Industry 4.0: Wearable IoT Device Applied to Warehouse Management

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Abstract: Companies in the retail sector need proper control of their stock to avoid financial waste and guarantee the effectiveness of their operations. A more detailed analysis of this problem reveals the complexity of implementing a management methodology that enables optimal control of all stock, since human errors occur during operations and various scenarios depend on different variables. Therefore, to solve the problem of efficient warehouse stock management and the resulting inefficiency of operations, this study proposes the implementation of a wearable, developed using a Raspberry Pi 4B with IoT and Node-Red, in conjunction with a mobile device, which assists operators during the processes of stocking, searching for and removing material from the warehouse more efficiently. As a result, the proposed system can identify, by reading an RFID tag with a mobile device, the characteristics of the equipment in question, showing all this information on an OLED display, as well as directing what will be done with this equipment via an app. Among the metrics that demonstrate the effectiveness of the proposed system is the time taken to stock and remove the material, since all the procedures are managed in real-time on the app and updated in its inventory control.

1 INTRODUCTION

The purpose of having a stock in a company is based on the notion that certain products or materials are expected to be used later, to meet market demand or internal demand. Among its many functions, the following can be mentioned: Increased scale in the retail and transport sectors, protection against price increases, as well as safeguarding the organization against uncertainties in demand and replenishment times. In a nutshell, stockpiling provides a better balance in terms of the organization's operations, making it possible to reduce labor costs and maximize installed capacity. (Bertaglia, 2012) To have access to these functionalities, it is often necessary to spend a lot of money, but stocks guarantee safety levels in complex and uncertain environments. (Gonçalves, 2013)

In this context, efficient stock management is essential, and there are alternatives to help this complex process. Among them, the use of technology, leveraged by the advent of Industry 4.0, has become increasingly attractive. This is justified by its potential to be used on a large scale, at an increasingly affordable cost, and because it incorporates challenges that are on the frontier of human knowledge, with the potential to revolutionize sectors in the field of logistics.

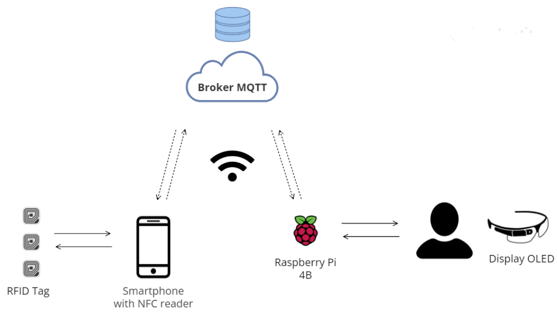

Figure 1: Schematic diagram of the proposal architecture.

The fourth industrial revolution, or industry 4.0, seeks to increasingly integrate various productive sectors, with machinery and devices connected, forming a complex and robust system. In this context, this in-

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dustry has six important attributes in terms of project management: The Internet of Things, cyber-physical systems, Big Data, automation, artificial intelligence, and cloud computing. (Borges et al., 2022)

From the current market reality, one case worth highlighting concerns order picking, since it is seen as a laborious, arduous, time-limited, repetitive, error-prone, and expensive process in warehouses. These characteristics put a significant strain on the human worker, creating fatigue and feelings of monotony, as well as dissatisfaction, generally leading to poor performance and employee demotivation.(Ponis et al., 2020) (Rejeb et al., 2020)

Because of this reality, one of the most prominent technologies in Industry 4.0 has begun to be used when it comes to manufacturing and logistics operations, which is Augmented Reality. It uses computer-generated displays, sound, text, and effects to enhance the user experience in the real world and support workers in their daily tasks, such as assembly, order picking, and maintenance. (Plakas et al., 2020)

This article aims to present a proposal for a system that uses an IoT wearable device to optimize operations within a warehouse, using a low-coast system to read RFID tags within an smartphone, and provide essential data to the wearable. To this end, this article is divided into related works, the state of the art in wearables in Industry 4.0, an overview of the proposed system, the methodology used, and, finally, the respective results and discussions.

