WIP - Application of Serious Games in a University Industrial Related Laboratory Working With Collaborative Robots

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Abstract — **This innovative practice WIP is about using serious games in robotics education. In the realm of STEM education, the professional development of students is intrinsically linked to practical experiences, such as hands-on exercises, experiments, and laboratory classes. However, the financial implications of acquiring and maintaining mechatronic devices such as robots, automation-related equipment, and instruments for these activities are high. These excessive costs, which cover initial funding and ongoing maintenance, pose challenges for educational institutions in establishing and maintaining well-equipped laboratories. In addition, access to these resources depends on their availability, creating restrictions on student learning opportunities. The state of Amazonas, Brazil, needs to solve these problems; as a city of numerous factories, there is a growing demand for well-trained professionals and a dwindling number of resources to apply to education. To address these challenges, we propose an approach that integrates simulation tools for application in educational games. These tools used to conduct simulations are essential for developing shop floor scenarios without physical equipment, effectively reducing the costs associated with mechanical collisions and problems related to student programming errors. The importance of using simulation tools in the learning process lies in their ability to offer a risk-free environment where students can experiment, learn, and perfect their skills without incurring additional expenses for corrective maintenance. Innovatively, the incorporation of gamification-based learning by simulating real problems based on the shop floor is gaining momentum. We believe this is the most attractive way for trainees or students to deliver fast, high-quality professionalism. This approach represents an appealing alternative for educators looking to enhance their educational experience. From this perspective, this paper presents the application of a serious game in the industrial laboratory at UFAM. The aim is to offer students a dynamic and engaging platform for learning about collaborative robots, taking advantage of the principles of the learning factory, and promoting good practices in an economical and risk-controlled virtual environment.**

Keywords — Collaborative Robots; Remote Laboratories; Serious Games; Industrial Related Laboratories.

I. Introduction

The professional development of STEM students is intricately tied to hands-on experiences such as practical exercises, experiments, and laboratory classes [1, 2]. Moreover, the availability of several types of equipment and the need for a professor or a student monitor to guide laboratory practices [3] limit learning opportunities for some students [4].

In [5, 6], this type of problem can be reduced by practicing simulation software, especially when physical devices are not present, and avoiding physical damage to the devices. However, the financial implications of acquiring and maintaining mechatronics devices, such as robots, automation-related equipment, and instruments for these activities, are expensive.

These high costs, encompassing initial funding and ongoing maintenance, pose challenges for educational institutions in establishing and sustaining well-equipped laboratories [7].

The accessibility of such resources is contingent upon their availability, creating potential constraints on learning opportunities for students. The state of Amazonas, Brazil, needs to address such problems [8]. There is an increasing demand for well-trained professionals and an ever-reducing number of resources to apply in education. This is particularly true when training employees to collaborate with collaborative robots for shop floor applications [9, 10].

The significance of simulation tools in the learning process lies in their ability to offer a risk-free environment where students can experiment, learn, and refine their skills without incurring additional expenses for corrective maintenance [11].

In addition, one of the practices adopted as a learning process is the integration of education and games, named game-based learning from the literature [12], which has been increasingly used because it results in improved attention span and greater student participation during the learning process [13, 14].

II. Literature review

A. Learning Factory

A learning factory is a realistic and simulated learning environment with processes and technologies based on the physical industrial shopfloor [15]. It follows a didactic approach emphasizing problem-solving and experiential learning [16].

The learning factory philosophy is facilitated by actions and interactions involving participants and can be used for educational, research, and training purposes [17].

A learning factory can have implementations focused on behaviorist, cognitive, or constructivist learning methodologies [15]. Behaviorist implementations of learning factories are inspired by behaviorism theory [18], which focuses on using rewards and punishments to shape desired behaviors. This system can be applied by completing the goal in the game.

The cognitive implementations of learning factories are inspired by cognitive learning [19], which involves tools that utilize a substantial number of visual resources with the objective of training problem-solving abilities. This is typically achieved by elucidating the production process and addressing a problem to develop critical thinking in related scenarios.

Finally, constructivist implementations are inspired by constructivist learning [20], which involves students developing solutions and understanding the environment through practical, experiential learning. This refers to creating an environment that can be experienced so that there can be reflection on what has been learned.

Integrating learning mechanisms may be a valuable strategy for implementing learning factories, contingent on the desired outcomes and the specific content to be transmitted. For example, combining the three mechanisms could facilitate the provision of rewards for meeting performance objectives that facilitate students' understanding of the subject matter and encourage them to engage in problem solving through experimentation.

