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DIDACTIC HARDWARE FOR MAPPING INDOOR ENVIRONMENTS

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ABSTRACT
The advancement of Industry 4.0 has brought profound changes in production processes, integrating technologies such as robotics, LiDAR sensors, and cyber-physical systems. This paper presents the development and evaluation of a didactic hardware system based on LiDAR and autonomous mobile robots (AMR), aimed at indoor mapping and professional training in the context of the Manaus Industrial Pole (PIM). The system, consisting of an A1M8 RPLIDAR LiDAR sensor, Raspberry Pi 4 and ROS2 framework, was tested in three scenarios simulating industrial environments. The results demonstrated high accuracy in mapping, with mean absolute errors ranging between 2.5 cm and 4 cm, depending on the complexity of the environment. The modularity of the system allowed it to be adapted to different levels of difficulty, proving to be an effective tool for the requalification of workers in enabling technologies of Industry 4.0. In addition, the proposal stood out as a low-cost, high-impact educational alternative, promoting an effective transition from theory to practice.

Keywords: Industry 4.0. Deal. Autonomous Mobile Robotics. Indoor mapping. Professional Requalification. Manaus Industrial Pole. Technological Education. ROS2. Technical Training. Industrial Automation.

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INTRODUCTION

Industry 4.0, considered the fourth industrial revolution, is radically transforming the manufacturing sector by integrating advanced digital technologies and cyber-physical systems into manufacturing processes and industrial operations. This revolution is marked by intelligent automation, big data analysis, Internet of Things (IoT) connectivity, and the extensive use of artificial intelligence (AI). These technologies provide a new era of smart factories, in which autonomous systems are able to communicate and make decisions in real time, without the need for direct human intervention. Advanced automation also enables mass customization, i.e., large-scale production of customized products according to customer preferences, keeping production costs low.

However, the incorporation of these technologies in industries requires profound changes, not only in the technological infrastructure, but also in the qualification of workers. Professionals need to be prepared to operate and maintain these complex systems. In Brazil, the Manaus Industrial Pole (PIM) plays a key role in the economy of the North region and in the country's technological development. With industries that produce everything from electronics to vehicles, PIM has sought to keep up with the fast pace of global innovation. However, the transition to Industry 4.0 presents significant challenges, particularly with regard to workforce training and reskilling.

The adoption of emerging Industry 4.0 technologies requires skilled professionals who understand both automated systems and the tools that support them. This includes advanced robotics, predictive analytics systems, and the use of sensors such as LiDAR (Light Detection and Ranging), which is essential for mapping and autonomous navigation of mobile robots. Technologies such as LiDAR, combined with autonomous mobile robots (AMR), are key to process automation in complex industrial environments, such as those found in PIM.

For Brazil to remain competitive on the global stage, the training of professionals specialized in Industry 4.0 technologies is essential. Implementing teaching tools that simulate these technologies in teaching environments can be an important step in ensuring that workers acquire the necessary skills. These tools can provide hands-on experience, allowing professionals to deal directly with systems that they will encounter in their daily activities, facilitating the transition from theory to practice.

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RESEARCH PROBLEM AND JUSTIFICATION

In this context, the central question of this research arises: how can a didactic hardware platform, using technologies such as LiDAR and AMR, be designed for indoor mapping and used as an educational tool for qualification in Industry 4.0 technologies in the Manaus Industrial Pole? The goal is to understand how these technologies can be adapted to the educational environment and used in a practical way to empower PIM workers.

This study is particularly relevant due to the growing urgency to empower PIM workers to deal with emerging Industry 4.0 technologies. The creation of an accessible, and robust didactic system, using LiDAR and mobile robotics, can offer a practical solution to meet educational and professional demands. In addition, this work is not limited to the implementation of a technological solution; It aims to explore how a practical educational platform can be used to train professionals with advanced skills in a short amount of time. The impact of this research can be significant for Brazilian industry, increasing the competitiveness of the PIM and preparing the workforce for the future of industrial automation.

LITERATURE REVIEW

OVERVIEW

The concept of Industry 4.0 was originally outlined by Kagermann et al. (2013) as a fusion between the physical, digital, and biological worlds. This revolution is fueled by the use of emerging technologies such as artificial intelligence (AI), the Internet of Things (IoT), advanced robotics, and big data. The goal of Industry 4.0 is to transform production systems into smarter, more flexible, and more efficient processes, allowing the integration of machines, products, and people into digital networks. According to Schwab (2016), this transformation allows production systems to be adapted in real time to respond to the demands of mass customization and product customization, without sacrificing operational efficiency.

The application of these technologies in productive environments has the potential to generate significant productivity gains, reduce energy consumption, and optimize the use of resources in supply chains. In addition, the integration of sensors, machines, and communication networks enables remote monitoring, automation of repetitive tasks, and data-driven decision-making, providing greater control and visibility over industrial processes (Hermann et al., 2016). This makes Industry 4.0 not only a technological

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revolution, but also a strategy to improve the sustainability and competitiveness of industries on the global stage.

Among the enabling technologies of Industry 4.0, autonomous mobile robotics (AMR) and LiDAR (Light Detection and Ranging) sensing play essential roles. AMRs are robots capable of navigating autonomously in dynamic environments, without the need to pre-program fixed routes. This sets them apart from traditional robots, which are limited by predetermined trajectories and lack the flexibility to adapt their navigation on the fly. According to Siciliano and Khatib (2016), AMRs represent a significant advance, especially in complex industrial environments, where the ability to adapt to unforeseen obstacles and changes in layout is essential to maintain operational efficiency.

LiDAR sensing, in turn, is a technology that uses laser beams to measure distances and create three-dimensional maps of environments. This technology is widely used in mobile robots to enable autonomous navigation, as it allows robots to "see" and interpret the environment around them accurately. By combining AMRs with LiDAR sensors, it is possible to develop autonomous navigation systems that operate in highly complex industrial environments, mapping and responding to changes in space in real time. This allows for the automation of logistical tasks, such as the transportation of materials within factories and warehouses, without the need for direct human intervention (Shan and Toth, 2018).

KEY CONCEPTS

The development of didactic hardware systems, which integrate AMRs and LiDAR, is based on active learning theories, with emphasis on Project-Based Learning (PjBL). Barrows and Tamblyn (1980) were pioneers in advocating this pedagogical approach, which promotes practical problem-solving as an effective way to learn theoretical concepts. By allowing students to work on real projects, this methodology increases the autonomy of learners and facilitates the practical application of the knowledge acquired.

In the context of Industry 4.0, PjBL (Project Based Learning) is particularly relevant, as it offers workers the opportunity to learn how to operate and program advanced systems, such as autonomous mobile robots, in simulated environments that replicate real working conditions. By using didactic hardware that allows them to simulate industrial systems, students can experience firsthand how Industry 4.0 technologies work, which facilitates the transition from theory to practice.