2 RELATED WORKS

This section presents the related works in the literature, providing an overview of how Industry 4.0 technologies can be applied in a warehouse scenario.

Recent works in the literature include (Hamdy et al., 2022), which aimed to propose a system that uses the Node-Red platform to apply the Internet of Things in a warehouse scenario. Based on a database, it was possible to manage inventory and forecast stock demand, using both quantitative and qualitative methods. In this context, the system could not be tested in a real warehouse, nor did it implement a user interface with a dashboard linked to Node-Red for real-time visualization of all inventory, which the author suggests as an opportunity for application in future work.

For the entire warehouse to communicate with the internet, it is necessary to have middleware that is also capable of receiving information from the materials and interacting with the user. Among the various devices that have this potential, the Raspberry Pi 4 Model B was an option used in the (Silapunt et al., 2022) study. Using this middleware, an intelligent manual pallet truck was created, whose installed Raspberry Pi processed and uploaded the data received on the server via the local Wi-Fi network and, with the web application developed, analyzed this data and carried out specific warehouse activities.

Based on (Periša et al., 2018), it can be seen that wearable devices are applicable to warehouse management. Through this study, a smart wearable bracelet was created, which had RFID tag readers, NFC, and a Bluetooth connection. When wearing the smart wristband, the user receives all the relevant information collected from the smart warehouse environment and can read barcode information from products and pallets. In addition, the user obtains the information needed to determine the location of specific pallets of products.

3 STATE OF THE ART IN WEARABLES FOR INDUSTRY 4.0

3.1 Augmented Reality in Warehouses

A use case is presented in a study on the possibilities of augmented reality in warehouse management. In this study, the global supply chain of the logistics company DHL is evaluated, which is one of the first companies to introduce augmented reality technology. The entire system runs on a platform, where a worker uses a smart glasses, like Vuzix, and a ring scanner to collect goods.

These devices provide the operator with various functions and information, starting with the operator's login, and visual aids displayed graphically through the glasses, where the user will see on the graphical tool the exact location of the goods, the quantity they should select and the next item. This information guides the worker precisely, quickly, and efficiently to a particular order item.

Therefore, this method of picking goods is much more efficient than the classic form of paper picking. Finally, about worker training and integration into the work process, it can be said that this technology is not difficult to use and can be quickly learned by the worker.(Husár and Knapčíková, 2021)

3.2 Wearable Devices in Inventory Management

The use of digital resources has proven to be a facilitator inefficient inventory management, which enables it to even be a crucial requirement in the market, since dealing with large-scale data is not a simple task, and through its use, new insights can be investigated for improvements in the supply chain process, as noted by (Anusha et al., 2022).

In this context, in a world of scarce resources, the use of information converted into knowledge is essential not only today but also for the future of humanity. Thus, this creation and utilization of knowledge is a basic condition in the supply chain, and inventory management must be supported by intelligent algorithms and modern heuristics that use this knowledge to avoid overstocking while combating stock shortages or losses (Cimen et al., 2021) (Manuel Vera, 2021).

3.3 Communication Between Hardware and RFID Sensors

Well-known logistics companies such as Amazon use sensors to optimize processes in which it is necessary to identify several items simultaneously, which would be too slow and error-prone without this implementation. Its application can extend even to the food industry since there are studies in which RFID tags are integrated with chip-free sensors to measure humidity, temperature, gas concentration, and pH. (Fathi et al., 2020)

The way it is applied varies according to need since this technology can be molded for different types of use. Analyzing the behavior and monitoring the movement of a visitor in a museum, for example, can be done using a set of mobile antennas and passive RFID tags. The embedded system was made up of an RFID reader, a 10-axis inertial management unit, and a logger that allows internal localization based on the detection of multiple tags located in known positions along the visitor's route. This approach was tested in simulation and in real museum practice.(Vena et al., 2021)

