







Article

UAVs for Business Adoptions in Smart City Environments: Inventory Management System

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Abstract: Unmanned aerial vehicle (UAV)-assisted inventory management, used for inventory control within an enterprise with large warehousing and manufacturing systems, is currently common practice. There are many applications for UAVs within an enterprise, but they are generally used in tasks that have high risk connotations to perform activities quickly, such as in the cases of large enterprises that generally require inventory of many products quickly and efficiently connected in a smart city environment. Having an up-to-date inventory as quickly as possible in a smart city environment allows users to have the necessary information to verify the availability of products, reducing waiting times. The use of UAVs systems compared to conventional systems, such as unmanned ground vehicles, has several advantages, including the fact that UAVs have their own cameras and can move independently within the warehouse. This paper proposes the development of a Supervisory Control and Data Acquisition system (SCADA) for the inventory management of the company DHL, using drones. This study evaluates the OPC communication protocols for the virtual environment and the 232 serial connection protocol for the real environment, using LabView and Factory I/O programs. For the development of the system, the use of a drone was evaluated for the recognition of the availability of merchandise with the use of infrared technology incorporated in the drone by means of an Arduino. The appropriate use of communication protocols allowed the necessary information to be obtained for the communication of the LabView and Factory I/O environment in which a virtual environment based on the DHL inventory system is available. The system allowed the development of a SCADA system for the management of inventory monitoring in real time of the availability of goods in the virtual environment, allowing to obtain the necessary information for its integration in a smart city environment.

Keywords: UAV; inventory management; business adoptions; smart city



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1. Introduction

Small unmanned aerial vehicles (UAVs) were created for military purposes. Eventually, the Federal Aviation Administration (FAA) authorized the civilian use of UAVs if the UAVs fly at a certain altitude level [1,2]. Due to the properties and advantages they provide, the use of such aircraft has become widespread in several areas of engineering. Drones can be defined as devices with the ability to fly and that remain unmanned, which can be controlled remotely, including through mobile applications for smartphones or tablets. With little time on the market, drones have become an essential complement in many occupations, reducing costs and optimizing space [2]. These aerial vehicles have a radio-controlled driving element, but they are not limited only to the indications they

receive. Drones can perform occupations or tasks autonomously, due to the sensors, gyroscope and GPS that are incorporated in their electronics. These elements allow UAVs to make choices without the participation of a person, making them instruments with a certain degree of sovereignty [2,3]. One of the emerging research areas of these devices is their application in smart cities [4]. The design of smart cities is based on the full integration of information and communication technologies (ICT) to provide efficient infrastructures and services at reduced costs, creating automated and intelligent services to improve the performance of infrastructures and the comfort level of city residents [4,5]. The European Platform for Smart Cities and the European Network of Living Labs defines smart cities as “The use of new discrete technological applications such as Radio Frequency Identification (RFID) and the Internet of Things through a more holistic conception of smart and integrated work that is closely related to the concept of user generated life and services”. Several technologies can contribute significantly in this regard, and UAVs can become an essential component in smart cities [6]. Smart cities leverage the physical infrastructure of communication systems, TIC infrastructure, social infrastructure, and business infrastructure to leverage collective intelligence [7,8]. Smart cities bring together the largest amount of technological development in various areas of engineering and enable engineering to reduce resource consumption, improve energy efficiency, reduce environmental pollution, reduce traffic congestion, reduce potential safety risks, improve the quality of life of citizens, and contribute to the sustainable development of cities. Much of the research on smart cities has focused on smart systems in buildings and businesses, which have driven technological development. In this sense, the development of an inventory management SCADA system for a simulated industry in Factory I/O that uses a drone platform is proposed, and its application in a smart city environment is considered. Not having a real environment for the tests to govern, a scenario was made in the Factory I/O software for inventory management. However, it is worth mentioning that the drone data acquisition is carried out in a real environment. The main objective is to validate the reboots of the drone for the acquisition of information on merchandise availability, and through this information, to be able to carry out inventory control through a SCADA system, which can be integrated into a smart city environment. To validate the proposal, the LabView, Tia Portal, and Factory I/O programs are used [8,9] (see Figure 1).

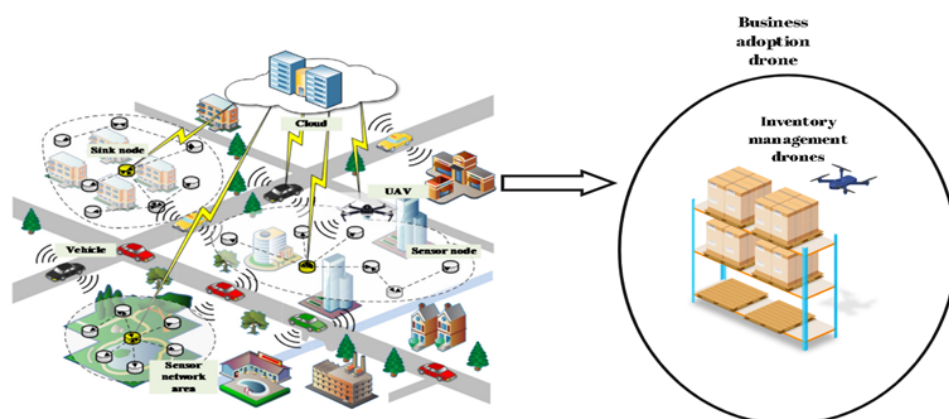


Figure 1. Drone applications in different fields in a smart city.