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In addition to PjBL, the concept of modularity in the teaching process is an effective strategy to ensure that students learn progressively, as highlighted by Pérez-Álvarez et al. (2018). Modularity allows learning to be broken down into blocks, where each module focuses on a specific skill or competency. This facilitates the learning of workers who are already inserted in the labor market and need to adapt to new technological requirements without completely interrupting their professional activities.

Modularity also allows learners to customize their learning paths, tailoring content according to their needs and previous experiences. In the context of Industry 4.0, where there is a diversity of technologies to be learned, such as AI, IoT, and automation systems, this approach offers a structured and efficient way to acquire new technical skills. Thus, workers can learn the skills most relevant to their roles, which increases knowledge retention and improves the applicability of concepts in the workplace.

SPACES AND OPPORTUNITIES TO BE EXPLORED

Although the literature on Industry 4.0 is extensive and well-developed, most studies focus on the application of these technologies in production systems and supply chains (Hermann et al., 2016). However, there is a significant gap when it comes to the use of these technologies in the educational and professional training context. The transition to Industry 4.0 requires not only the adoption of new technologies, but also the reskilling of workers to cope with these innovations. This is particularly important in emerging countries, such as Brazil, where educational and technological infrastructure still needs significant improvements to keep up with the demands of the digital economy (Sousa et al., 2018).

The lack of studies exploring the practical application of technologies such as AMR and LiDAR in worker training represents an opportunity for innovation in the field of technical education. The use of didactic hardware platforms that simulate real working conditions can be a viable solution to fill this gap. In addition, there is a growing need to develop educational methods that prepare workers for technological challenges in an accessible and practical way, which makes this study particularly relevant.

By exploring how Industry 4.0 technologies can be applied in training programs, this study adds to the existing literature by offering a practical and accessible approach to worker training. The implementation of didactic hardware systems, using AMRs and LiDAR sensors, offers a viable alternative for the requalification of workers in Brazil, especially in industrial centers such as Manaus, where the need to adapt to new technologies is urgent.

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METHODOLOGY

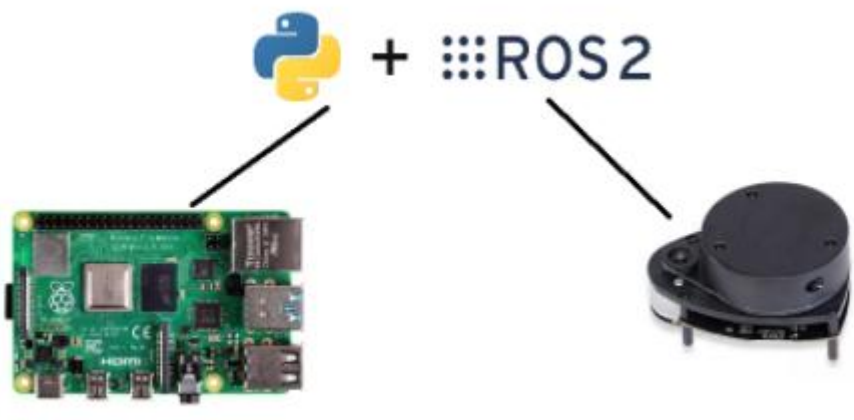
RESEARCH PROPOSAL

This study adopts an experimental design, focusing on the educational and industrial application of an indoor mapping system based on didactic hardware. The choice of this type of design was motivated by the need to test a practical and replicable system in different scenarios that simulate typical industrial environments. The main hardware used is the RPLIDAR A1M8 LiDAR sensor, a sensor widely used for 3D mapping and autonomous navigation. This sensor was integrated into the Raspberry Pi 4 processor, a low-cost computer, but with enough capacity to process LiDAR data in real time.

The choice of the Raspberry Pi 4 is justified by its accessibility, ease of use and compatibility with the ROS2 (Robot Operating System) framework, which was used for the control of the mapping system. ROS2 is a widely adopted middleware in robotics for its modularity and ability to support the integration of different types of sensors and actuators. In this case, ROS2 was essential to enable the collection of data from the LiDAR sensor and the execution of mapping algorithms and autonomous navigation.

The experimental platform was configured to simulate the real environment of an industrial plant, where mapping and navigation are critical for the automation of logistics processes. The system was tested in three distinct scenarios to assess its accuracy, robustness, and adaptability to different spatial configurations. Figure 1 presents the system diagram, highlighting the key components and integration between the LiDAR sensor, the Raspberry Pi, and the ROS2 software.

Figure 1: Diagram of the didactic hardware system used for indoor mapping, including the LiDAR sensor, the Raspberry Pi 4, and the integration with ROS2.



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DATA COLLECTION

The data was collected through experiments carried out in three test scenarios, which were designed to simulate different levels of spatial complexity and challenges encountered in real industrial environments. The scenarios were:

Scenario 1 – Empty room: A simple environment, without obstacles, where the objective was to test the system's ability to map open spaces efficiently and quickly. This scenario represents industrial areas such as warehouses or loading and unloading areas. (Figure 2)

Scenario 2 – Intersection of aisles and doors: A more complex environment, with intersections and changes in direction, where the system has been tested on its ability to navigate aisle environments, which are typical in factories and warehouses. The accuracy of the system when dealing with irregular intersections and routes was evaluated in this scenario. (Figure 3)

Scenario 3 – Environment with furniture and obstacles: An even more complex space, with obstacles such as furniture and other objects that simulate industrial equipment and machinery. This scenario is designed to test the robustness of the system in detecting obstacles and navigating in dynamic environments. (Figure 4)

Data collection was carried out in real-time, with the hardware system capturing the readings from the LiDAR sensor and processing this information to generate maps of the environment. In addition, the trajectories of the mobile robots were recorded for further analysis. The study participants, composed of workers in the requalification phase at the Manaus Industrial Pole (PIM), interacted directly with the system in practical workshops, where they were able to observe and manipulate the mapping in real time.

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Figure 2: Representative image of scenario 1 (empty room) with the mapping trajectory performed by the LiDAR system.