B. Game-based Learning

As stated by [21], games are rule-based and adhere to the established rules of the game. They are responsive, enabling player actions and providing feedback and system responses. Games present challenges, incorporating elements of chance, progress, and other factors that motivate players to engage [22].

There are diverse ways of incorporating game elements into the learning process, the two main types being severe games and gamification [15].

A serious game is defined as a game whose primary objective is not entertainment. The main objective is often learning, which can use simulation approaches and technologies for teaching by developing concepts and improving skills [23, 12].

In the context of digital technology and its applications, gamification is a term used to describe a process whereby game elements are integrated into an environment or context that is not inherently game-like [24].

The core of game-based learning was presented in [25], which defines the components in three distinct layers: the system, the engine, and the game-play layers.

The system layer is linked to the hardware of the computer and the network and thus determines the performance of a game's engine, the quality of graphics and sounds, and the features required for the network.

The engine layer represents the abstraction layer of the system layer. It defines the physics of the system, graphics, rendering, audio, and artificial intelligence that will be presented by nonplayer characters (NPCs).

The game-play layer is responsible for defining all the rules of the game. In general, there are three categories of regulations: setup, which consists of the settings players make before the game begins; game progress, which consists of what will happen during the game; and resolution, which consists of the actions that will cause the game or level to end on the basis of the state of the game.

There has been a notable surge in interest in this field in recent years. As posited by [26], games can be potent experiences involving individual attributes, such as motivation and engagement. However, to achieve this, implementing game elements must not be excessively simplified to the extent that the player cannot engage, which could diminish existing interest and engagement.

C. Collaborative Robots

Expanding industrial processes has necessitated more precise, high-quality solutions at the lowest possible cost and with a brief implementation period to fulfill demands [27, 28]. One potential solution to this issue is the utilization of collaborative industrial robots (CoBots), which operate in conjunction with one or more human beings throughout the process. Using CoBots is essential for complex and flexible processes [29].

To comply with the safety criteria, collaborative robots (CoBots) must operate at lower speeds than noncollaborative industrial robots do and possess specific sensors and equipment to enable collaborative operation [30].

The interactions between CoBot and humans are classified [31] as collaborative, coexistent, cooperative, or synchronized. Collaborative interaction occurs when the robot and the human perform different activities simultaneously but complete the same activity or product. Coexistence of interactions occurs when the robot and human work in the same space but with various activities and times.

Cooperative interaction occurs when a guard separates the human and the robot, but they work in adjacent areas and do not perform activities dependent on each other. Synchronized interaction occurs when the robot and the human operator share a work environment, but only one is at the workstation at any given time [32, 33].

The learning factory philosophy is facilitated by actions and interactions involving participants and can be used for educational, research, and training purposes [17].

III. Purpose, Materials, and Methods

This project aims to create a serious game to help teach the programming of collaborative robots (CoBots) via formal and informal learning methodologies.

This serious game project, named the Laboratory of Automation Robotics - Serious Game (LARSG), will be based on behaviorist and constructivist learning models through the use of reward stimuli and reinforcement punishments for each activity carried out and allowing students to be active participants in the creation of the learning environment so that they can interact, experiment and reflect on the actions they take in the game.

First, we implement communication between LARSG and the collaborative robot UR5e from URs.

On the basis of this communication, we implement CoBot monitoring and control through UR Sim Polyscope v5.9.4. The performance of LARSG is evaluated on an i3-1005G1 CPU with a 1.20 GHz computer to assess whether it can be run on a student computer.

A. CoBot digitalization

The initial stage of creating the LARSG consisted of digitizing the training bench and the UR5e by importing the 3D model and material meshes created via PTC Creo software, which was used to develop the CADs.

The physical workbench positioned in the automation laboratory at UFAM is shown in Fig. 1. The import of the 3D modeling of the CoBot and the workbench can be seen in Fig. 2.

B. Establishment of communication

Following the importation of the 3D model, the subsequent step was establishing communication with UR5e via simulation. This stage entails communicating with the virtual machine to generate the digital twin.

The vector kinematics and dynamics of UR5e were simulated via UR SIM Polyscope v5.9.4. To establish communication between the LARSG and the simulator, it was necessary to configure communication via the TCP/IP socket, whose data stack was processed and analyzed to obtain the angle information for each CoBot joint.