As can be seen in Figure 1, nowadays, UAVs possess a sufficiently robust platform to address the problems faced by rising industries [8]. Based on the structure of a smart city, drones equipped with the necessary elements are used to allow the management of an inventory which has a wireless communication that reports the availability of products within an industry, allowing to provide stock information to consumers within a smart city [3]. The article is structured as follows. Section 2 presents a review of the state of the art to determine the different technologies applied for inventory management within a smart city environment. Section 3 presents a theoretical basis for the development of the

SCADA system for inventory management. Section 4 presents the design of management systems evaluated in the virtual environment of LabView and Factory I/O and their implementation in a real environment for inventory management using the drone. The last section presents the results obtained by the implementation of the SCADA system for inventory management.

In recent years, the contribution of UAV's within virtual environments has been of great importance for the development of smart city environments. The development presented has allowed large corporations to incorporate these systems to increase efficiency within the industry in the generation of inventories. The major problem with large warehousing systems is a lack of inventory knowledge and inaccurate records that cause low efficiency in the delivery of products to the public. The following paragraphs present a bibliometric analysis of the most relevant databases to analyze the technological development in inventory management systems with drones in the smart city environment. From the bibliographic review, two search strings have been detected, i.e., (inventory AND management AND UAV) and (UAV AND smart AND city), in which a total of 153 and 475 articles, presented on the left and right, respectively, have been detected. These aerial vehicles have a radio-controlled driving element, but they are not limited only to the indications they receive. Drones can perform occupations or tasks autonomously, due to the sensors, gyroscope, and GPS that are incorporated in their electronics. These elements allow UAVs to make choices without the involvement of a person, making them instruments with a certain degree of sovereignty [3].

As can be seen in Figure 2, the subject of the use of UAVs in inventory systems and the development of smart cities has presented a great interest since 2016, with a great peak in the year 2021, as a response to problems caused by the COVID-19 pandemic [9]. The development of the so-called industry 4.0 and 5.0 has allowed the integration of these systems in an architecture that responds to a smart city environment. Collecting the data of the products in stock through inventory management within an industry allows to provide information to the citizens in a quick and simple way [10,11]. The following paragraphs present a review of the most relevant articles on the use of UAVs in the development of inventories. In [11], a detailed study is presented for the determination of the safety distance between the drone and the metal shelves labeled with the inventory labels inside a warehouse. In their case study, a high-frequency RFID identification system is used. The system mounted on the drone allows to identify the strength of the received RSSI signal to determine the drone's flight safety value. The study determined that the safety distances for the correct identification of the products are 1.5 m from the ground and 1.3 m from the drone to the tag. Figure 3 shows the geometric analysis of the inventory management system evaluated in three dimensions for the determination of the safety distance.

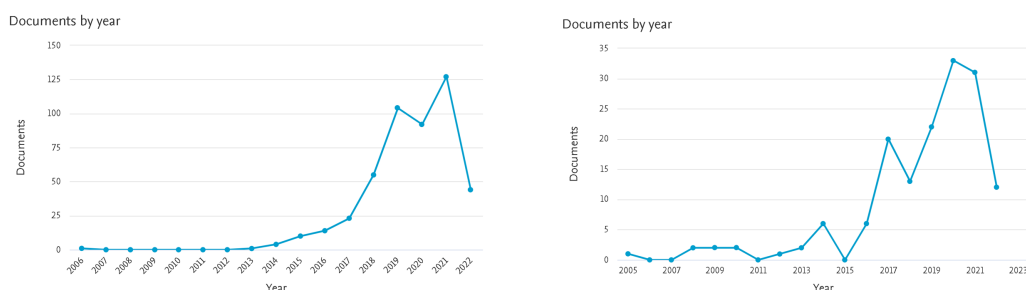


Figure 2. Number of documents published per year in the SCOPUS database for the search strings determined in the research.

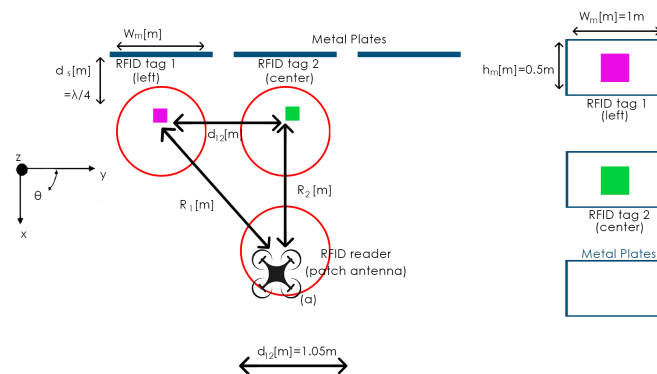


Figure 3. Geometric analysis for the calculation of distances in three dimensions of the proposed inventory management systems [11].