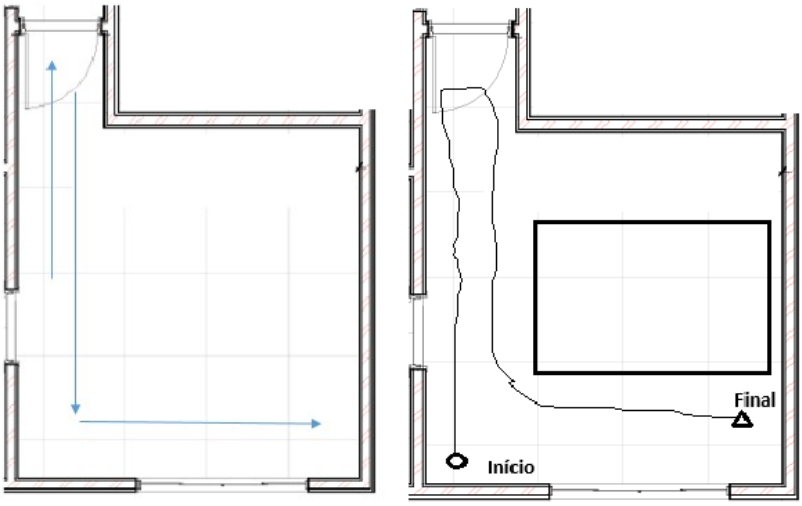

Figure 3: Image of scenario 2 (intersection of corridors and doorways), highlighting the intersections and navigation challenges.

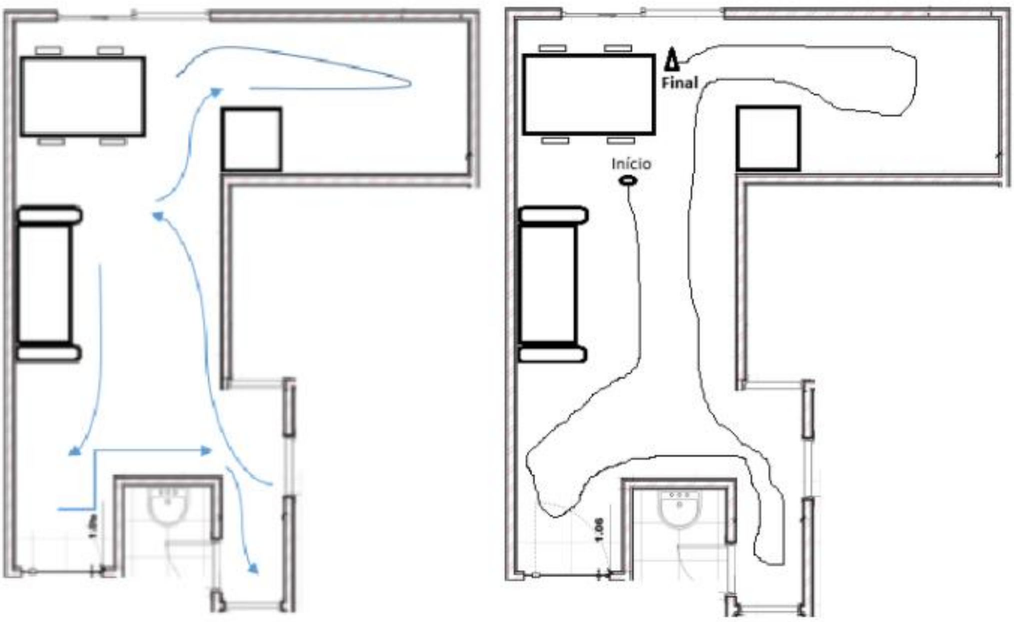

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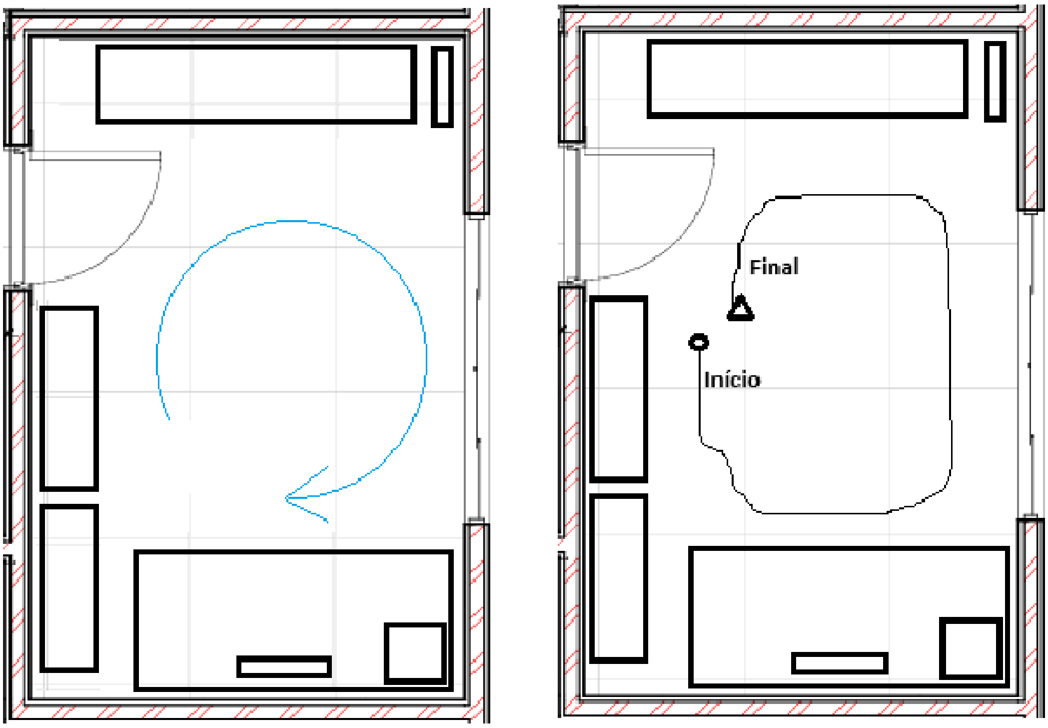
Figure 4: Image of scenario 3 (environment with furniture and obstacles), showing the obstacles and the trajectory taken by the mobile robot.



DEFINITION OF SCENARIOS

The selection of the test scenarios was made based on simulations of typical industrial environments, such as storage areas, factory corridors and machine shops. Each scenario was designed to represent an increasing level of difficulty, in order to evaluate how the mapping system would behave in different contexts. The sample of workers was composed of technical professionals who participated in requalification programs in the PIM. These workers were chosen because they represent a direct target audience of Industry 4.0 technologies, with the need to update technical skills to deal with autonomous systems and enabling technologies.

The choice of these participants is in accordance with the objective of the study, which is to test the hardware system as an educational tool for professional reskilling. The workers involved had familiarity with industrial environments, but little or no prior experience with autonomous systems or LiDAR technology. This allowed them to evaluate the effectiveness of the hardware system as a practical teaching platform.

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ANALYSIS OF THE RESULTS

The analysis of the collected data was conducted using Mean Absolute Error (MAE) and Spatial Resolution metrics to compare the maps generated by the system with the floor plans of the tested environments. MAE was used to measure the accuracy of the distances estimated by the system compared to the actual distances, while Spatial Resolution was employed to evaluate the quality of the generated maps, focusing on their ability to identify details of the environment.

