Management system of smart warehouses using IIoT for optimize inventory control

Sistema de gestión de almacenes inteligentes usando IIoT para optimizar el control de inventario

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Abstract

In the industry, the supply chain develops activities related to the flow of goods. A nerve point of this chain is warehouses, whose operational efficiency allows to minimize product losses and reduce overall costs. This work proposes the automation of a goods warehouse through its integration and interoperation with emerging technologies based on the Industrial Internet of Things (IIoT), with the aim of knowing and planning the stock in real time to optimize its management, since a recurring problem is having outdated inventories, which impact on the lack of traceability of the product. A methodology based on the design of an experimental management system is propose, through RFID devices and a microcontroller allows to monitor the inputs and outputs of goods, the second part of the system is a web application with a user interface where information about inventories could be viewed and analyzed in real time. This research will allow to lay the foundations of automation through IIoT of a warehouse with the purpose of turning it into an intelligent unit that provide strategic information.

Smart Warehouses, IIoT, Industry 4.0, Intralogistics

Resumen

En la industria, la cadena de suministro desarrolla las actividades relacionadas con el flujo de mercancías. Un punto neurálgico de esta cadena, lo constituyen los almacenes, cuya eficiencia operativa permite minimizar las pérdidas de producto y reducir costos. En este trabajo se propone la automatización de un almacén de mercancías mediante su integración e interoperación con tecnologías emergentes basado en el internet industrial de las cosas (IIoT), con el objetivo de conocer y planificar el stock en tiempo real para optimizar su gestión, pues un problema recurrente es tener inventarios desactualizados, lo que a su vez repercute en la falta de trazabilidad del producto. Para este fin se propone una metodología basada en el diseño experimental de un sistema de gestión que mediante dispositivos RFID y un microcontrolador permita monitorear las entradas y salidas de mercancías, la segunda parte del sistema es una aplicación web con una interfaz de usuario donde se podría visualizar y analizar información sobre los inventarios en tiempo real. Esta investigación permitirá sentar las bases de automatización a través de IIoT de un almacén con el propósito de convertirlo en una unidad inteligente, brindando información estratégica.

Almacenes inteligentes, IIoT, Industria 4.0, Intralogística

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Introduction

Companies as economic entities have as their main goal to increase their profitability and improve their management, for this, they are constantly looking for the optimisation of workflows. We are currently experiencing a fourth industrial revolution called Industry 4.0, which brings with it a trend towards full automation of manufacturing through integration with digital technologies (Schwab, 2018). Thus, it is clear that the ability of companies to grow and adapt in this new technological environment will determine their longevity.

The impact of this technological transformation is broad, based primarily on the digitisation and automation of production and distribution processes in industry, which blurs the boundaries between physical objects, integrating a complex system of interconnected and interdependent elements (Sukhodolov, 2019).

While there is no agreed definition of the term Industry 4.0, it can be summarised, according to Hermann, Pentek & Otto (2015) in six design principles: 1. interoperability, interconnectedness of elements (material and human) of Industry 4.0; 2. virtualisation, simulation models that display information from sensors and systems; 3. decentralisation, connected objects have autonomous decision-making capabilities; 4. real-time capability, dynamic environment that actively interacts for analysis and decision-making; 5. service orientation, ability to offer a catalogue of services that allows interaction and the creation of new applications; and 6. modularity, flexibility for the addition, subtraction or substitution of any element (Estévez, 2016). The design principles underpin innovations in four key industry components: cyber-physical systems (CPS), IoT, internet of services (IoS) and smart factory.

It is these core principles that will enable production to adapt, automatically enabling the diagnosis, adjustment and optimisation of processes. Through the use of IoT and its services it is possible to identify possible operational guidelines for Industry 4.0 that can be implemented, the information is summarised in table 1.

	Cyber-physical systems	Internet of things	Internet of services	Smart Factory
Interoperability	x	x	X	x
Virtualisation	x	-	-	x
Decentralisation	x	-	-	x
Real-time capability	-	-	-	x
Service orientation	-	-	x	-
Modularity	-	-	x	-

Table 1 Design principles of each component of Industry 4.0
Source: Hermann et al., 2015

The ability of IoT systems to exercise interoperability, and of IoS to offer service-orientation and modularity, enables disruptive transformation ranging from multiple market segments, economic activities and public services to government and city organisation.

In the environment of industry-focused solutions, Industrial IoT (IIoT) appears as a subset of IoT, which focuses on the specialised requirements of industrial applications, such as manufacturing, oil and gas and utilities (Chan, 2017). These designs use sensors and connected peripheral devices to improve product quality and operational efficiency of factories in real time. According to Banda (2015) Industry 4.0 as a revolutionary method of organising production involves a whole process of systemic innovation that necessarily leads to a redefinition of business models to achieve radical, disruptive improvements that can eventually become a competitive advantage.