Nicola Marconico, in [12], presented a design with a solution for an inventory management system using an ultra-wide band (UWB) system that uses wireless infrastructure anchor nodes with a soul sensing system. The system evaluation presents a theoretical update rate of 2892 Hz evaluated with the hardware available. The proposed system analyzes the current consumption of each of the proposed nodes, in which a consumption of 27 mA is obtained in comparison with traditional systems. Finally, the system is implemented using open-source software, and the messages are synchronized with the use of TDMA to activate the UWB radio band. The system is validated in a real way for drone tracking in a warehouse mock up, see Figure 4.



Figure 4. Validation of a model with an autonomous inventory flight [12].

In [13], presented in 2018, an efficient detection framework for a 2D barcode is proposed based on the distance of the drone equipped with the 2D barcode reader and the tag. The identification of the codes is performed using LBO and HOG methods for the visualization of the regions, using super vector machine for the classification of the labels. Finally, for the final detection of the system, the weighted sum score is used, with the visualization of images collected in real form, see Figure 5. The system identifies four types of barcodes with an accuracy of 98.08% and a recovery of 98.27%.

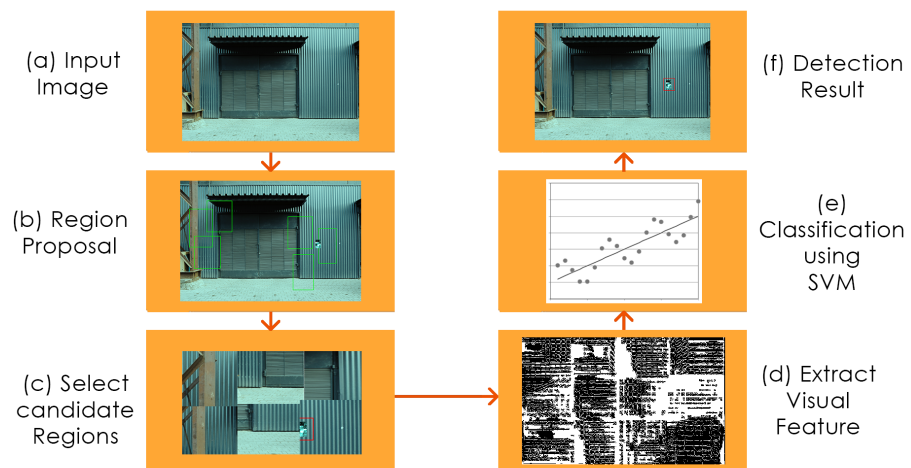


Figure 5. Implemented inventory management system methodology [13].

Finally, in [14], an automatic inventory management system is presented to maintain the traceability of industrial products with RFID radio frequency identifiers. The system is implemented under a versatile and scalable architecture that contemplates a great robustness of cybersecurity and decentralization to speed up external audits. The system is characterized by having a decentralized blockchain on a ledger for data storage and data management. The system was validated in several scenarios, presenting a robust system and a fast increase of efficiency in manual inventory tasks, due to the response latency, each of the chains has an average of 15 s with a transmission rate of 9.4 kB per 100 requests. Figure 6 shows the implementation of the system with the most important elements of the system and the elements installed in the drone.

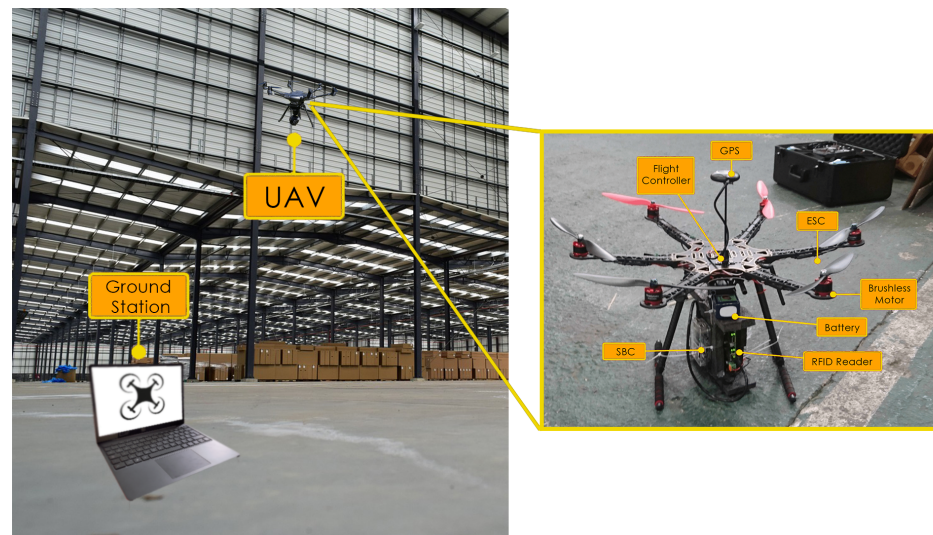


Figure 6. Test environment of the test system and elements mounted on the drone [14].