In addition, the results obtained by the mapping system were compared with commercial solutions available on the market, such as home cleaning robots and autonomous vehicles used for transporting goods. This allowed us to establish a performance benchmark to assess the feasibility of the proposed system. The data were analysed using statistical tools to ensure the validity of the results and allow the generalisation of the conclusions to other industrial contexts.

To complement the quantitative analysis, qualitative observations were carried out during the practical workshops, where the workers interacted with the system. These observations included feedback on the system's ease of use, learning curve, and applicability in real-world industrial scenarios. Feedback from participants was coded and analyzed to identify strengths and areas for improvement in the system's design.

CONCLUSION OF THE METHODOLOGY

This study used an experimental design to test an indoor mapping system based on didactic hardware, focusing on educational and industrial application. The use of the LiDAR sensor, integrated into the Raspberry Pi 4 and ROS2, has proven effective in creating accurate maps and autonomous navigation in different scenarios. The data collection in the three scenarios allowed us to evaluate the robustness and accuracy of the system, which was successful in both simple and complex environments. The analysis of the data indicated that the system has the potential to be used as an educational tool for the requalification of PIM workers, preparing them for the requirements of Industry 4.0.

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Table 1: Profile of the study participants, including previous experience in industrial environments and level of familiarity with Industry 4.0 technologies.

MODULES	ACTIVITIES	SKILLS	KNOWLEDGE	SKILLS	ATTITUDES
1 - Preparation of the Rapsy plate	Installation of the operating system of the processing board, and preparation of the ROS2 environment, updating packages in the system.	Minimum knowledge and experience of handling the Linux platform	Knowledge in embedded operating systems, software installation.	Ability to install and configure embedded systems, solve technical problems. Update and manage packages on a Linux system.Prepare the ROS2 development environment, ensuring version compatibility.	Proactivity in problem solving, attention to detail, Organization and attention in carrying out the installation steps to avoid future mistakes.
2 - Study of the peripherals used in the mapping prototype	Understanding of what a LiDAR sensor is and the power supply part of the prototype, scoring the minimum specifications for use. Understanding of the sensor's operation and operating peculiarities: working frequency, actuation angle, number of beams emitted.	Notion of hardware and interconnection of computer peripherals.	Knowledge in hardware, sensors and interconnection of peripherals.	Ability to integrate hardware with software, understanding sensors and peripherals. Identify and understand the minimum specifications for LiDAR sensor use.	Collaboration and effective communication with technical teams, investigative posture. Attention to detail to ensure electrical safety and correct system power.
3 - Study of the ROS 2 framework	The entire architecture of the operation of the frammework will be presented, pointing out the type of interaction between packages and types of messages exchanged.	Familiarity with programming languages	Knowledge of frameworks and software architecture.	Skills in programming and use of development frameworks. Map how different components of ROS2 interact to create an integrated system.	Technical curiosity, adaptation to new technologies.
4 - Practical integration module	The integration of the sensor will be carried out together with the processing board. Required installation of packages and configuration of the sensor driver. An understanding of how to generate the point cloud read by the sensor will be acquired in a virtal way, through Rviz	Need for python language	Knowledge of hardware and software integration.	Ability to integrate complex systems.	Ability to work under pressure, critical posture. Willingness to learn new concepts and techniques of communication between systems.

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5 - Practical test of the operation of the prototype	The unified test of the entire prototype will be carried out, the operation and execution commands of the packages necessary to carry out the mapping will be worked on. At the end of the mapping, the storage functionality of the generated map will be used through the tool command, and the storage directory will be directed.	Interconnection of components, and correct functioning of packages	Knowledge about integrated systems testing.	Skill in systems testing, fault identification, handling of integrated systems in the acquisition of physical data.	Responsibility, focus on quality and precision.

RESULTS

MAIN RESULTS

The experiments carried out with the proposed hardware system demonstrated very positive results in terms of accuracy and efficiency in mapping the three test scenarios.

In the first scenario, the simplest environment, which consisted of an empty room, the system obtained a Mean Absolute Error (MAE) of 2.5 cm. This indicates a high accuracy in mapping open and unobstructed areas, which is ideal for environments such as warehouses and loading and unloading areas in factories. The simplicity of the environment allowed the RPLIDAR A1M8 LiDAR sensor to capture accurate information from walls and surfaces without significant interference.

In the second scenario, which consisted of an intersection of aisles and doorways, the system was able to accurately map the most complex changes in direction and routes, albeit with a slight increase in processing time. The MAE in this scenario was slightly higher, reaching 3.2 cm, which still represents an acceptable level of accuracy, especially in dynamic industrial environments, where routes and intersections are common. This scenario simulated factory areas with narrow aisles and intersections, a type of environment that requires greater autonomous navigation capability.

In the third scenario, the most complex, with furniture and obstacles, the system presented a MAE of 4 cm, which is expected in environments with a higher density of objects. The presence of obstacles increased the time needed to process the information and perform the mapping, but the system was able to accurately identify and map these obstacles. This scenario simulated more challenging industrial areas, where there is a