However, the biggest challenge that discourages the implementation and full benefits of Industry 4.0 technologies are the costs involved with the technology. In the supply chain, the implementation of RFID technology is hampered by the cost of RFID tags and adoption problems. The costs involved with the useful life of the systems tend to make organizations reluctant to implement these Industry 4.0 technologies and, in the case of organizations that have already implemented the technology, they tend to fall behind in maintaining these systems due to the costs and the inaccuracies of the system, since the lack of maintenance makes the systems unreliable.(Tikwayo and Mathaba, 2023)

3.4 Wearable Device Apple Vision Pro

The Apple Vision Pro is a wearable device with significant potential to transform human interaction with the digital world. This device can provide real-time access to information and detailed guidance for the execution of complex tasks, enhancing operational efficiency across various contexts.

In daily life, the Apple Vision Pro can have a substantial impact on user health and well-being. The device can monitor user health, providing alerts when rest is needed or if a position could cause injury. Furthermore, real-time feedback allows users to quickly correct errors and learn new skills more efficiently.

In industry, the Apple Vision Pro has the potential to improve both operational efficiency and product quality. Workers can use the device to inspect products on a production line, identifying defects that may be difficult to detect with the naked eye.

4 OVERVIEW OF THE PROPOSED SYSTEM AND VALIDATION TESTS

This section presents the architecture of the proposed system. Figure 1 shows a schematic diagram of the desired architecture and its functionalities.

Generally speaking, the proposed system includes RFID tags, whose identifications will be read by a mobile application, which interacts with the tag via its NFC sensor, and publishes the tag's identification ID via MQTT communication, according to the task to be performed. The tasks are divided into three forms:

1. **Stocking:** Once the material has been identified, you want to store it in a suitable place in the warehouse. Thus, according to the item's ID, Raspberry Pi 4B will process this data, and, depending on the material's characteristics, the cloud database will indicate the appropriate storage address on the display.
2. **Pickup:** Once a material is to be withdrawn, it can be updated in the database system by reading the relevant tag and clicking on the "withdraw" button in the application.
3. **Detail and Search:** Within the mobile application, the user will enter the material they want to search for or have its detailed information and, according to the information contained in the database, the display will be informed of the address where the item is located and its respective characteristics. Among the information returned

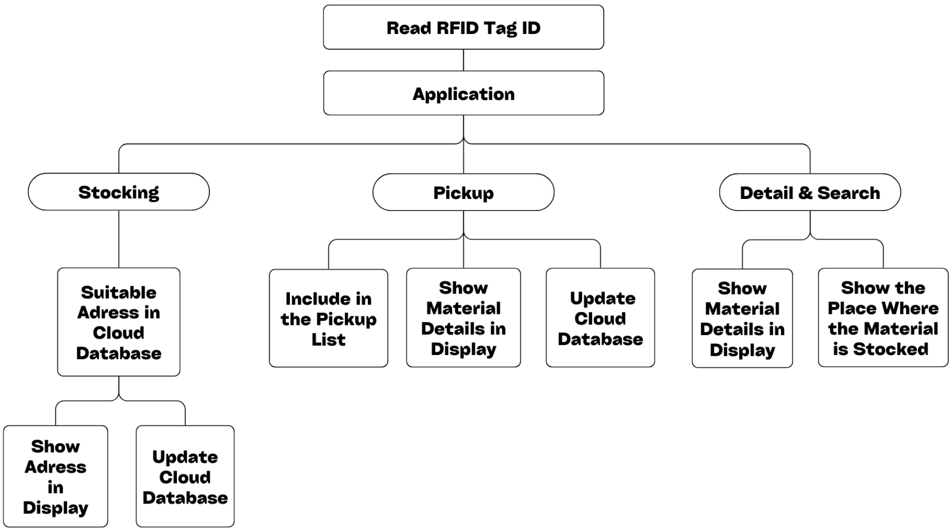


Figure 2: System Flowchart.

is material location data, name, part number, serial number, and status, among others. As a result, the operator can see all the desired information about a particular item in an up-to-date display.