Based on the bibliometric analysis carried out, it is observed that the integration of UAVs in smart cities has become greatly important, which is why this article evaluates the response of the communication protocols of a drone to record the inventory of a warehouse, based on the model of the company DHL, and with the aim that the information allows the management of inventories to have information available within a smart city environment. The case study proposes the development of a real environment for the detection of goods with the use of a drone using infrared sensors, with Arduino integrated in the drone. The drone sends the information using dedicated protocols in case study 232 to

the LabView environment, which is connected via an OPC connection to the Factory O/I virtual environment, which simulates the DHL inventory system. The data obtained in LabView from the drone and from the virtual environment allow the development of a SCADA for inventory management, so that the information obtained can be used as a base point for integration into a smart city environment. The aim of the work is to evaluate the OPC communication protocols for the virtual environment and the 232 series connection protocol for the real environment, using the LabView and Factory I/O programs, in order to validate the robustness of the use of drones in inventory management activities in order to have the inventory information available in the shortest possible time, which will allow the development of this type of system in a smart city environment.

2. Materials and Methods

2.1. UAVs for Inventory Systems

The scope of UAVs has extended from their military applications for which they were designed to their use as entertainment media in civilian applications [15,16]. UAVs today perform several tasks that constitute one of the bases of Industry 4.0, from dynamic data collection, storage, processing, and exchange of information with other devices in the factory coordinating tasks of high importance for the industry [14]. UAVs have been used for inventory management in recent years due to their wide degree of mobility in small spaces. Drones can fly through the aisles where the product shelves are located, being able to follow programmed routes in such a way that they can determine their relative position with respect to the interior in which they are flying [17].

2.2. SCADA Systems for Inventory

The modern concept of SCADA is the combination of telemetry with the acquisition of data that are transferred back to a central site where the necessary analysis and controls are carried out and subsequently displayed on a series of screens for observation by the operators, see Figure 7 [18]. SCADA systems are of high importance in any industry, specifically for the storage and distribution of any material. Automation plays an important role in all fields. It emphasizes on automating any process that increases productivity, accuracy, and safety by reducing the time to perform a task [19]. These systems allow operators to have a real-time overview of the product stock for purchase or dispatch. The great development of communications allows hosting this information in the cloud to generate reports based on the needs of the corporate side and customers who are involved in a smart city environment [12,14,19].

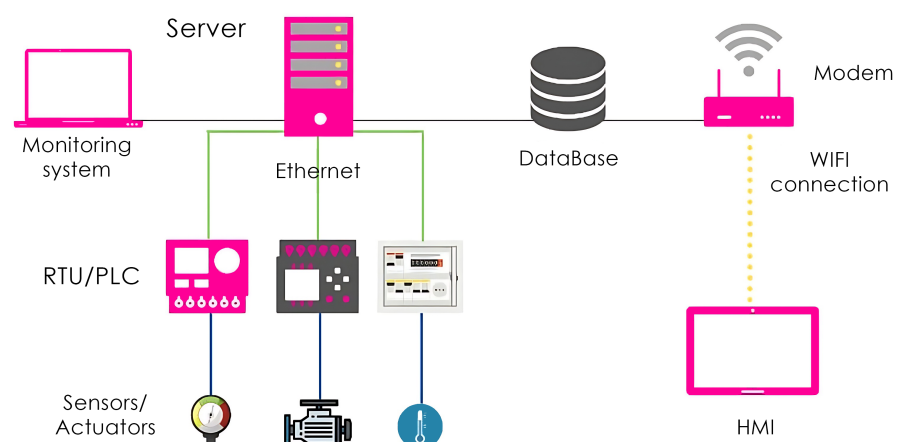


Figure 7. General schematic diagram of a SCADA system.

3. Implementation of the Proposal

3.1. System Proposal

The proposed system consists of a drone, which, through the integration of an Arduino that has an infrared system, allows to obtain information on the availability of the shelves. All this information is transmitted through a serial port to a computer with LabView. Once the information on the availability of the merchandise is obtained through LabView, it is connected via an OPC connection to the TIA portal program, in which the necessary programming is found. Then, through internal communication, the Factory I/O program can modify the Automated Warehouse scene, which has several elements that enable the delivery of the package, which is detected in the real environment and transferred to the virtual environment. One of the benefits of the proposed system is that it allows to keep a record of the stock of products, which, when integrated into a web server in the cloud, will allow the application of this system in an environment of a smart city, see Figure 8.

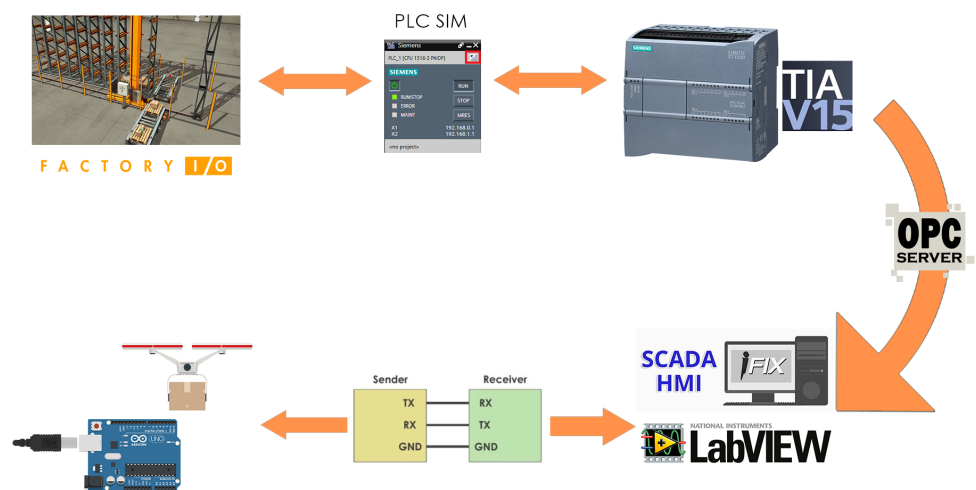


Figure 8. General SCADA system schematic.