C. Game Mechanics

In addition, learning factory concepts are used at each level of the game to enable the student to develop a basic industrial process that is defined at the end of each level. The game modes have two approaches: level mode (LM) and free-run mode (FRM).

Fig. 1. UFAM physical workbench in the automation laboratory.

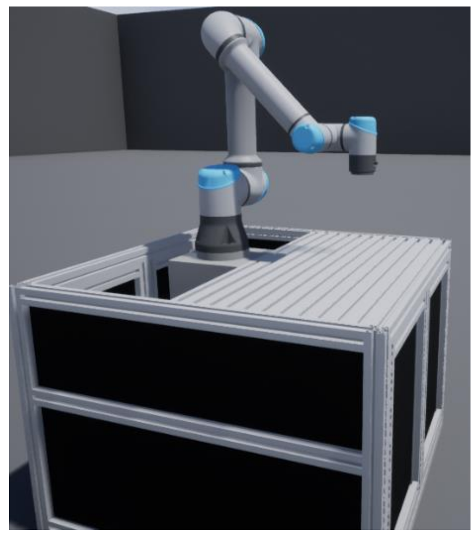

Fig. 2. The UFAM workbench 3D model was imported into Unreal Engine.

LM is a level-by-level mode that follows the behaviorist model of formal education, in which students need to follow the preestablished steps in a script given to them at their level.

Moreover, one of the features that is available in game mechanics is a tutorial mode that is designed to teach the user the basics of the terminology of each robot joint, the teach pendant, the electrical connection with external devices, the configuration of the tool center point (TCP), and the programming flow of the robot's movement.

If the student player wants to skip the mode, he can. An example of a CoBot joint tutorial is shown in Fig. 3. The avatars of the NPC professor have not yet been considered.

The FRM will follow a constructivist model to allow students to build their experimentation environment and evaluate a robot's programming without risking physical collisions or damaging any parts of the CoBot.

Furthermore, the mode also functions as a digital twin that allows the CoBot to communicate with and control the lab bench and insert sensors and virtual objects to emulate an industrial process.

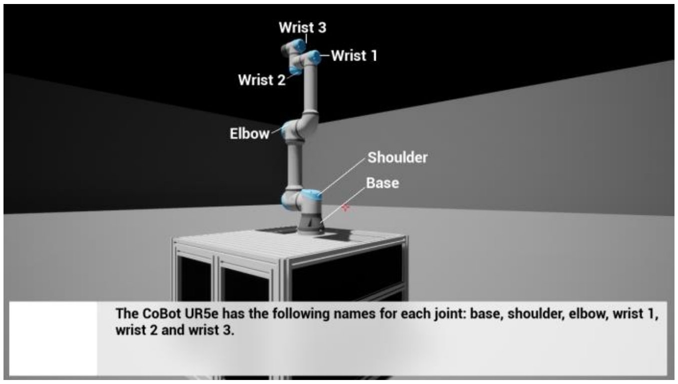

Fig. 3. Example of a CoBot joint tutorial.

An example of the FRM feature is shown in Fig. 4, which illustrates the insertion of a belt conveyor into the LARSG learning environment to simulate the transport of products to be managed by the system.

The game development tool used was Unreal Engine 4.23.1, which was chosen for its programming flexibility, immersion in the game due to the reality of the graphics, community support, and greater ease of creating and importing scenarios from CAD/CAM software. The project architecture is shown in Fig. 5.

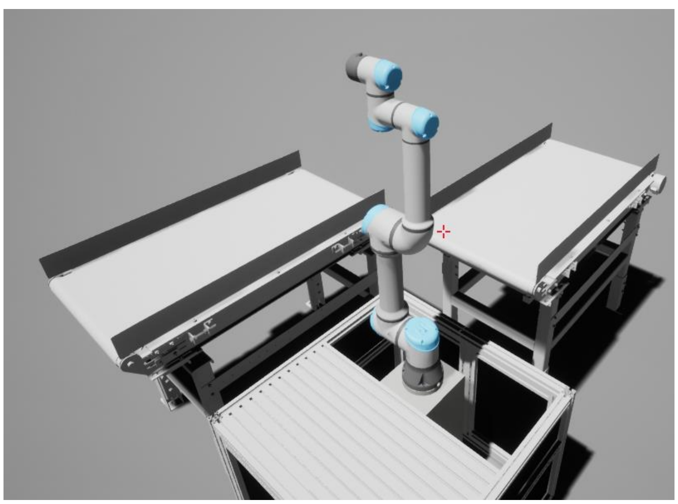

Fig. 4. FRM feature example.