In more detail, the system can be divided as shown in Figure 2.

4.1 RFID Tags

Passive RFID tags, which store unique identifications (IDs), function as passive antennas that receive radio frequency signals and can be attached using labels to materials that require stricter control.

RFID tags, employing Radio-Frequency Identification technology, have emerged as indispensable tools for optimizing and automating processes across various domains. Equipped with microchips and antennas, these tags facilitate data transmission through radiofrequency, enabling efficient identification and tracking of objects, animals, or even individuals. This technology represents an evolution compared to conventional barcodes, offering the capability of remote reading, resulting in faster and more precise data collection in diverse environments.

The distinctive advantage of RFID tags lies in their ability to store and transmit unique information associated with each label. This feature not only streamlines logistical operations but also contributes to product authentication and ensures the integrity of the supply chain.

4.2 Smartphone Application

To read RFID tags and then enable the user to perform tasks based on the ID of the tag read, a smartphone application was developed that has an interface for interaction with the user, as well as a backend that directs the application's MQTT communications with the broker.

Figure 3: RFID Tag.

In the Figure 4, it's show that the smart phone application is able to help the operator to search any good, pick up the item, update the database and stock, using the NFC reader in the smart phone for identify the ID number of the RFID tag.

Among the ways to use the functionalities of the mobile application is the possibility of turning on or off the device's NFC sensor, using a button. When a RIFD tag is identified, its respective ID number is shown on the smart phone screen. Based on this identification, the operator specifies what he wants to do with that material.

We will assume that the indoor location is associated with the Smartphone Application and the Cloud Server communication.

Figure 4: Smartphone application layout.

4.3 Wearable Device

A Raspberry Pi 4B, with a Linux-based operating system, will be responsible for running code which, when connected to the internet via Wi-Fi, will be able to receive specific information from the requested sensors and send it to a server in the cloud. Once this data has been processed, the microprocessor receives it and uses it to help the operator through augmented reality visualization on the OLED display.

The Figure 5 illustrates how the wearable device is used. The OLED display is supported by a support made by 3D printing, which was developed to be viable as a wearable device and be suitable for the display fittings and their respective connections to the Raspberry Pi.

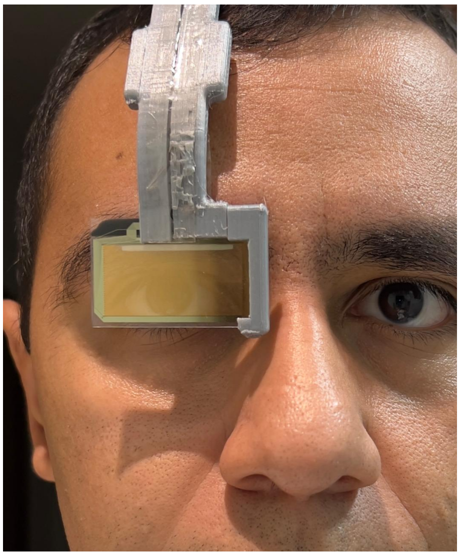


Figure 5: Wearable Device with display.

4.4 Cloud Server

A server hosted in the cloud can have a variety of resources to meet the demands of software or storage services. Working as a complement to the microprocessor, which has limited resources due to its structure, the server is capable of storing, processing, and managing a large amount of data, and can integrate applications such as MySQL, i.e. a structured database that helps control data and can be presented in the form of a dashboard.

In practice, the server receives the RFID tag identifications checks its database for the information relating to these requested identifications, and sends an action back to the microprocessor. Also it is responsible for managing the client's physical location in the indoor environment. This feedback provides the necessary information for the Raspberry Pi to transmit the data requested by the operator to an OLED display so that the operator can interact with the environment and this information can be linked to the material in the form of augmented reality. This form of interaction constitutes an Internet of Things mechanism and helps make the system lean.

