teach pendant. In each experiment, positioning speed and accuracy were monitored, and users filled out questionnaires to provide feedback.

The experiments included the following tests:

5.1 Picking up and placing three objects (Fig. 14): Users were instructed to pick up objects from a table and position them as close as possible to a central point on the table. The goal was to strike a balance between time and accuracy.

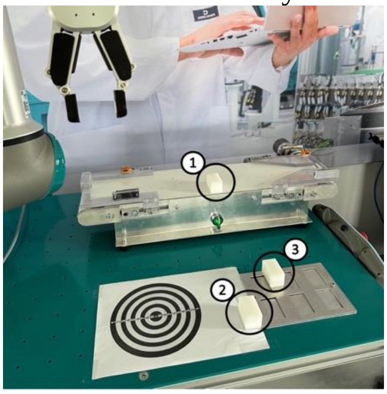

Fig. 14– Test 1 – Picking up and placing objects no. 1, no. 2 and no. 3

5.2 Reaching the four landmarks (Fig. 15) : This test only evaluated the speed of reaching thin landmarks, requiring attention and precision from the users.

Fig. 15- Test 2 - Reaching the four landmarks

5.3 Picking up and placing a PET bottle in a box (Fig. 16): This test was more difficult, involving picking up and placing a PET bottle in a box. The goal was to achieve an optimal ratio between time and accuracy.

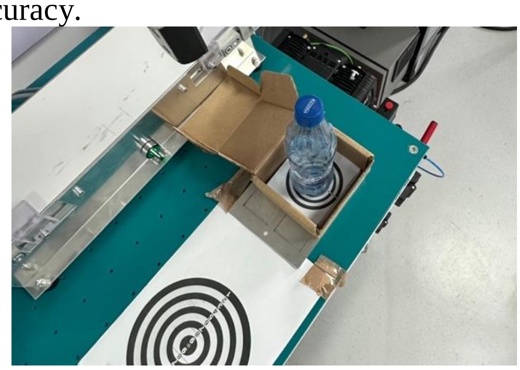

Fig. 16- Test 3 – Pick up and place object in box

Before performing the tests, users were given three minutes to familiarize themselves with the devices. Each experiment included the same starting point and identical object positions when using the Myo Armband or teach pendant.

The analyzes included the following aspects:

- **Time Analysis:** Average test time was calculated for using the Myo Armband and teach pendant. The goal was to compare the averages and determine which device achieved the lowest time.
- **Accuracy Analysis:** The average score for accuracy was calculated for both devices. The accuracy score was evaluated based on how close users placed the objects to the desired center point. The device with the highest average score was considered more accurate.
- **Equivalent multicriteria analysis:** For this type of analysis, both the accuracy score with a weight of 50% and the time with a weight of 50% were considered. Values were normalized for comparison and an equivalent multicriteria score was calculated for each device. The device with the higher score was considered better.

The experiments also included a series of gestures for controlling a robot, as well as specific tests for each type of experiment described above. The ultimate goal was to determine which device offered the best combination of time and accuracy in performing the respective tasks.

CHAPTER 6 – EXPERIMENTAL RESULTS

This section of the PhD thesis concerns the results of the experiments carried out for the evaluation of industrial robot control devices: the Myo Armband and the teach pendant. The experiments were conducted on a sample of 13 people with an average age of 26.5 years. The participants were not provided with the measurements and were asked to complete the questionnaires based on their personal estimates and experiences.

6.1. Quiz results:

The questionnaire was structured in three parts to assess different aspects of the devices. Participants were asked to rate the devices based on ease of robot movement, positioning accuracy, programming time, and overall user satisfaction.

Ease of Robot Movement:

Most participants (92%) chose the Myo Armband as better in terms of ease of movement of the UR10e robot.

In terms of individual device use, the majority rated the Myo Armband as good or very good (85%), while a small proportion (15%) rated it as mediocre. No one chose the options "bad" or "very bad". In the case of the teach pendant, 8% rated the device as bad.

Positioning accuracy:

85% of participants found the teach pendant more useful for positioning accuracy as opposed to ease of movement results.

Individually, the majority (92%) rated the teach pendant as very good in terms of positioning accuracy, while 46% rated the Myo Armband as mediocre or poor.

Programming time:

92% of participants preferred to use gestures to save positions for the robot using the Myo Armband instead of writing instructions in the teach pendant.

In terms of programming time, most (77%) rated the Myo Armband as good for saving positions with gestures, while opinion on the teach pendant was divided, with 31% rating it as mediocre.

Overall user satisfaction:

Although the Myo Armband has disadvantages in terms of accuracy, most (85%) felt it was better to use compared to the teach pendant.