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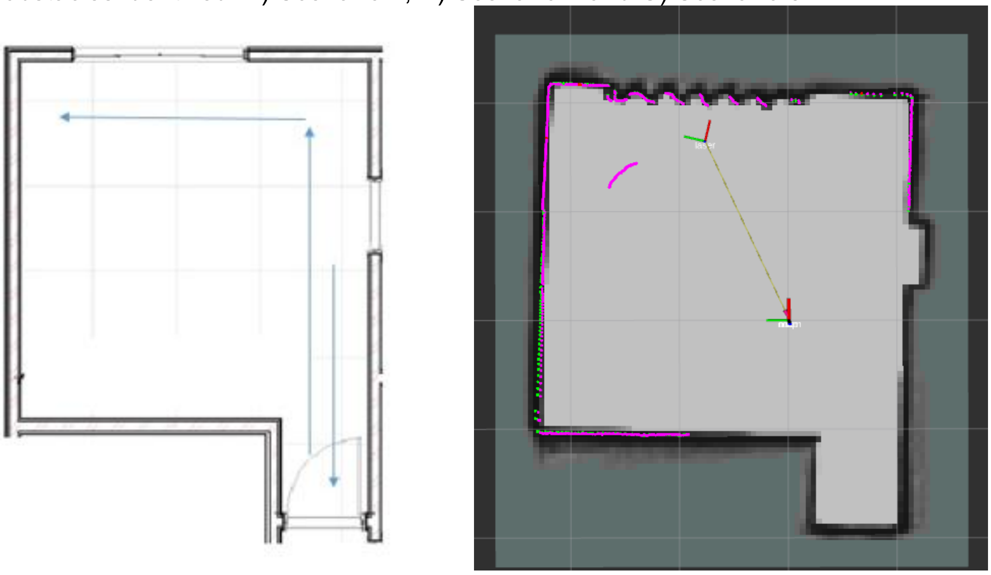
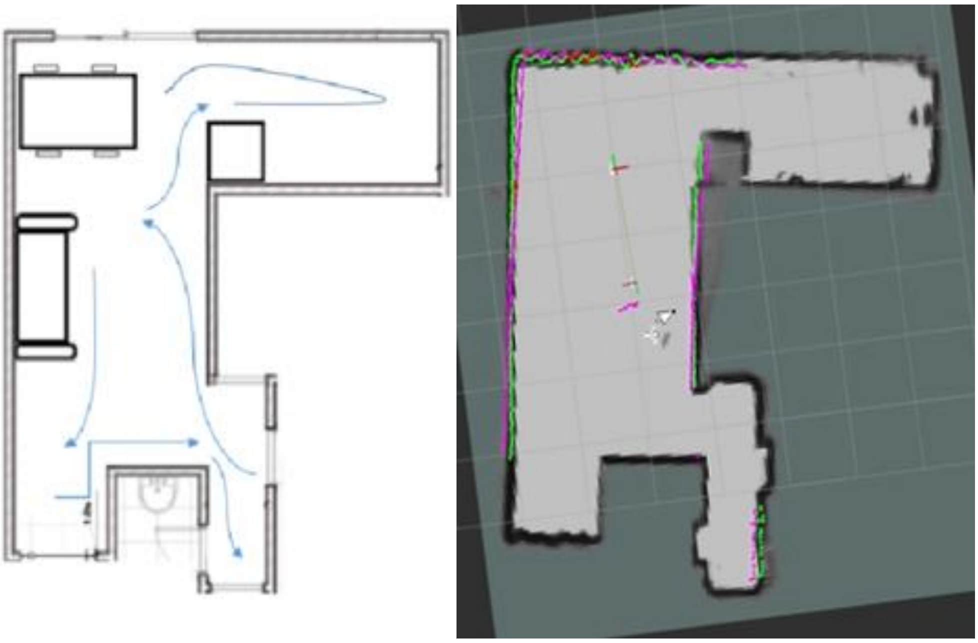
higher concentration of machinery and equipment, and where the system's ability to detect obstacles in real time is crucial.

Figure 5: Visual representation of the system-generated maps for each test scenario, highlighting the accuracy and obstacles identified. A) Scenario 1, B) Scenario 2 and C) Scenario 3



A) Scenario 1



B) Scenario 2

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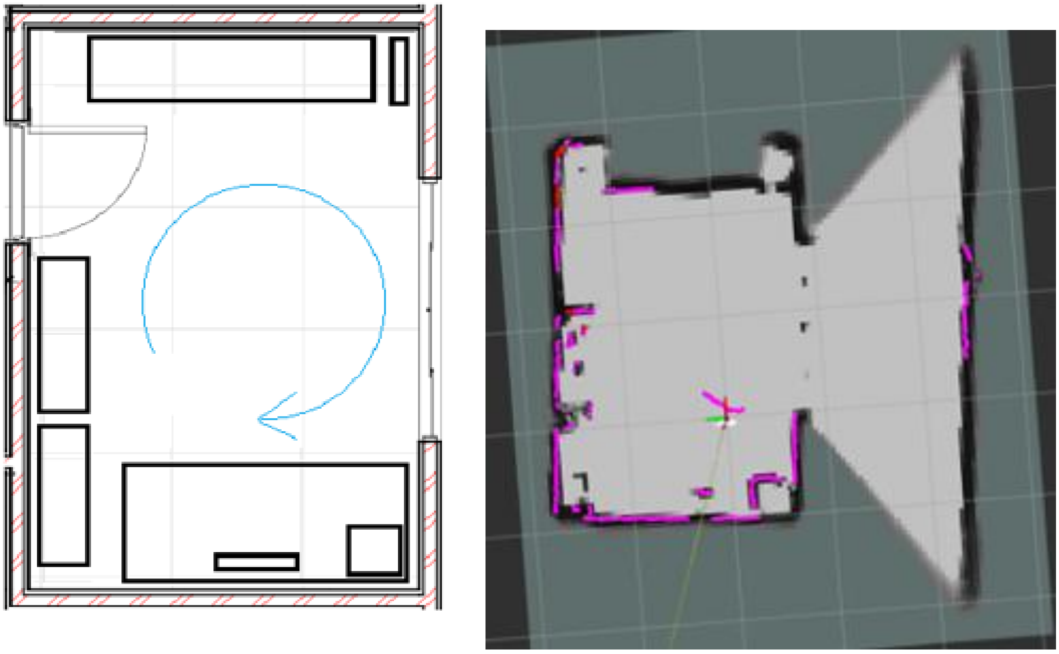

C) Scenario 3

- In item (A), the highlight is the reading accuracy, so that it is possible to distinguish the presence of a curtain in the background of the image, and due to the recess in the wall, it is possible to observe where one of the doors of the room is located.
- In item (B), the same element can be observed, the curtain at the bottom of the image, however we have other components present, with the intersection of the corridor.
- In item (C), it is possible to observe a series of objects detected within the environment, such as the small contour of the support of the shelves, and the objects present in it. An interesting fact of this environment is the presence of a glass window, which allows the laser beam to pass through, even when closed, generating this conical formation on the side of the captured image.

DATA ANALYSIS AND INTERPRETATION

The analysis of the data collected from the three scenarios reinforces the effectiveness of the proposed system in terms of accuracy and applicability in industrial environments. Compared to commercial mapping systems, such as household cleaning robots and autonomous vehicles used in industries, the system developed in this study

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proved to be competitive, especially when considering the significantly lower cost of the hardware used.

Household cleaning robots, for example, use similar sensor technology for navigation and mapping, but the system proposed in the study offers greater flexibility, as it was developed to be a didactic tool. The modularity of the system and the integration with the ROS2 framework allow for a customized adaptation to different industrial scenarios and environments, something that standardized commercial robots cannot do with the same ease. Table 2 presents a comparison between the commercial systems and the proposed system, highlighting the main performance criteria, such as cost, accuracy and adaptability.

The use of ROS2 in the system also facilitated the collection and analysis of LiDAR sensor data in real time. In addition to enabling autonomous navigation, ROS2 offered support for the integration of other sensors, such as depth cameras or ultrasonic sensors, which could be a future advantage for system enhancement. The combination of the LiDAR sensor with the ROS2 was a key factor in obtaining the results, as this integration allowed the creation of a modular and expandable system, ideal for educational and industrial purposes.

Table 2: Performance comparison between the proposed hardware system and commercial mapping and navigation systems.

