RESEARCH

Wireless Control of Heavy Rotating Platforms Based on Arduino and XBee Modules

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Abstract

This paper presents a system-based structure embedded for wireless control of heavy dual-degree-of-freedom rotating platforms. The design of a controller is proposed to allow remote access of operators through an XBee-based communication system, facilitating real-time automatic parameter adjustments. The wireless connection between the controller and the platform is established using an Arduino Leonardo board, eliminating dependence on Wi-Fi or TCP/IP protocols to enhance system robustness in industrial environments. The obtained results in a lab environment prove reliable platform control at distances up to 50 meters. Additionally, the link range can be increased by adding directional antennas compatible with the system hardware, optimizing remote control performance and reliability.

Keywords: Remote control; Arduino; XBee; Rotating platforms

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Introduction

Rotating platforms are used in a variety of applications such as communications, material handling, and cargo transport. These systems are currently limited by operational difficulties related to wired support, given the high installation costs, fragility of the environment, and inability to adapt to environmental changes. With the emergence of new technologies and the development of wireless devices, it is relatively easy to deploy them in environments where physical lines are a potential barrier. A viable solution to ensure remote control is the transmission of the control signal via radio frequency (RF) (Bernabé et al., 2024), being an affordable variant, those based on XBee from Digi International.

Novel researches apply the abovementioned modules in this field; some of them use it to check parameters in storage facilities through wireless RF chips and Zigbee protocol stacks (Wang, 2011). Ambikabhuvaneswari (2018) tracks e-bikes and retrieves information using LoRa and the XBee module. Another research (Adewasti *et al.*, 2018) deals with the development of a human-machine interface in LabVIEW so as to control a robot and observe the results of various environmental factors, such as temperature measurement, the presence of toxic gases, human presence detection, and can also transmit real-time video of that particular location wirelessly. The design development of a robot control system to monitor earthquake locations using Arduino based on XBee Pro is evidenced in (Shahzad *et al.*, 2017).

XBee Latency analysis with good results in the control of drone-mounted machines through remote channels is developed in XBee latency analysis for drone-mounted machine control over wireless communication channels (Sit *et al.*, 2021). Another study that evidences the reliability of XBee is (Gavra *et al.*, 2023), where an analysis of the characteristics of the mesh network topology is proposed to verify the range extension and how it affects the signal strength indicator and performance. The implementation of an unmanned vehicle system based on this technology is addressed in

(Karyemsetty *et al*., 2015) and proves that it is possible to monitor the vehicle's travel route on Google Maps using the latitude and longitude transmitted by the GPS receiver. In maritime positioning systems (San Filippo, 2015), node positioning algorithms are applied to track and identify operational movements onboard the vessel. The engine control and observation of its parameters is found in (Floriduz *et al*., 2015) with the description of a wireless temperature measurement system, intended for thermal analysis of rotating parts of electrical machines. The device was designed and manufactured to be installed on machines with a consumption less than 15 kW.

The abovementioned researches corroborate that XBee in combination with a programmable logic device can guarantee good quality in the wireless link. Furthermore, the reviewed studies show the advantage of implementing remote control solutions in areas or systems where the deployment of physical lines is complicated. This paper proposes a solution that uses an Arduino Leonardo board and an XBee S1 module as technical support (Hongyim, 2017). It consists of developing a wireless controller to increase the platform control range. The advantage lies in obtaining a system with the possibility of improving its performance regarding the parameters being tested and the accessibility without the need for wired support. The use of the TCP/IP protocol offers scalability, stability, security, and interconnection between different networks and devices (Hongyim, 2019). Due to its operating principle, the proposed wireless control is an option for IoT applications.

Materials and Methods

To achieve the established objectives, a market analysis was carried out focused on identifying the most accessible technologies from an economic and documentary perspective. A systemic analytical method was applied to extract key elements from the reviewed literature in order to develop a proposal that fits the system's needs. Given the existing technological restrictions in the country, particularly in the manufacture of printed circuits and the importation of electronic components, it was decided to choose for the use of open-source hardware and software as much as possible. This choice not only reduces associated costs but also promotes the sustainability and adaptability of the proposed system.

General System Structure

This paper proposes the implementation of a system with the structure shown in Figure 1. Its definition starts from the need to achieve remote communication between the control center and the platform. As can be seen, the actuator mechanism is equipped with an external control element composed of an Arduino Leonardo board and an XBee module, to guarantee the wireless connection. The control board is connected via a radio frequency link in the 2.4 GHz band to the management and control server which can be a desktop PC or mobile handset.