Methodology

In a supply chain, data management and the handling of products, materials and goods, as part of the production processes of the logistics network, can be optimised to have a better impact on the value chain, as shown in figure 1.

Figure 1 Representation of supply chain with its elements
Source: leanmanufacturing10.com

A logistics process can be divided into different areas, ranging from purchasing logistics to possible recycling (Peia, Zhaoa, Zhangb & Guoc, 2019).

Intralogistics groups together the internal logistics of the production area, i.e. the tracking and loading of products within a controlled and confined environment within the boundaries of the company, as well as the information flows that are generated, covering from the time the supplies are received in the raw material warehouse until they leave the production phase and are arranged in the warehouse as a finished product.

In this sense, intralogistics 4.0 involves the digitalisation and automation of intralogistics, through its integration and interoperation with IT systems and networks, to improve internal management, improving the administration of processes and inventories (LD Flexible Logistics, 2021), as shown in Figure 2.

Figure 2 Scope of intralogistics
Source: Peia, S., Zhaoa, J., Zhangb, N. & Guoc, M., 2019

Among several ways to improve the performance of the company, there is the optimisation of the planning, control and execution activities of the warehouse, since, as Madroño (2010) mentions, inventories are company assets and, as such, they represent an investment. The warehouse represents the balance between the supply and demand aspects of any company, its function goes beyond being a simple place for the accumulation of raw materials, supplies, components and finished product, since within it, functions are carried out that make the economic activity of the company possible.

The organisation of a warehouse basically consists of three parts: incoming goods receipt management, goods storage management and goods distribution management (Van Geest, Tekinerdogan, & Catal, 2020). The latter being a topic of interest in this paper, as the finished product warehouse, often located in the marketing warehouses of manufacturing companies or in the warehouses of wholesale and retail companies, is necessary for the uninterrupted supply of customers and consumers.

The main activities of the warehouse are delimited by input and output flows and include: product reception, storage and handling, order preparation, dispatch, and stock organisation and control (Escrivá, 2005) as illustrated in figure 3, and one of the main problems it presents lies in inventory calculations, so it can be inferred that it provides vital information for decision making in strategic planning.

Figure 3 Warehouse flows
Source: Own Elaboration

However, with the increase in the complexity of operations and high variety of customer orders, as well as the demand for real-time information, the warehouse presents new challenges and therefore a need to adapt to technological innovations and changes in the supply chain, so it is evident the step towards a "smart" entity based on automation both to integrate and manage inventories, and to regulate the flow of goods, so it is the subject of various studies to improve its management, as shown in Figure 4.

Figure 4 Main research topics for the implementation of smart warehouses
Source: Liu, X. et al., 2018

Thus, there has been a gradual migration in the importance of the warehouse from stock accumulation to high-speed operations, which demand to ship more products through the same physical assets, while reducing overall costs (Taliaferro et.al., 2016).

It is important to note the inclusion of inventories in the company's financial statements as a reflection of its economic operation, therefore, determining the optimal order quantity is one of the main aspects of inventory management that can facilitate cost-optimal inventory management (Senthilnathan, 2019).

The organisation and control of the warehouse depends on several factors, the most relevant of which are the mismatch between consumer demand and production or supply, and mainly random fluctuations in demand and replenishment times in the supply chain (Vidal et.al., 2004). The most common strategies to manage these fluctuations are related to operational efficiency, the achievement of which depends on timely and useful information. However, even when exploring the ways in which information creates value, it is important to understand the creation of this value from a supply chain perspective. According to Taliaferro et.al. (2016), across the manufacturing and distribution value network, business outcomes can arise from the integration of IT and operating technologies (OT) through Industry 4.0 applications.

Designing an effective value-creating system requires the adoption of inventory management techniques to ensure that adequate inventory levels are maintained, orders are not duplicated, and product quality is consistent.

Niemi, Huiskonen, & Kärkkäinen (2009) recommend that such techniques, based on open, standards-based solutions to reduce maintenance costs and increase productivity, should gradually take place in the company, with the aim of generating the necessary knowledge and maturity to enable continuous improvement in its control methods.

Results

The causes that generate the need to maintain inventories underlie the procurement process and the degree of operational efficiency. A review of the literature has been made in this sense, where from the perspective of computer science, solutions that allow automatic inventory control and often involve improvements in management systems stand out, however, it is interesting to look for an "intelligent" solution that allows visualisation and analysis of inventory data in real time, instilling the necessary agility within the company's processes to take care of the volatility in customer demands.