Feature	Structure Sensor MARK PRO	ZEB Scan	RP LiDAR A1M8
Sensor Type	Depth and infrared sensor	Portable LiDAR	Rotary LiDAR
Main Application	3D scanning of objects and indoor environments	3D mapping for indoors and outdoors	2D mapping and basic navigation for robots
Resolution	Average	Discharge	Average
Reach	Up to 3.5 meters	Up to 100 meters (depending on model)	Up to 12 meters
Precision	Approximately 1%	Approximately 1-3 cm	2% error for 6-meter distance
Refresh Rate	About 30 frames per second	About 300,000 points per second	8,000 points per second
Real-Time Mapping	Yes	Yes	Yes
Analysis Software	Compatible with multiple 3D capture platforms and apps	Proprietary software and integration with other platforms	Compatible with ROS systems and other APIs
Portability	Portátil, juice	Portable, easy to carry	Compact, ideal for small robots
Price	Approximately \$500 - \$600 USD	Approximately \$20,000 - \$50,000+ USD	Approximately \$100 - \$150 USD
Flexibility	It has an application aimed at small projects, but with medium complexity of details.	Robust applicability for mapping large areas, such as building and stadium works.	Smaller application, due to the low frequency, requires the slowest mapping speed.

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Educational Applicability	It is possible to use it in didactic applications, but it requires a drive integrated with the Structure SDK for operation in ROS2. It is designed for integration with using this tool mainly for iOS devices.	It does not have an applicability, due to the high cost of acquisition and the lack of integration available. As a commercial tool, it works on a dedicated software.	Fully compatible with educational applicability, RPLiDAR's proposal is to offer easy integration to the ROS2 framework, already having several packages in repositories, another great positive point is its low acquisition value.
			

RESEARCH QUESTION REVIEW

The results obtained with the three test scenarios support the initial hypothesis that a didactic hardware system, based on LiDAR and AMR technologies, can be an effective tool to train workers in Industry 4.0. The accuracy achieved in all three scenarios demonstrates that the system is robust enough to handle different types of industrial environments, from the simplest to the most complex.

The modularity of the system allowed it to be adjusted to handle the variability of scenarios, which is crucial in real industrial environments, where frequent changes in layout and the presence of new obstacles are common. This adaptability is an important characteristic in training processes, as workers need to be exposed to a variety of situations and challenges to acquire robust technical skills. Additionally, the system's ease of use and its ability to generate real-time maps provide an immersive learning experience, which is essential for hands-on training.

The system's ability to identify obstacles and accurately map industrial environments is an indicator that it can be utilized in a variety of educational applications. For example, in workshops and reskilling programs, workers can interact directly with the system, learning to program and operate enabling Industry 4.0 technologies. This practical experience is fundamental for the transition from theory to practice, something that was reinforced by the positive feedback from the study participants. Table 2 summarizes the main results obtained

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in the three test scenarios, focusing on the challenges faced and the solutions offered by the system.

Table 3: Summary of the key results of the three test scenarios, including the specific challenges of each scenario and the solutions provided by the system.

Scenario 1 (Room without obstacles)	Scenario 2 (Room and corridor)	Scenario 3 (Room with furniture, cabinets and tools)
Simple mapping scenario, mapping carried out without the need and large displacement, simple reading structure. Highlight point, mapping accuracy, being able to identify the undulation of a window curtain.	Scenario with moderate mapping difficulty, displacement carried out on a longer route. It was successful in mapping the environment, easy detection and reading of points with intersections	Scenario of greater complexity, with the presence of objects of different sizes and shapes, coherent identification of objects and support points. A highlight is the reading of a glass window, which allowed the passage of the laser beam, formed a conical image at one of the lateral ends of the map according to the sensor's angle of exposure.

In terms of cost-effectiveness, the proposed hardware system is a highly viable solution for educational and training programs. The use of affordable components, such as the Raspberry Pi and the LiDAR sensor, combined with the flexibility of ROS2, makes the system an attractive alternative for educational institutions that want to implement practical robotics and automation labs without a high investment. This provides institutions with the opportunity to better prepare their students and workers for the technological demands of Industry 4.0, ensuring that they acquire essential skills to operate in highly automated and connected environments.

DISCUSSION

The results presented indicate that the proposed hardware system was successful in achieving the objectives established for indoor mapping in three different industrial scenarios. The first scenario, a fourth void, represented the simplest environment and provided a basis for evaluating the accuracy of the system without the interference of obstacles. The observed low margin of error (2.5 cm) demonstrates the effectiveness of the LiDAR sensor in capturing distance data accurately, especially in environments with few elements that could interfere with laser readings. This result is consistent with the literature dealing with the application of LiDAR in simple industrial settings (Shan and Toth, 2018).

In the intersection of aisles and doorways, the system faced additional challenges, as the need to process multiple directions and routes increased the complexity of mapping. The slight increase in the Mean Absolute Error (MAE) to 3.2 cm was considered acceptable, given the complexity of the environment. The system's ability to accurately map

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intersections reinforces its viability for industrial environments where narrow corridors and route changes are common. This result is in line with studies of autonomous mobile robotics (Siciliano and Khatib, 2016), which highlight the importance of systems capable of handling dynamic and unstructured scenarios.

In the third scenario, the most challenging, which included furniture and obstacles, the system presented an MAE of 4 cm. Although this value is higher than in previous scenarios, it is still within an acceptable margin for industrial environments with high obstacle density. The accuracy in detecting and mapping obstacles is indicative of the robustness of the system and its applicability in places with machines and equipment that change position frequently. The combination of the LiDAR sensor with the ROS2 framework has enabled efficient autonomous navigation, as described by Hermann et al. (2016), who point out the importance of integrating sensors and robust software to ensure efficient response in industrial environments.

COMPARISON WITH THE RESULTS OF THE LITERATURE

The findings of this study corroborate the existing literature on the use of Industry 4.0 technologies, such as AMRs and LiDAR, for mapping and autonomous navigation in industrial environments. The study by Siciliano and Khatib (2016) highlights the importance of advanced sensors, such as LiDAR, for the creation of autonomous systems capable of operating in dynamic and complex environments, such as the Manaus Industrial Pole (PIM). The system proposed in this study offers a more accessible and adaptable solution, especially for worker training programs.