IV. CONCLUSION AND FUTURE WORK

The results, although preliminary, were satisfactory in terms of the feasibility of building 3D models via the Unreal Engine. The implementation of communication between LARSG and UR5e met the usability requirement because of the stability of the communication latency and FPS, which remained constant. The exploratory tests shown in Fig. 6 were conducted on the basis of user experience.

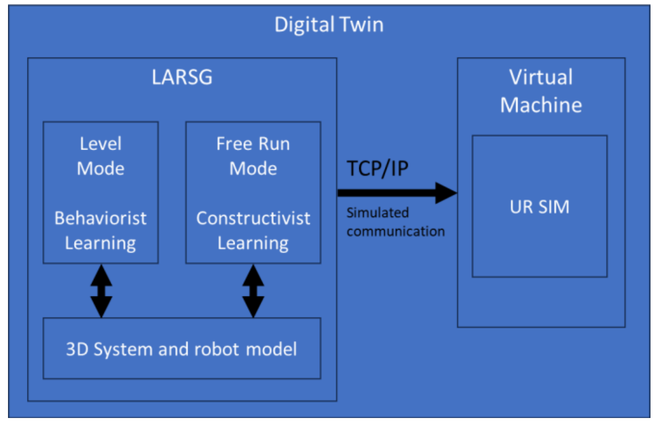

Fig. 5. Purpose of project architecture.

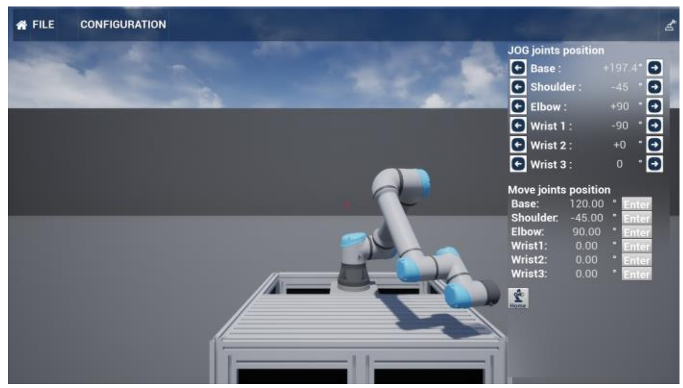

Fig. 6. Preliminary interface to control UR5e. A video playback is available at [33].

The remaining stages of the LARSG will be conducted as future work to implement the Learning Factory. This will entail the implementation of a series of scenarios that exist on the factory floor. In future work, the remaining phases of the LARSG will be conducted to implement the learning factory. This will entail the implementation of a series of scenarios that exist on the shop floor. Initially, an industrial process is employed to palletize router boxes with a payload of less than 5 kg.

The aim is to instruct students about the real problems they may encounter in the industry. This will enable students and industry professionals to improve their practices in programming collaborative robots.

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REFERENCES

[1] A. Ożadowicz, "Modified blended learning in engineering higher education during the COVID-19 lockdown—building automation courses case study", Educ. Sci., vol. 10, no. 10, p. 292, Oct. 2020. Accessed: May 1, 2024. [Online]. Available: https://doi.org/10.3390/educsci10100292.

[2] M. Gugole, F. Fiore, T. Rosi, G. Zendri, and A. Montresor, "Stem-Kit: An interdisciplinary approach to learning physics and computer science," in 2023 IEEE Frontiers Educ. Conf. (FIE), College Station, TX, USA, Oct. 18–21, 2023. IEEE, 2023. Accessed: May 1, 2024. [Online]. Available: https://doi.org/10.1109/fie58773.2023.10343208.

[3] W. d. S. Picanco, G. S. Machado, M. M. de Carvalho, F. A. d. C. Ayres, R. L. P. de Medeiros, and V. F. de Lucena, "Learning-IoT: Methodological framework for remote robotics teaching," in 2022 IEEE Frontiers Educ. Conf. (FIE), Uppsala, Sweden, Oct. 8–11, 2022. IEEE, 2022. Accessed: May 10, 2024. [Online]. Available: https://doi.org/10.1109/fie56618.2022.9962451.

[4] K. A. A. Gamage, D. I. Wijesuriya, S. Y. Ekanayake, A. E. W. Rennie, C. G. Lambert, and N. Gunawardhana, "Online delivery of teaching and laboratory practices: Continuity of university programs during COVID-19 pandemic", Educ. Sci., vol. 10, no. 10, p. 291, Oct. 2020. Accessed: May 10, 2024. [Online]. Available: https://doi.org/10.3390/educsci10100291.