Factory I/O and Tia Portal

We start from the design of a scene in the Factory I/O software of an Automated Warehouse. Certain elements have been added to it to allow the transfer of pallets from the shelves to another point in the warehouse. Specifically, there is a rack with a capacity of 18 spaces for pallets with merchandise distributed on 6 floors and 3 columns. These spaces represent the location that the merchandise occupies in a real warehouse, see Figure 9.



Figure 9. Automated warehouse scene at the Factory I/O.

To move the merchandise to different points in the warehouse, four roller conveyors are used to move the different pallets to the three pre-established exits, Figure 10. To classify the different boxes, a rotating table is implemented, which directs the pallets according to their corresponding exit.

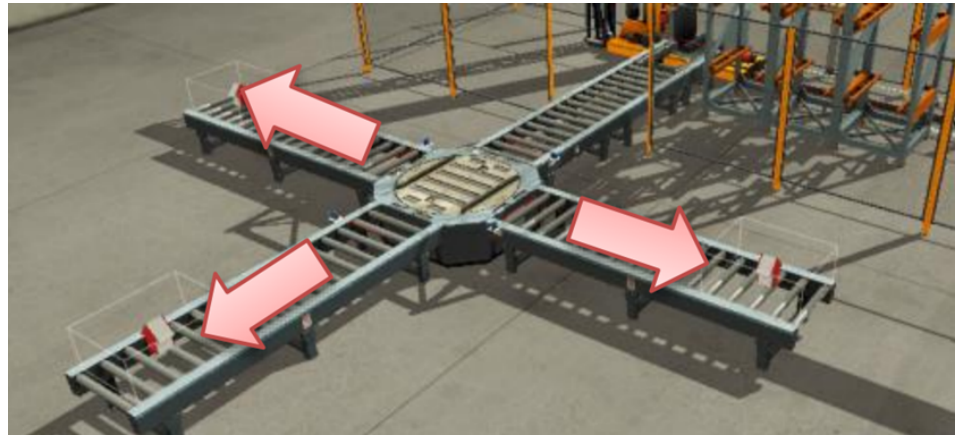


Figure 10. Roller conveyor management implemented in a Factory I/O environment.

Finally, the simulation of the capacitive and reflective sensors is performed, which are associated with each of the roller conveyors, whereby after detecting the pallets, they generate a signal to change the startup status. For the communication of the Factory I/O and the programming software, the following configuration is necessary, where the addresses are assigned to the outputs and inputs, which must be the same as those assigned in the programming software. It is necessary to use a logic programmer to perform the automated pallet transfer process. For this, a programmable logic controller, PLC, of the 1200 family and programming in the Tia portal were used. The different communication protocols for acquisition, monitoring, and control of the system are shown in Figure 11. Figure 10. To classify the different boxes, a rotating table is implemented, which directs the pallets according to their corresponding exit.

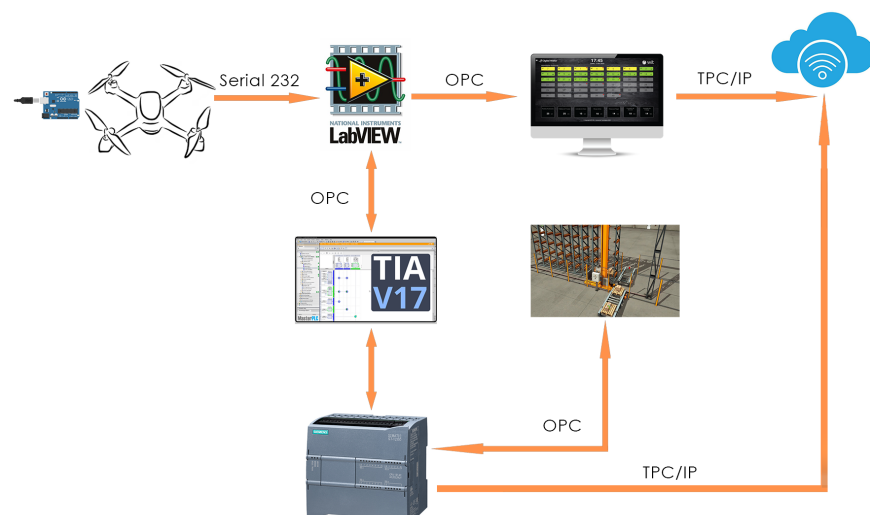


Figure 11. Virtual PLC in operation for the connection of Factory I/O and the Tia portal software.

3.2. Physical Representation of the Warehouse

Once the system has been evaluated in the virtual environment, we proceed to design a mock up that represents the shelves, and inside these are stored different types of boxes to evaluate the system in a real environment. Figure 12 shows the simulated system and its

comparison with the real implemented model. As can be seen, boxes have been placed on floors 2, 4, and 6, which represent the pallets of merchandise in the Factory I/O warehouse.