Compared to commercial systems, the proposed didactic hardware proved to be competitive in terms of accuracy and flexibility, with the added advantage of being an educational tool. Home cleaning robots and industrial autonomous vehicles, which use similar technologies, have their functionalities limited to specific and pre-programmed contexts. However, the system developed in this study, in addition to being affordable, can be customized for a variety of industrial and educational scenarios. The use of the ROS2 framework, which is widely used in robotics for its modularity, was essential

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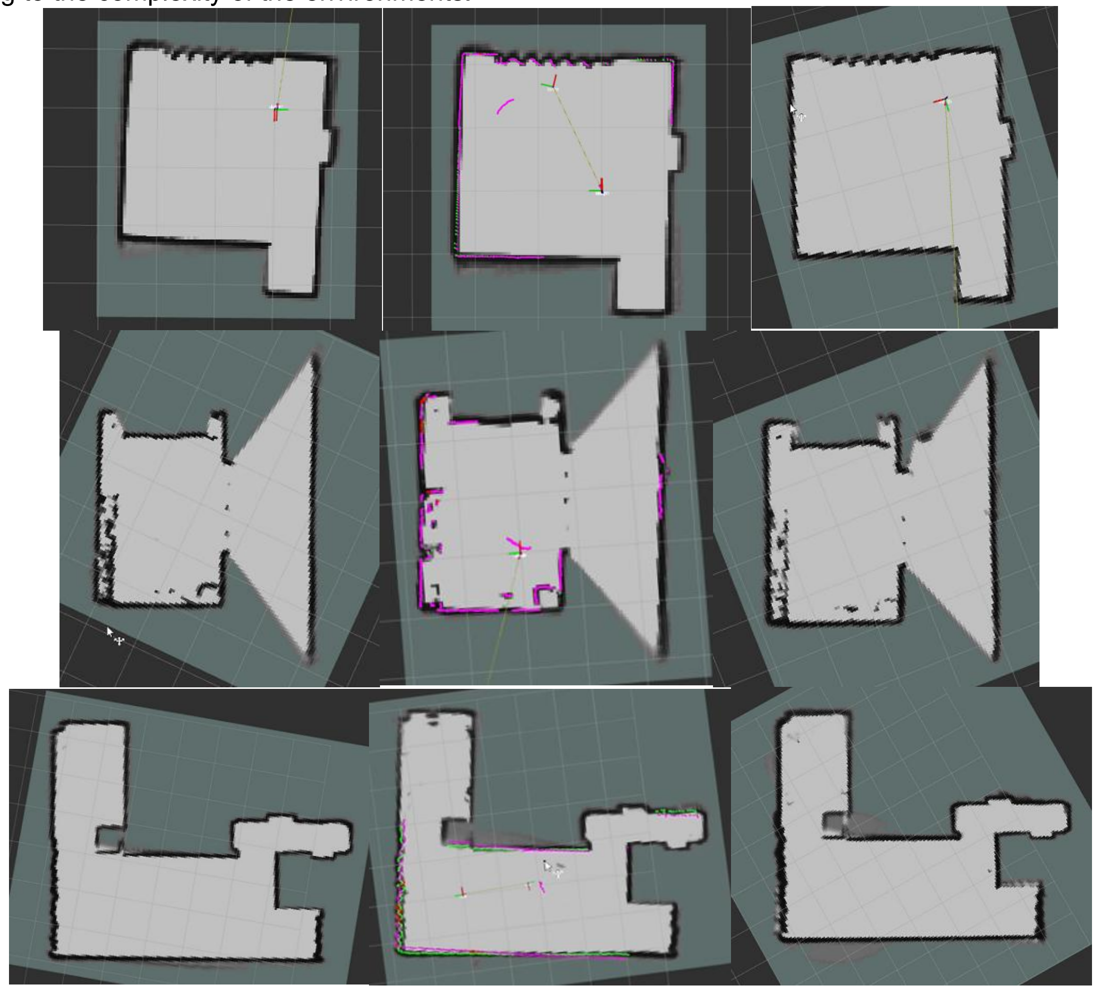
Figure 6: Comparative graph of the MAE values between the three scenarios, highlighting the error variation according to the complexity of the environments.



to obtain these results. Studies such as Schwab's (2016) emphasize the need for flexible and easy-to-integrate technologies to meet the demands of Industry 4.0, and this study contributes to this discussion by proposing a solution that can be replicated in different industrial and educational contexts.

In addition, the modularity of the system, highlighted by Pérez-Álvarez et al. (2018), offers a significant advantage in terms of reskilling workers. Learning in progressive modules facilitates the assimilation of technological skills in an efficient and practical way, something that is necessary in fast-moving environments, such as PIM. The approach of dividing learning into blocks that can be adjusted as the learner progresses was validated by the results of the experiments, in which workers were able to interact directly with the system and understand the steps involved in mapping and autonomous navigation.

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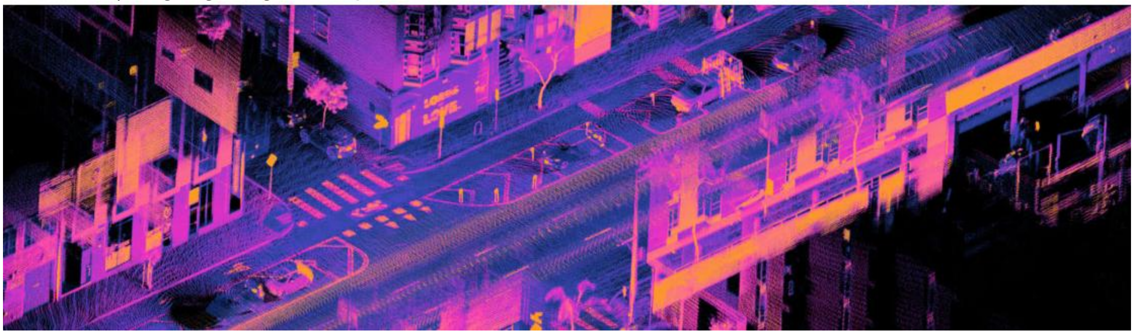
IMPLICATIONS AND LIMITATIONS OF THE STUDY

The results of this study have important implications for both the field of educational robotics and the training of workers in Industry 4.0 technologies. The proposed didactic hardware system offers an accessible and practical platform for teaching emerging technologies, such as LiDAR and AMRs, which are critical to the future of industrial operations. The accuracy of the results obtained in the three scenarios demonstrates that the system can be used in both educational settings and real industrial contexts, providing a hands-on learning experience for PIM workers.

However, the study also has some limitations. The first of these is the fact that the experiments were conducted in controlled environments, which may not reflect all the variables present in a real industrial environment. Although the three scenarios were designed to simulate typical industrial conditions, such as aisles and moving obstacles, the absence of factors such as constant movement of machines and workers may have impacted the results. Future studies should explore the application of the system in real industrial settings, where interaction with external variables can provide a more comprehensive assessment of its effectiveness.

Another limitation is related to the scalability of the system. While the hardware used is affordable, implementing additional sensors, such as depth or ultrasonic cameras, can increase the cost and complexity of the system. The integration of these sensors, while potentially improving accuracy, must be balanced with the educational objectives and resources available for training programs.