[5] S. Tselegkaridis and T. Sapounidis, "Simulators in educational robotics: A review," Educ. Sci., vol. 11, no. 1, p. 11, Jan. 2021. Accessed: May 10, 2024. [Online]. Available: https://doi.org/10.3390/educsci11010011.

[6] G. B. Sætren et al., "Simulator versus traditional training: A comparative study of night driving training," Proc. Human Factors Ergonomic. Soc. Annu. Meeting, vol. 63, no. 1, pp. 1669–1673, Nov. 2019. Accessed: May 10, 2024. [Online]. Available: https://doi.org/10.1177/1071181319631528.

[7] J. B. d. Silva, "A utilização da experimentação remota como suporte para ambientes colaborativos de aprendizagem", Florianop., SC, 2006. Accessed: May 10, 2024. [Online]. Available: http://repositorio.ufsc.br/xmlui/handle/123456789/88357.

[8] V. Ferreira de Lucena, J. P. de Queiroz-Neto, I. B. Benchimol, A. Pereira Mendonca, V. Romao da Silva, and M. Ferreira Filho, "Teaching software engineering for embedded systems: An experience report from the manaus research and development pole", in 2007 37th Annu. Frontiers Educ. Conf. - Global Eng.: Knowl. Without Borders, Opportunities Without Passports, Milwaukee, WI, USA, Oct. 10–13, 2007. IEEE, 2007. Accessed: May. 23, 2024. [Online]. Available: https://doi.org/10.1109/fie.2007.4417966.

[9] J. P. Queiroz-Neto, J. M. De Sousa, M. S. Pereira, and N. A. Gouvea, "Advanced training in industrial robotics using project-based learning and design thinking in a partnership between the university and industry," in 2023 IEEE Frontiers Educ. Conf. (FIE), College Station, TX, USA, Oct. 18–21, 2023. IEEE, 2023. Accessed: May 1, 2024. [Online]. Available: https://doi.org/10.1109/fie58773.2023.10342896.

[10] V. F. De Lucena, A. Brito, and P. Gohner, "A germany-brazil experience report on teaching software engineering for electrical engineering undergraduate students", in 19th Conf. Softw. Eng. Educ. Training (CSEET'06), Turtle Bay, HI, USA. IEEE. Accessed: May. 2, 2024. [Online]. Available: https://doi.org/10.1109/cseet.2006.6.

[11] E. L. M. Naves, T. F. Bastos, G. Bourhis, Y. M. L. R. Silva, V. J. Silva, and V. F. Lucena, "Virtual and augmented reality environment for remote training of wheelchairs users: Social, mobile, and wearable technologies applied to rehabilitation", in 2016 IEEE 18th Int. Conf. E-Health Netw., Appl. Services (Healthcom), Munich, Germany, Sep. 14–16, 2016. IEEE, 2016. Accessed: May. 2, 2024. [Online]. Available: https://doi.org/10.1109/healthcom.2016.7749418.

[12] D. Djaouti, J. Alvarez, and J.-P. Jessel, "Classifying serious games," in Advances in Game-Based Learning. IGI Glob., pp. 118–136. Accessed: May 10, 2024. [Online]. Available: https://doi.org/10.4018/978-1-60960-495-0.ch006.

[13] B. C. Müller, C. Reise, and G. Seliger, "Gamification in factory management education – A case study with lego mindstorms," Procedia CIRP, vol. 26, pp. 121–126, 2015. Accessed: May 10, 2024. [Online]. Available: https://doi.org/10.1016/j.procir.2014.07.056.

[14] Z. Zhan, L. He, Y. Tong, X. Liang, S. Guo, and X. Lan, "The effectiveness of gamification in programming education: Evidence from a meta-analysis," Comput. Educ.: Artif. Intell., p. 100096, Sep. 2022. Accessed: May 10, 2024. [Online]. Available: https://doi.org/10.1016/j.caeai.2022.100096.

[15] E. Abele, J. Metternich, and M. Tisch, Learning Factories: Concepts, Guidelines, Best-Practice Examples. Springer, 2019.

[16] M. Sudhoff, C. Prinz, and B. Kuhlenkötter, "A systematic analysis of learning factories in Germany - concepts, production processes, didactics," Procedia Manuf., vol. 45, pp. 114–120, 2020. Accessed: May 10, 2024. [Online]. Available: https://doi.org/10.1016/j.promfg.2020.04.081.