Individually, the majority (85%) reported very good overall satisfaction with the Myo Armband. Opinions on the teach pendant were divided, with 46% rating it as very good or good, and 46% rating it as mediocre or bad.

General conclusions:

- The Myo Armband was preferred as the better device in terms of ease of movement, programming speed and overall satisfaction, while the teach pendant excelled in terms of accuracy.
- User experience and overall satisfaction had a greater impact in choosing the device, even if it had disadvantages in terms of certain features.
- The experiments provided a comprehensive insight into the advantages and disadvantages of each industrial robot control device.

6.2. Test analysis:

Test 1 - Picking up and placing three objects (plastic parallelepiped):

- The average time for each object varied between the two devices. The Myo Armband achieved the fastest time for object 1 and object 3, while the teach pendant had the fastest time for object 2.
- The teach pendant scored better in positioning accuracy for all three objects.

Test 2 - Reaching the four milestones (sticks):

- The teach pendant had a shorter average time compared to the Myo Armband to reach the four milestones. However, the fastest time was achieved with the Myo Armband.
- Accuracy was not specifically measured in this test as it was a mandatory requirement to complete the test.

Test 3 - Picking up and placing an object (PET bottle) in the box:

- The average time to retrieve and place the PET bottle in the box was better with the Myo Armband.
- The teach pendant scored better in terms of accuracy for this test.

Multicriteria analysis with equal weights for time and accuracy revealed that depending on the complexity of the tasks, one device was better than the other. The Myo Armband excelled in the simpler tasks, while the teach pendant was preferred for the more complex tasks.

Conclusions:

- Participants had different opinions about their preferred devices based on their personal experiences and preferences.
- Most participants felt that the Myo Armband provided a more intuitive and direct experience, while the teach pendant required more time to program.

These are the main results and conclusions of the evaluations of the industrial robot controllers: the Myo Armband and the teach pendant.

CHAPTER 7 – FINAL CONCLUSIONS. PERSONAL CONTRIBUTIONS. FUTURE DIRECTIONS OF RESEARCH

This research paper explores an innovative approach to industrial robot control using the Myo Armband. The research was conducted on two types of robots: KUKA KR15 and Universal Robots UR10e. The goal was to test the feasibility of controlling these robots by capturing the user's muscle signals and arm movements using the Myo Armband.

After experiments, it was found that UR10e robots are more suitable for this control method, as they allow smoother and more natural movements. Thus, the O1 objective of the research, regarding the choice of suitable robots for this approach, has been achieved.

After optimizing the control system, three series of tests were performed to evaluate the performance of the robots in terms of time and accuracy with both the Myo Armband and a conventional teach pendant. The results indicated that despite the superior performance of the teach pendant from a technical point of view, users preferred the user experience provided by the Myo Armband. This emphasizes the importance of natural interaction and pleasant experience for users, demonstrating the achievement of the O2 objective of the research.

The O3 objective of collecting user impressions and opinions on the experience of using the Myo Armband and Teach pendant was achieved through a questionnaire completed by users after the tests were completed. This questionnaire was designed to allow participants to express their opinion without being influenced by objective test results. Thus, by obtaining direct feedback from users on their experience, the researcher was able to assess their level of satisfaction and preferences in terms of control mode.

Regarding objective O4, which refers to the comparative analysis between the results obtained from the questionnaires and the measured performances, the researcher carried out a detailed analysis of the feedback of the users and correlated this feedback with the data measured during the tests. This approach was aimed at identifying possible discrepancies between user perceptions and concrete results, focusing on measurements such as test completion time and movement accuracy.

Throughout the analysis, a relationship was observed between users' subjective perceptions and their measured performance. For example, users who reported that the Myo Armband was easier to use also had better test results, while those who reported that the teach pendant was more accurate scored higher on the precision tests. However, there were also instances where users chose the Myo Armband as their preferred device, even though they achieved superior performance with the teach pendant, or vice versa. These discrepancies underline the importance of the user's subjective experience and its influence on the overall perception of device effectiveness.

Thus, by carefully analyzing the correlation between subjective perceptions and objective performances, objective O4 was met by highlighting the importance of prioritizing user experience over pure performance of robot control devices.

The author's contributions were significant in the development of control programs and integration with robots. He created complex programs to take the signals from the Myo Armband and translate them into precise movements of the robots on their movement axes. The author also created a virtual operating system that allows simultaneous control of two Myo Armbands and developed programs for interpreting signals and coordinating the movement of robots.