The implementation of the IIoT-based system will be supported by an Auto-ID technology monitoring system, primarily radio frequency identification (RFID) systems, which use electromagnetic fields to identify and track tags attached to products. The entrance to the warehouse will have an RFID reader and each product will have an RFID tag attached to it. The system is complemented by a microcontroller that will keep the inventory updated, registering incoming and outgoing goods in real time.

To implement this control, the information will be sent to the cloud allowing its concentration and access to it from any location and by any device connected to the internet. Numerical analysis software (Scilab) will be used to measure, collect, analyse and report the data, providing an interface for decision making. Figure 5 shows a general diagram of the proposed solution.

Figure 5 Architecture of the proposed solution
Source: Own Elaboration

It is important to note that the IoT development platform chosen will be the one that meets the characteristics of accessibility, documentation, applications and price, because the commercial implementation must justify the investment according to the cost-benefit.

Hardware Module

- A. Microcontroller (MCU): the Photon Particle hardware development kit is used, which combines an ARM Cortex M3 microcontroller with a Broadcom Wi-Fi chip in a miniature-sized module called PØ (P-zero).
- Photon Particle concentrates a 3.3VDC SMPS power supply, a radio frequency antenna and user interface components on a printed circuit board (PCB). The great advantage for integration is that the design is open source.
- B. RFID module: it is the data input to the system. A high frequency (HF) band will be considered for implementation. Reading/recording of scan times, reading attempts, reading, reading and sending of tag data shall be recorded.

There are also different types of tag technology, for cost reasons, those classified as passive, i.e. read-only, will be considered.

Software Module

- A. Management system: is a computer program designed to provide connectivity between the RFID system, which will be integrated with a management application that connects to a database, providing a high level of automation to the processes of entry and exit of material in the warehouse, as well as inventory control.
- B. Web application: is a client-server computer program that the user can use by accessing a web server through a browser. In this case, IoT devices will send information to a cloud-based server, where it will be interpreted and organised in an interface that can be accessed.

Hardware and software integration

For the reception of the parameters, an RFID reader will be used to send the data to the microcontroller, the connection is shown in figure 6; the microcontroller will be in charge of receiving, processing and sending the data.

Figure 6 RFDI connection diagram
Source: Own Elaboration

For this function, an interface could be implemented for on-site visualisation of the data it collects. It will then be responsible for sending the data from the microcontroller to a cloud server hosted on an open-source IoT platform.

The Particle Cloud API is a REST (Representational State Transfer) that allows the device to be controlled, by assigning a unique URL, using GET to obtain data, POST to call a function, and PUT to update firmware.

Variables and functions written in the firmware are exposed as sub-resources on the device. All requests from the device come through the API server using TLS (Transport Layer Security) security.

For data analysis, the free software Scilab is used, which is capable of numerical analysis and scientific calculation. The Scilab package for automatic module management (ATOMS) contains a tool that allows dynamic interaction with the microcontroller and enables the exchange of information from the cloud, which will be used to obtain analytical models of the processes.

This platform can be accessed via a web interface that allows the user to interact remotely through an internet connection and from any device, giving the possibility of both receiving data and controlling the system, customising the visualisation according to specific needs (figure 7), offering an innovative solution to create an intelligent warehouse.

Figure 7 Block diagram
Source: Own Elaboration

The detailed flow of the inventory management system is shown in Figure 8.

Figure 8 Flow chart
Source: Own Elaboration

IIoT requires certain elements to enable communication between devices and objects, for which the objects must be uniquely identifiable. The RFID tag enables the product to wirelessly communicate information that enables inventory control. When the "smart" merchandise reports input/output data, it travels over IP networks to a cloud-based database that stores and classifies the data so that it can be analysed.

Ultimately, the smart warehouse will provide real-time information through a visualisation of stock variability, enabling faster and more accurate decision making by taking into consideration fundamental aspects of warehouse management such as product lifecycle, traceability, the nature of the production or commercial process and the financial aspects related to inventories.

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Conclusions

Warehouse management aims to strategically control the entire storage and movement of inventories. Faced with increasingly complex functions that make the warehouse a dynamic entity, it is necessary to provide efficient accessibility for incoming and outgoing goods, under the constraints of space and quality factors, in addition to minimising operating costs.

Technological solutions support decision making by generating accurate, reliable and timely information about the warehousing process and inventory control.

The future roadmap is to implement IIoT-based technical optimisation in other important warehouse management processes, including a development that can be linked to customer or supplier management systems.

It is possible to evaluate that the goods, in addition to the RFID tag, which allows counting the stock in the warehouse, include a sensor to measure certain data of interest, such as changes in quantities, spatial location or other information, with the aim of making all processes involved in warehousing more efficient.