4.5 OLED Display

The component in which the operator can interact with the environment, with augmented reality, to identify relevant information about a material, be it its location, part number, serial number, material status, and status of said item.

The transparent OLED display has the capability to allow the wearer to see the surrounding environment, even if information is being shown on the display.

4.6 Validation Tests

Validation tests for a wearable device in a warehouse environment should indeed focus on critical aspects such as accurate identification of materials. The device must be capable of accurately recognizing and differentiating between various materials and products in the warehouse.

In addition, the device's ability to provide clear guidance to the operator is crucial. For instance, the device could use arrows or other visual indicators to guide the operator to the exact location of the material. This must involve testing the accuracy of the device's navigation system and its ability to integrate with the warehouse's inventory management system.

These tests help ensure that the device not only improves the efficiency of warehouse operations but

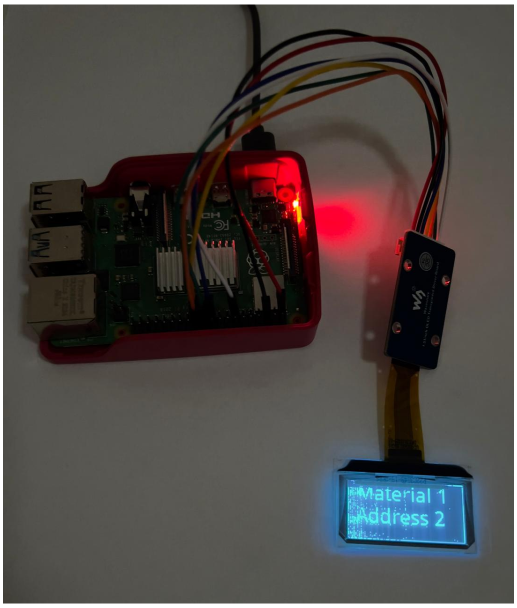


Figure 6: Raspberry Pi with OLED display.

also minimizes errors, thereby enhancing the accuracy and reliability of the material handling process.

5 METHODOLOGY

5.1 Internet of Things

The Internet of Things is becoming one of the main foundations of Industry 4.0, helping companies and organizations to strengthen their level of competitiveness in the market. In this context, linked to the popularization of embedded systems with Wi-Fi connectivity, wireless communication and exchange of information between devices has proved to be an alternative for guaranteeing the security of this information and its scalability.

5.2 Node-Red Development Environment

The Node-Red programming tool has been widely used in the context of research and industry when it comes to developing programs for automation, making it possible to connect devices, APIs, and online services. (Node-Red Site, 2023)

Unlike other types of development environments, Node-Red is a browser-based editor, built in Node.js, which is capable of connecting flows via nodes. Because it has vast libraries of nodes, Node-Red can perform various functions, such as communicating between devices using the MQTT protocol, connecting a system to a database hosted in the cloud, performing logical-mathematical operations, and executing code locally.

5.3 Interaction Between Devices via MQTT Protocol

The operator needs to perform actions that indicate to the device its need for information. To do this, the operator can interact with the device using buttons which, when pressed, help to select the correct item to be evaluated.

Once the desired item has been selected, communication takes place between the smartphone application and the display, and for this, we chose to build communication via the MQTT (Message Queuing Telemetry Transport) protocol. This protocol is based on the transport of messages in a client/server format, enabling communication between (MQTT Site, 2023) machines, which, in the case of this work, is the communication between the Raspberry Pi and the OLED Display integrated with augmented reality.

As an alternative to setting up MQTT communication, we chose to implement a code in the Node-Red development environment. Through this code, the microprocessor can send requests arising from the operator's handling of the wearable device, which, in return, receives information relevant to warehouse management. Once the item data is returned to the device, the operator can see the exact location of the material or its particular characteristics.

6 RESULTS

As a result of implementing the system, it was possible to demonstrate its operation and functionality. Figure 4 illustrates the layout of the mobile application.