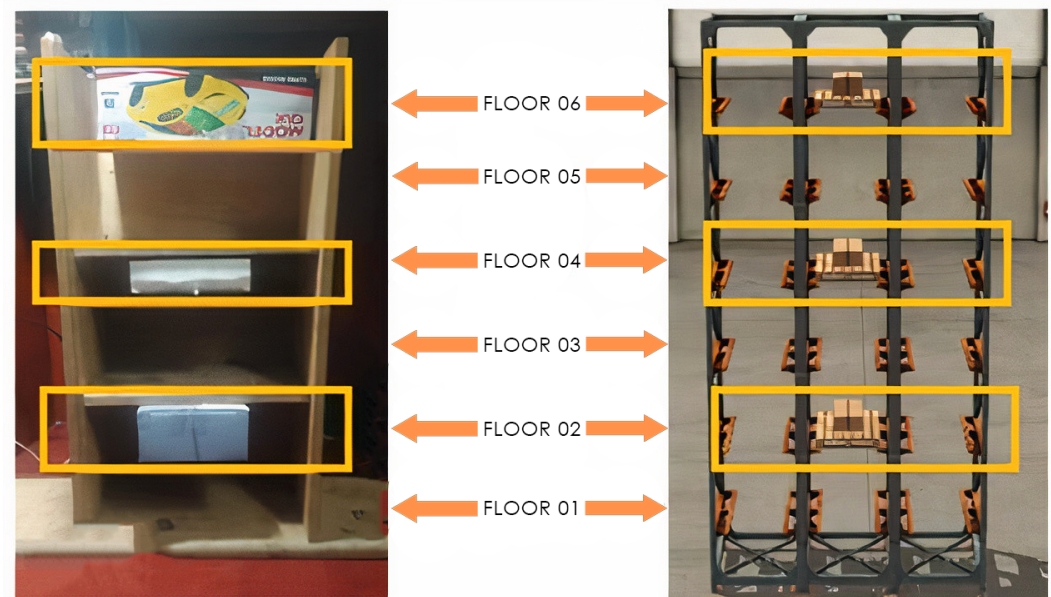


Figure 12. Comparison between the Factory I/O rack and the implemented system.

3.2.1. OPC Connection

To control the variables of the Tia Portal through LabView, it is necessary to make an OPC communication, for which the following configuration is made:

1. Open NetToPLCsim and assign the IPs of the computer and the PLC;
2. The connection is started in the NI OPC;
3. Create the channel and the device in which the connection will be made in NI OPC Servers, the connection channel, in this case TCP/IP Ethernet;
4. We proceed to the creation of the tags which are associated with the existing variables in the Tia Portal;
5. In LabView software, the I/O Server is created, where an OPC Client connection is selected and then the variables created in NI OPC Servers are added;
6. Subsequently, a VI is created where the buttons are added, and the variables created in the NI OPC Servers are dragged.

To make the connection between these elements, the state of the NI OPC Servers variables must be changed. Finally, in the buttons created, the Data Binding configuration must be changed, where the Data Socket option is selected and the NI OPC Servers variable is assigned to the corresponding button, see Figure 13.

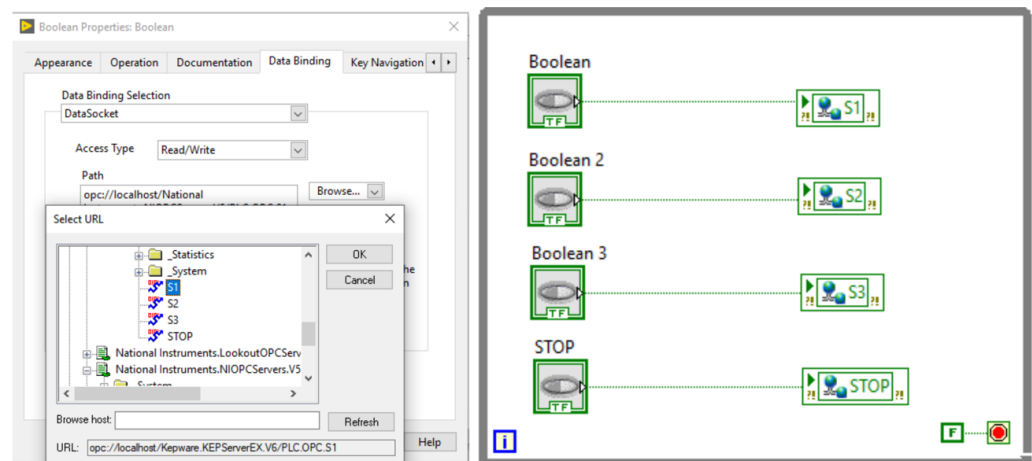


Figure 13. Configuration of the buttons for the OPC client connection in LabView.

3.2.2. RS232 Serial Connection

LabView is a general-purpose programming system, but it also includes function libraries and development tools specifically designed for data acquisition and instrument control. That is, it consists of its own libraries for serial communication. In the Arduino ID, this communication can be enabled using the `Serial.begin()` line code, which will allow sending and receiving data through the USB port.