Throughout the research, challenges also emerged, such as the lack of an efficient communication protocol for one of the robots or the need to have newer equipment to be able to test the proposed solutions. However, these obstacles were overcome thanks to the author's efforts and the financial support obtained from the DRÄXLMAIER company.

Regarding future research directions, it is proposed to develop a more precise control of the orientation of the industrial robot. It is also planned to explore advanced control methods such as the use of devices such as Kinect, Leap Motion , Xbox, Gamepad or even brain computer control technologies to manipulate UR10e robots. The author is committed to continuing this research to evaluate the effectiveness and applicability of these methods in different contexts.

CHAPTER 8 – Bibliography

[1] K. Capek, Rossum's Universal Robots, translated by Paul Selver. 1923.

[2] T. R. Kurfess, Robotics and automation handbook, vol. 414. CRC press Boca Raton, FL, 2005.

[3] I. Margolius, "The robot of Prague," The Friends of Czech Heritage , 2017. https://czechfriends.net/images/RobotsMargoliusJul2017.pdf. (accessed Jun. 09, 2019).

[4] K. Vijay, "K. Vijay, Introduction to robotics." University of Pennsylvania. , Philadelphi, USA.

[5] S. B. Niku, Introduction to robotics: analysis, control, applications. John Wiley & Sons, 2020.

[6] M. Vukobratovic, Introduction to robotics. Springer Science & Business Media, 2012.

[7] IFR, "Executive Summary World Robotics 2-2022," 2022. https://ifr.org/img/worldrobotics/Executive_Summary_WR_Industrial_Robots_2022.pdf (accessed Jun. 13, 2023).

[8] A. Kazi, J. Bunsendal, D. Haag, R. Baum, and R. Bischoff, "Next generation teach pendants for industrial robots," Advances in Human-Robot Interaction, pp. 47–66, 2005.

[9] Z. Zhang, "Microsoft kinect sensor and its effect," IEEE multimedia, vol. 19, no. 2, pp. 4–10, 2012.

[10] M. Banda, V. Ciupe, C. Moldovan, I. Maniu, and R. Kristof, "Investigations on collaborative remote control of virtual robotic manipulators by using a Kinect v2 sensor," in ITM Web of Conferences, EDP Sciences, 2019, p. 03004.

[11] R. V Aroca, A. Péricles, B. S. de Oliveira, L. Marcos, and G. Gonçalves, "Towards smarter robots with smartphones," in 5th workshop in applied robotics and automation, Robocontrol, Citeseer, 2012, pp. 1–6.

[12] J. Lambrecht, M. Chemnitz, and J. Krüger, "Control layer for multi-vendor industrial robot interaction providing integration of supervisory process control and multifunctional control units," in 2011 IEEE Conference on Technologies for Practical Robot Applications, IEEE, 2011, pp. 115–120.

[13] M. Safeea and P. Neto, "Kuka sunrise toolbox: Interfacing collaborative robots with matlab," IEEE Robot Autom Mag, vol. 26, no. 1, pp. 91–96, 2018.

[14] Thalmic Labs, "Thalmic Myo Presskit." https://www.thalmic.com/press (accessed Apr. 13, 2018).

[15] Ultraleap, "Leap Motion Controller TM." https://www.ultraleap.com/product/vr-developer-mount/ (accessed Jun. 13, 2023).

[16] Z. Lu, X. Chen, Q. Li, X. Zhang, and P. Zhou, "A hand gesture recognition framework and wearable gesture-based interaction prototype for mobile devices," IEEE Trans Hum Mach Syst, vol. 44, no. 2, pp. 293–299, 2014.

[17] KUKA Robot Group, KR 15 SL Specification. 2006.

[18] Thalmic Labs, "Myo techspecs." https://www.myo.com/techspecs (accessed May 08, 2018).

[19] Universal Robots, "UR10e Medium-sized, versatile cobot." https://www.universal-robots.com/products/ur10-robot/ (accessed May 20, 2023).

[20] R. Kristof, V. Ciupe, C. Moldovan, I. Maniu, M. Banda, and A. M. Stoian, "Arduino mobile robot with Myo Armband gesture control," SACI 2019 - IEEE 13th International Symposium on Applied Computational Intelligence and Informatics, Proceedings, pp. 294–297, May 2019, doi: 10.1109/SACI46893.2019.9111627.

[21] R. Kristof, V. Ciupe, C. Moldovan, I. Maniu, M. Banda, and A. M. Stoian, "On the

design of a myoelectric human-machine interface for the control of an industrial robot,” SACI 2019 - IEEE 13th International Symposium on Applied Computational Intelligence and Informatics, Proceedings, pp. 291–294, May 2019, doi: 10.1109/SACI46893.2019.9111521.