Figure 7: Visual representation of the evolution of the system with the integration of additional sensors (LiDAR + depth cameras), highlighting the improvements and associated additional costs.



https://www.pix4d.com/pt/blog/lidar-photogrametria/

Above we can see what looks like a photo taken with pink and yellow tones, however this image represents the mapping of an intersection with LiDAR technology. An interesting

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point to highlight is that LiDAR technology alone would not be able to enrich so many details in this image, for this a camera is used to assist, applying what we call "texture", combining the shapes obtained by LiDAR, with the images captured by the camera, so we notice the presence of items such as paintings, the crosswalk and the writing on the wall next to it, details that could not be represented only with mapping using LiDAR technology. To add this functionality, the cost considered would be a good camera to capture details in the same proportion as the LiDAR used.

CONCLUSION OF THE DISCUSSION

The study showed that the didactic hardware system, composed of LiDAR and AMR, is an effective solution for the training of workers in Industry 4.0. The accuracy in mapping different industrial scenarios and the flexibility of the system make it a valuable tool for both educational and industrial purposes. The practical implications of this study reinforce the importance of investing in accessible and adaptable technologies, especially in regions such as the Manaus Industrial Pole, where there is a growing demand for professional retraining. However, future research in real industrial environments and the integration of additional sensors may further expand the applicability and robustness of the system.

CONCLUSION

This study developed and tested a didactic hardware system based on LiDAR and autonomous mobile robots (AMR) for the mapping of indoor environments, with the aim of training workers in Industry 4.0 technologies. The research was conducted in three test scenarios, which ranged from simple to more complex environments, representing different industrial challenges. The results indicated that the proposed system was able to accurately map the three scenarios, with margins of error ranging between 2.5 cm and 4 cm, depending on the complexity of the environment.

The system's performance was particularly effective in simple scenarios, such as the empty room, but it also demonstrated robustness in dealing with obstacles and intersections in the most complex scenarios, such as corridors and areas with furniture and equipment. The use of the LiDAR sensor combined with the ROS2 framework has proven to be an efficient solution for real-time data collection and mapping, which reinforces the applicability of the system in industrial and educational contexts.

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The modularity of the hardware system allowed adaptations that met the requirements of different scenarios, proving to be a flexible tool for professional requalification in the Manaus Industrial Pole (PIM). In addition, the study demonstrated that the system can be used to simulate typical industrial environments, which is fundamental for worker training programs in Industry 4.0. Thus, the system not only met the requirements of accuracy and efficiency, but also provided a practical platform for the development of technical skills among participants.

MAIN CONTRIBUTIONS

This work contributes significantly to the field of educational robotics and training in emerging technologies, by proposing a low-cost and easy-to-implement platform. The developed system fills an important gap by providing a practical and affordable solution for the application of Industry 4.0 enabling technologies in educational and training contexts. In addition, the use of an affordable LiDAR sensor and a low-cost processor, such as the Raspberry Pi, makes the system a viable alternative for institutions looking to offer technological training without large financial investments.

The modularity and flexibility of the system are other highlights By allowing adaptation to different industrial scenarios, the system demonstrates its potential to be used in a variety of contexts, from small manufacturing environments to large industrial plants. In addition, the proposed educational platform can be adapted to different levels of complexity, from basic training to specialization in advanced technologies, which makes it a highly versatile tool for the training of qualified professionals for Industry 4.0.

The research also offers an important contribution by highlighting the importance of didactic hardware systems in the process of professional retraining. By providing a platform that allows for the simulation of real industrial environments, the system allows workers to gain hands-on experience with cutting-edge technologies, which facilitates the transition from theory to practice. This is particularly relevant in regions such as the Manaus Industrial Pole, where the need for technological qualification is high and access to advanced educational solutions is still limited.

RECOMMENDATIONS FOR CONTINUITY IN FUTURE WORK

While the results of this study were promising, there are several opportunities for future research that could expand the reach and applicability of the developed hardware system.

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Firstly, it would be interesting to explore the implementation of the system in real industrial environments, where navigation and mapping challenges are more dynamic and complex than in controlled environments. This would make it possible to evaluate the effectiveness of the system in real industrial conditions, considering factors such as the constant movement of machines, vehicles and workers, which were not replicated in the controlled scenarios of this study.

Another area of future research is the integration of additional technologies into the system, such as depth cameras and artificial intelligence (AI) algorithms. The combination of LiDAR with depth cameras can further increase mapping accuracy, especially in environments with complex height variations or in areas with a high density of objects. In addition, the incorporation of AI would allow the system to learn from interactions in the environment, improving its ability to navigate autonomously and detect obstacles over time.

Finally, it would be interesting to carry out studies that evaluate the impact of the use of hardware-based educational systems on learning and the retention of technical knowledge among professionals in retraining. Research that explores the impact of hands-on learning on student motivation and performance can offer valuable insights for the development of new educational methodologies. In addition, longitudinal studies could track the progress of workers using the system in training programs, measuring the long-term impact on the adaptation and development of their technological skills.

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REFERENCES

1. Atzori, L., Iera, A., & Morabito, G. (2010). The Internet of Things: A survey. Computer Networks, 54(15), 2787–2805.

2. Lopes, R. C. (2016). Desenvolvimento econômico e urbanização: o impacto do Polo Industrial de Manaus na cidade de Manaus. Revista de Economia Contemporânea, 20(1), 99–118.

3. Barrows, H. S., & Tamblyn, R. M. (1980). Problem-Based Learning: An approach to medical education. Springer.

4. Hermann, M., Pentek, T., & Otto, B. (2016). Design principles for Industrie 4.0 scenarios: A literature review. Technische Universität Dortmund.

5. Ivanov, D., Dolgui, A., & Sokolov, B. (2019). The impact of digital technology and Industry 4.0 on the ripple effect and supply chain risk analytics. International Journal of Production Research, 57(3), 829–846.

6. Kagermann, H., Wahlster, W., & Helbig, J. (2013). Recommendations for implementing the strategic initiative INDUSTRIE 4.0. Final report of the Industrie 4.0 Working Group.

7. Pérez-Álvarez, M. R., García-Prieto, F. J., & Pérez-López, M. C. (2018). Modular learning: An innovative and effective approach for continuous training in the workplace. Journal of Workplace Learning, 30(2), 1–12.

8. Schwab, K. (2016). The fourth industrial revolution. World Economic Forum.

9. Shan, J., & Toth, C. (2018). Topographic laser ranging and scanning: Principles and processing (2nd ed.). CRC Press.

10. Siciliano, B., & Khatib, O. (2016). Springer handbook of robotics. Springer.

11. Sousa, M. N., Pereira, R. G., & Teixeira, M. M. (2018). Institutos de pesquisa e desenvolvimento e sua contribuição para a inovação no Polo Industrial de Manaus. Revista de Gestão e Projetos, 9(1), 88–109.

12. Teixeira, C. V., & Razzolini Filho, E. A. (2010). O Polo Industrial de Manaus e a Indústria 4.0: Oportunidades e desafios. Revista Brasileira de Inovação, 9(2), 312–328.