3.3. SCADA System

In the LabView work environment, we have the configuration of the scene drive buttons in the Factory I/O. These variables represent the marks ranging from M60.0 to M60.3, which will activate a coil in the Tia portal program and will oversee executing a programmed displacement of the pallets. The configuration of the buttons as well as the block diagram of the serial communication is shown in Figure 14.

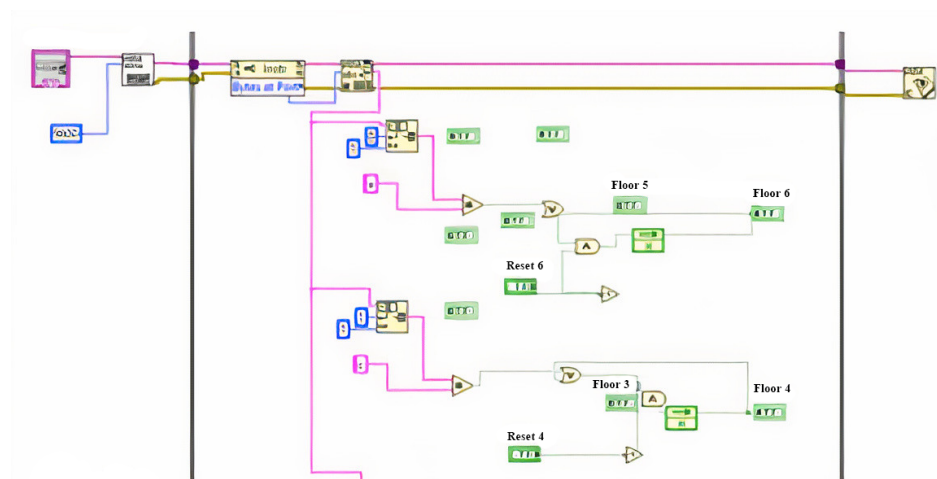


Figure 14. Button configuration for OPC and RS232 serial connection.

3.4. Product Monitoring System

To obtain the registry of the boxes that are on the different floors of the real system implemented, infrared sensors are used, connected to the Arduino microcontroller, and this in turn is integrated into the drone. The operating schematic of the drone-integrated inventory system using infrared sensors is presented in Figure 15.

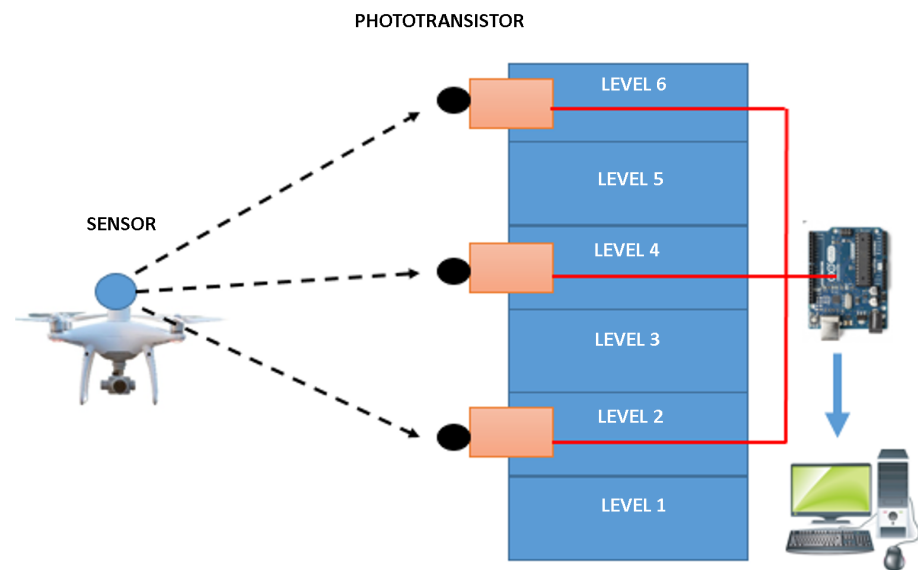


Figure 15. Sensor connection diagram.

In the case study, we made use of a folding drone with a basic design, which is programmed with a repetitive sequence with a time of 5 minutes. The system is able to deliver an instant report to the SCADA inventory monitoring system. The most relevant data of the drone are presented in Table 1.

Table 1. Main characteristics of the folding drone.

Main Features		
Dimensions	140 × 81 × 57 mm (L × W × H)	
Weight	249 g	
Speed	4 m/s (P Mode)	
	2 m/s (P Mode)	
	1.5 m/s (C Mode)	
Max flight time	30 min	
Power Transmission	2.4 GHz: <19 dBm (MIC/CE)	
Camera	1/2.3" CMOS	
	Pixel: 2 MP	
Battery capacity	2600 mAh	

To ensure that the drone can detect the availability of boxes, each box is connected to a phototransmitter that carries the product availability signal to an Arduino microcontroller, which is connected via serial communication to the inventory management center on a computer with the SCADA system developed by LabView. For the emission of the signal received by the photo transmitter, an infrared sensor has been incorporated in the front part of the drone, so that it can be received by the photo transmitter, see Figure 16.



Figure 16. Integration of the infrared sensor into the drone.