The layout of the app shows the connection status of the smartphone's NFC sensor and the connection between the app and the MQTT broker. In addition, the app has buttons that act sending the ID of the identified item. Although all the buttons send the ID, they send it via a specific topic, which tells the wearable device what kind of information it should pass to the display.

As a result of processing the tag ID read, the display was able to show the following results for each task:

As a way of measuring the impact of this device on a real warehouse application, a qualitative comparison was made of the average time taken to update the system and the database of a warehouse that does not

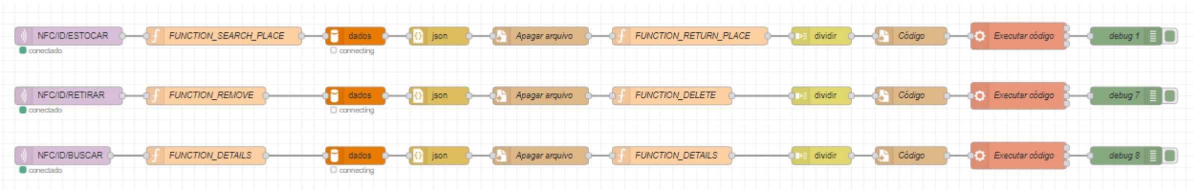
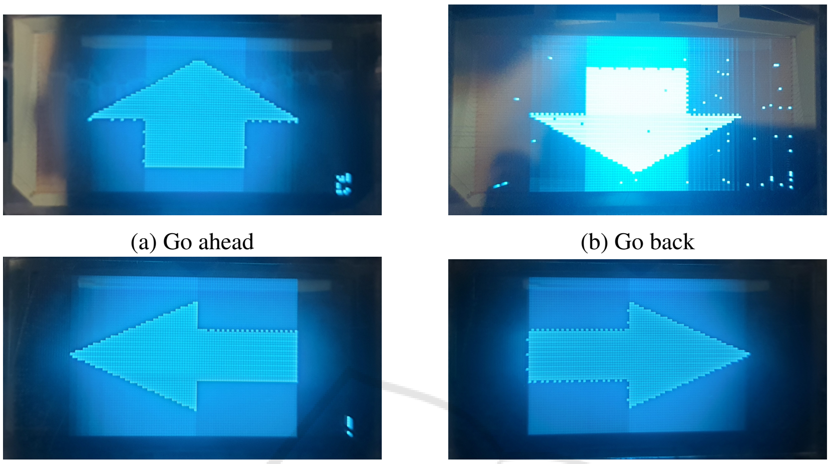


Figure 7: Raspberry Pi Flow in Node Red.



(a) Go ahead (b) Go back

(c) Turn left (d) Turn right

Figure 8: Illustration of arrows for operator direction.

have this type of infrastructure. In this context, for the user to write off materials that have been stored and removed from the system, it is necessary to fill in a lot of information and, the more materials that need to be processed, the longer it takes to complete all the write-offs, especially if the warehouse has few employees available to carry out the write-offs. In the case of the proposed system, the material write-off is carried out automatically by the system in the database, making the user's routine more productive and with less manual work.

In the Figure 8, it's shown an illustration of arrows for operator direction when it's needed to find some materials. Like a GPS guide, the display guide the operator to the correct position of an especific good. The position of the good is saved in the cloud database and track the position of the operator by the GPS inside the smartphone e show how to go to the item.

In addition, the proposed system offers greater security in the process of identifying material for storage and withdrawal, since each item has a unique identification, which reduces the chance of human error when carrying out the collection.

7 CONCLUSIONS AND FUTURE WORK

In this work, a wireless communication system was developed and implemented between an embedded device, i.e. a Raspberry Pi 4B, and a smartphone application, using the MQTT protocol. The system aims to provide information about items in a warehouse to an operator via a transparent OLED display connected to the Raspberry Pi, generating a user experience with the environment. In addition, the system has been integrated with RFID tags and a smartphone's NFC reader, which allow items in the warehouse to be identified, facilitating stock control and monitoring and providing low-cost identification of rfid tags using a smartphone..