[17] S. Chatti and T. Tolio, Eds., CIRP Encyclopedia of Production Engineering. Berlin, Heidelberg: Springer Berl. Heidelb., 2020. Accessed: May 10, 2024. [Online]. Available: https://doi.org/10.1007/978-3-642-35950-7.

[18] B. F. Skinner, Science and Human Behavior. New York: Macmillan, 1953.

[19] P. Jean, The Psychology of Intelligence. London: Routledge Kegan Paul, 1950.

[20] L. S. Vygotsky and M. Cole, "Mind in society: Development of higher psychological processes." Harvard University Press, 1978.

[21] Deterding, S. Gamification: "Designing for Motivation. Interactions", 2012, 19, 14–17.

[22] Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011). From game design elements to game-fulness: Defining "gamification." In MindTrek'11, Tampere, Finland, September 28–30, 2011 (pp. 9–15).

[23] R. Damaševičius, R. Maskeliūnas, and T. Blažauskas, "Serious games and gamification in healthcare: A meta-review," Information, vol. 14, no. 2, p. 105, Feb. 2023. Accessed: May 10, 2024. [Online]. Available: https://doi.org/10.3390/info14020105.

[24] R. Dörner, S. Göbel, W. Effelsberg, and J. Wiemeyer, Eds., Serious Games. Cham: Springer Int. Publishing, 2016. Accessed: May 10, 2024. [Online]. Available: https://doi.org/10.1007/978-3-319-40612-1.

[25] E.-S. Aziz, J. E. Corter, Y. Chang, S. K. Esche, and C. Chassapis, "Evaluation of the learning effectiveness of game-based and hands-on gear train laboratories," in 2012 IEEE Frontiers Educ. Conf. (FIE), Seattle, WA, USA, Oct. 3–6, 2012. IEEE, 2012. Accessed: May 13, 2024. [Online]. Available: https://doi.org/10.1109/fie.2012.6462269.

[26] Kapp, K.M. "The gamification of learning and instruction: Game-based methods and strategies for training and education"; 1st ed.; Pfeiffer & Company: Washington, DC, USA, 2016.

[27] AYANI, M.; GANEBÄCK, M.; NG, Amos H. C. Digital Twin: applying emulation for machine reconditioning. Procedia CIRP, v. 72, p. 243-248, 2018. Available: https://doi.org/10.1016/j.procir.2018.03.139.

[28] ROSEN, Roland, et al. About the importance of autonomy and digital twins for the future of manufacturing. Ifac-papersonline, v. 48, n. 3, p. 567-572, 2015.

[29] J. Lee, G.-T. Park, and S. Ahn, "A performance evaluation of the collaborative robot system," in 2021 21st Int. Conf. Control, Automat. Syst. (ICCAS), Jeju, Korea, Republic of, Oct. 12–15, 2021. IEEE, 2021. Accessed: May 12, 2024. [Online]. Available: https://doi.org/10.23919/iccas52745.2021.9649859.

[30] J. A. Marvel, "Sensors for safe, collaborative robots in smart manufacturing," 2017 Ieee Sens., Glasgow, Oct. 29–Nov. 1, 2017. IEEE, 2017. Accessed: May 11, 2024. [Online]. Available: https://doi.org/10.1109/icsens.2017.8234264.

[31] F. Santoni and A. V. R. Lucato, "Robótica colaborativa: A utilização de robôs nos processos produtivos", RECIMA21 - Rev. Cient. Multidiscip. - ISSN 2675-6218, vol. 1, no. 1, Nov. 2021, Art. no. e210914. Accessed: May 12, 2024. [Online]. Available: https://doi.org/10.47820/recima21.v1i1.914.

[32] J. Kreitz, M. Lee, H. SubPark, P. Y. Oh, and J. H. Oh, "Implementing ROS communications for sensor integration with the RB5 collaborative robot", in 2020 10th Annu. Comput. Communication Workshop Conf. (CCWC), Las Vegas, NV, USA, Jan. 6–8, 2020. IEEE, 2020. Accessed: May 11, 2024. [Online]. Available: https://doi.org/10.1109/ccwc47524.2020.9031202.

[33] Álvaro de Azevedo Peres Neto. Unreal Engine Running With UR Sim Polyscope. (May 4, 2024). Accessed: May 10, 2024. [Online Video]. Available: https://youtu.be/mBICmG7eSv.