4. Results

In first instance, the circuit that contains the infrared sensors and work in conjunction with the Arduino, which simulates a drone, will be responsible for detecting the boxes in our model, sending the signal through the serial communication protocol 232 from Arduino in the LabView virtual environment. Once the data are obtained through the OPT communication protocol, the PLC 1200 is activated to send the programmed commands to the Factory I/O virtual environment, classifying the boxes depending on the floor where they are located, with the help of the rotary table, which allows the boxes to move to their corresponding exit, Figure 17.



Figure 17. Real implementation and virtual environment in the Factory I/O.

As can be seen in the SCADA environment, it monitors the current location of the relocation box on the shelves and in turn allows the control of the relocation of the shelves to a new location, see Figure 18.

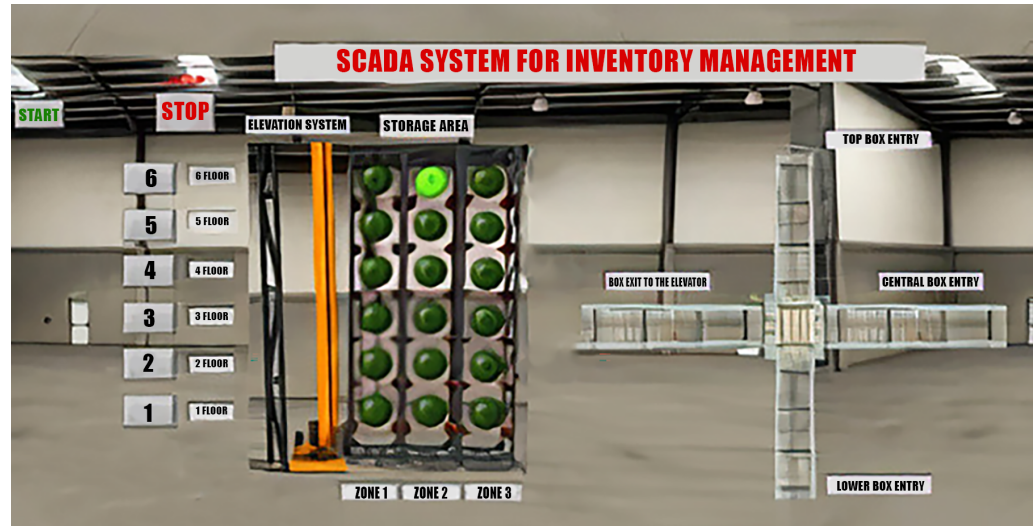


Figure 18. SCADA system, with the LabView interface for monitoring.

By activating the LED in the SCADA system, a signal is generated that activates the stacker crane in the Factory I/O, allowing the boxes to be transported, see Figure 18. Based on the detection of the drone, the boxes are classified depending on the floor they are on, for which a rotating table is used, which allows the boxes to be moved to their corresponding exit.

As shown in Figure 19, the developed system allows the integration of a virtual environment with a real environment. This allows to validate the operation of the SCADA system for inventory management within a company. All the data that are acquired by the Arduino device and stored in LabView can be sent to a cloud through the available Ethernet connection and allow a more detailed analysis of the inventory delivering the necessary management information as well as provide reports that can be sent to users within a smart city environment.



Figure 19. Classification and output of boxes.

5. Conclusions

The use of drones has grown significantly due to its various applications, such as agriculture, for environmental and climate studies, for scientific studies, or even for future medical studies. The development of these systems has allowed them to be properly integrated into smart cities, as they facilitate the way of living of human beings.

The use of drones for the recognition of the availability of goods in real industrial environments can be of great benefit, as it can quickly and safely access places that are at a great height, reducing time and physical and human resources, such as forklifts, ladders, and so on. On the other hand, it can be identified that infrared technology is sufficient to provide the necessary information to verify the availability of goods.

The proper use of communication protocols allows the integration of a virtual environment and a real environment as the study case, which through the acquisition of data from the sensors with the help of the Arduino microcontroller can control a virtual environment programmed in the Factory I/O. Through the simulation, it was possible to verify the use of field instruments, such as infrared sensors and microcontrollers, in addition to the use of a logic programmer for actuator control in the Factory I/O scene and two types of OPC.

Server communications for Tia Portal and LabView, as well as 232 network connections between Arduino and LabView allow us to obtain the necessary information for inventory management. A SCADA system allows us to link the variables of a process in real time and bring them into a monitoring system, where software such as LabView allows us to control, measure and record operations remotely. The availability of data such as stock availability of products offered by large companies through an inventory management system based on UAV systems allows us to validate the robustness of the architecture to integrate it into the development of smart cities.

The research carried out here is limited to identifying the availability of goods for dispatch in an automated way in a virtual environment; however, for future work and once its operation has been verified, active RFID systems can be integrated to provide more information that can be integrated into a smart city environment, such as date, dispatch time, etc. Finally, in future research, we propose the development of an application that connects to a cloud service that manages the inventory information in order to perform automated dispatches based on the consultation of the availability of the goods, time, and date of delivery, taking into account the location of the person for the dispatch of goods.

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Conflicts of Interest: The authors declare that they have no conflict of interest regarding the publication of this paper.

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