The system can be tested in a real scenario, with different types and quantities of items. The proposed system is applicable in various contexts involving inventory management, warehousing, and logistics, helping to improve the efficiency and safety of processes. In future work, we suggest integrating the system with other technologies, such as cameras and robots, to expand the functionalities and possibilities for operator interaction with the environment.

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REFERENCES

Anusha, D. J., Panga, M., Fauzi, A. H., Sreeram, A., Issabayev, A., and Arailym, N. (2022). Big data analytics role in managing complex supplier networks and inventory management. *International Conference on Sustainable Computing and Data Communication Systems, ICSCDS 2022 - Proceedings*, pages 533–538.

Bertaglia, P. R. (2012). *Logística e gerenciamento da cadeia de abastecimento*. Saraiva.

Borges, I. B., Alves, J. L., de Lima, L. K. A., and de Nadae, J. (2022). Indústria 4.0: impactos das novas tecnologias no gerenciamento de projetos. *Exacta*, 20:832–860.

Cimen, E. B., Kurban, I., Selmanoglu, O., Sahin, M., and Kilinc, D. (2021). A hybrid stock optimization approach for inventory management. *HORA 2021 - 3rd International Congress on Human-Computer Interaction, Optimization and Robotic Applications, Proceedings*.

Fathi, P., Karmakar, N. C., Bhattacharya, M., and Bhattacharya, S. (2020). Potential chipless rfid sensors for food packaging applications: A review. *IEEE Sensors Journal*, 20:9618–9636.

Gonçalves, P. S. (2013). *Administração de Materiais*. Elsevier.

Hamdy, W., Al-Awamry, A., and Mostafa, N. (2022). Warehousing 4.0: A proposed system of using node-red for applying internet of things in warehousing. *Sustainable Futures*, 4:100069.

Husár, J. and Knapčíková, L. (2021). Possibilities of using augmented reality in warehouse management: A study. *Acta logistica*, 8:133–139.

Manuel Vera, J. (2021). Inventory control under unobserved losses with latent state learning. In *2021 7th International Conference on Computer and Communications (ICCC)*, pages 1594–1599.

MQTT Site (2023). Mqtt oficial site. Available at: https://mqtt.org/. Accessed in September 13th, 2023.

Node-Red Site (2023). Site oficial da node-red. Acessado em 15 de novembro de 2023.

Periša, M., Sente, R. E., Cvitić, I., and Kolarovszki, P. (2018). Application of innovative smart wearable device in industry 4.0. EAI.

Plakas, G., Ponis, S. T., Agalianos, K., Aretoulaki, E., and Gayalis, S. P. (2020). Augmented reality in manufacturing and logistics: Lessons learnt from a real-life industrial application. *Procedia Manufacturing*, 51:1629–1635.

Ponis, S. T., Plakas, G., Agalianos, K., Aretoulaki, E., Gayialis, S. P., and Andrianopoulos, A. (2020). Augmented reality and gamification to increase productivity and job satisfaction in the warehouse of the future. *Procedia Manufacturing*, 51:1621–1628.

Rejeb, A., Keogh, J. G., Wamba, S. F., and Treiblmaier, H. (2020). The potentials of augmented reality in supply chain management: a state-of-the-art review. *Management Review Quarterly 2020 71:4*, 71:819–856.

Silapunt, R., Panpanyatep, W., and Boonsothonsatit, G. (2022). Design and development of the smart object for the iot-enabled smart warehouse. In *2022 International Electrical Engineering Congress (iEECON)*, pages 1–4.

Tikwayo, L. N. and Mathaba, T. N. D. (2023). Applications of industry 4.0 technologies in warehouse management: A systematic literature review. *Logistics*, 7(2).

Vena, A., Illanes, I., Alidieres, L., Sorli, B., and Perea, F. (2021). Rfid based indoor localization system to analyze visitor behavior in a museum. *2021 IEEE International Conference on RFID Technology and Applications, RFID-TA 2021*, pages 183–186.