References

Banda, H. (2015). Impacto de la Manufactura Inteligente en la Industria y la Academia. Cuartas Jornadas de la Facultad de Ingeniería y ciencias Agropecuarias. Universidad de las Américas. Ecuador.

Chan, B. (2017). IoT vs. Industrial IoT: 10 Differences That Matter. diciembre 14, 2017, de IoT For All Sitio web: <https://www.iotforall.com/iot-vs-industrial-iot-differences-that-matter>

Escrivá, J. (2005). El almacén en la cadena logística. En Almacenaje de productos (pp. 6-21). España: McGraw-Hill/Interamericana.

Estévez, R. (enero 19, 2016). Energía e Industria 4.0. julio 10, 2021, de EcoinTELigencia Sitio web: <https://www.ecointeligencia.com/2016/01/energia-industria-4-0/>

Frank, R. (2013). Understanding Smart Sensors (3ª ed). Artech House.

Hermann, M. Pentek, T. & Otto, B. (2015). Design Principles for Industrie 4.0 Scenarios: A Literature Review.

Kumar, R. (2016). Economic Order Quantity (EOQ) Model. Global Journal of Finance and Economic Management. 5, (1), pp. 1-5.

Liu, X., Cao, J., Yang, Y. & Jiang, S. (2018). CPS-Based Smart Warehouse for Industry 4.0: A Survey of the Underlying Technologies. Computers, 7, 13.

LD Logística flexible. (febrero 3, 2021). Intralogística 4.0: Clave de la eficiencia y productividad. Recuperado de: <https://www.ld.com.mx/blog/logistica/intralogistica-4-0/>

Madroño, M. (2016). Administración Financiera del Circulante. México: Instituto Mexicano de Contadores Públicos.

Niemi, P., Huiskonen, J., & Kärkkäinen, H. (2009). Understanding the knowledge accumulation process—Implications for the adoption of inventory management techniques, International Journal of Production Economics, 118(1), pp. 160-167.

Particle docs. (febrero 3, 2021). Photon Datasheet (V017). <https://docs.particle.io/datasheets/wi-fi/photon-datasheet/>

Particle docs. (febrero 3, 2021). Device Cloud. <https://docs.particle.io/reference/device-cloud/api/>

Peia, S., Zhaoa, J., Zhangb, N. & Guoc, M. (2019). Methodology on developing an assessment tool for intralogistics by considering cyber-physical production systems enabling technologies. International Journal of Computer Integrated Manufacturing 32, (4-5), pp. 406-412.

Schwab, K. (2018). The Fourth Industrial Revolution. enero 20, 2021, de Britannica Sitio web: <https://www.britannica.com/topic/The-Fourth-Industrial-Revolution-2119734>

Senthilnathan, S. (noviembre, 2019) Economic Order Quantity (EOQ). SSRN Electronic Journal

Shukla, A., Jain, G., Chaurasia, K. & Venkanna, U. (2019). "Smart Fruit Warehouse and Control System Using IoT," 2019 International Conference on Data Science and Engineering (ICDSE), Patna, India, pp. 40-45.

Sukhodolov, Y. (2019). The Notion, Essence, and Peculiarities of Industry 4.0 as a Sphere of Industry. In: Popkova E., Ragulina Y., Bogoviz A. (eds) Industry 4.0: Industrial Revolution of the 21st Century. Vol 169. Springer, Cham.

Sung, W. & Lu, C. (2018). "Smart Warehouse Management Based on IoT Architecture," 2018 International Symposium on Computer, Consumer and Control (IS3C), Taichung, Taiwan, pp. 169-172

Taliaferro, A., Guenette, C., Agarwal, A., & Pochon M. (2016). Industry 4.0 and distribution centers Transforming distribution operations through innovation. Deloitte University Press.

Van Geest, M., Tekinerdogan, B. & Catal, C. (2020) Design of a reference architecture for developing smart warehouses in industry 4.0. Computers in Industry. Elsevier. 124.

Vidal, C., Londoño, J., & Contreras F. (2004). Aplicación de los Modelos de Inventarios en una Cadena de Abastecimiento de Productos de Consumo Masivo con una Bodega y N Puntos de Venta; 6(1):35 - 52.

Yerpude, S. & Singhal, T. (2018). Impact of Internet of Things (IoT) Data on Demand Forecasting. Indian Journal of Science and Technology, 10, 15.

Žunić, E., Delalić, S., Hodžić, K., Beširević, A. & Hindija, H. (2018). "Smart Warehouse Management System Concept with Implementation," 2018 14th Symposium on Neural Networks and Applications (NEUREL), Belgrado, pp. 1-5.