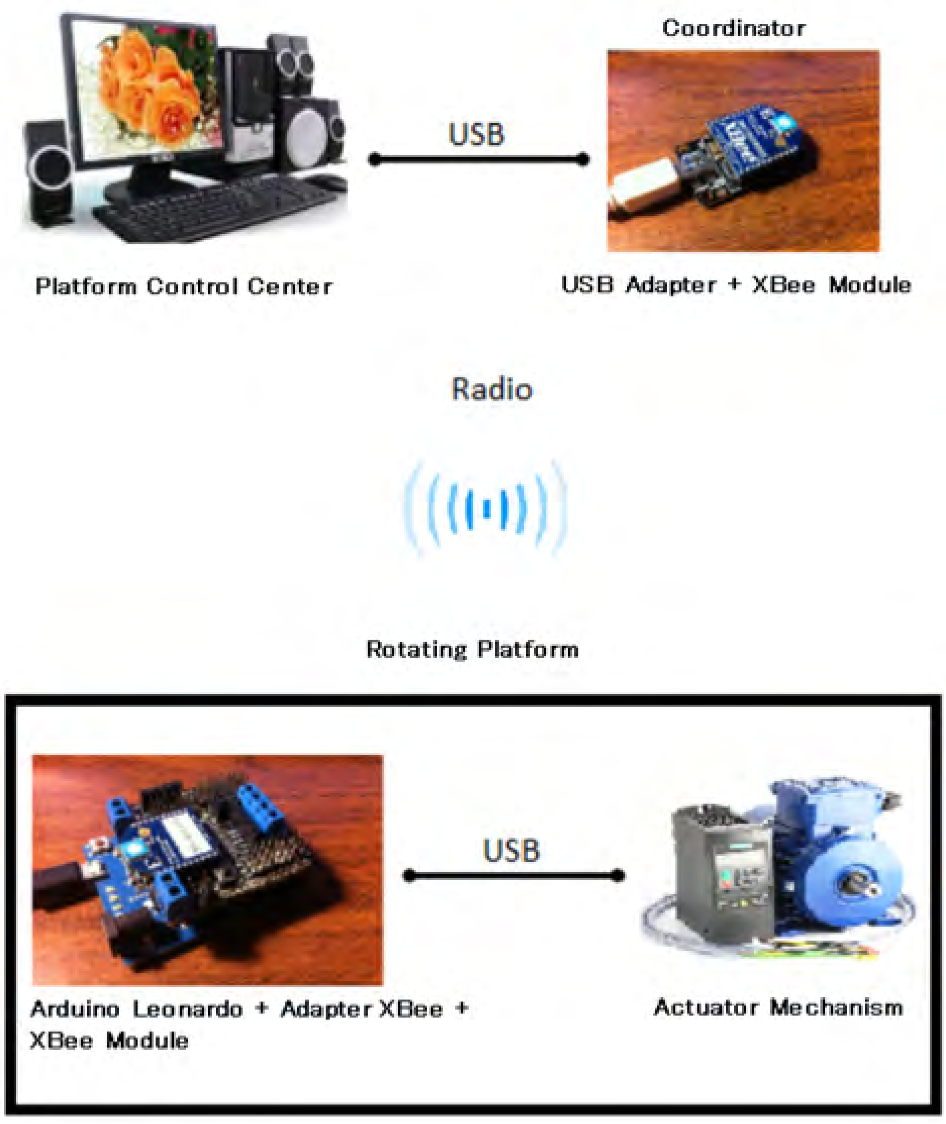

Figure 1. Block diagram of the proposed control system

The programmable controller is developed under the premise of using open hardware, which implies that the designs and specifications are publicly accessible. This characteristic allows the creation of the system at a reduced cost and promotes collaboration and innovation in the design of automated systems. To guarantee its functionality, the controller must include input interfaces that allow the connection of external devices, as well as the ability to integrate wireless modules.

The coupling elements are fundamental to adapt the controller to various industrial applications and facilitate its interaction with other systems.

Regarding the actuator mechanism of the rotating platform, it consists of a frequency drive (VFD). This device is crucial to carry out the conversion between the control signal (0 V - 10 V) and the voltage/current levels required by the alternating current motor (ACM), which is equipped with an encoder. The use of the VFD allows a precise control over the speed and motor torque, thus optimizing system performance (Matondang & Adityawarman, 2018).

Selected Hardware

During the component selection process for the design, the requirements established in the general system structure were considered. The use of Arduino as the main device is determined by competitive acquisition costs, ease of programming, and versatility in input interfaces, compared to other alternatives such as FPGA, PIC, or other microcontrollers. This choice is based on the need for an accessible and adaptable development environment that satisfies the specific project requirements.

Arduino Leonardo Development Board

The Arduino Leonardo, shown in Figure 2, is a development board distinguished by integrating an ATmega32U4 microcontroller, which has original USB capabilities. This characteristic allows the Leonardo to communicate directly with a computer, facilitating to emulate devices such as keyboards or peripherals through the USB-HID protocol (Penttinen, 2013). The board has 20 digital input/output pins, of which 7 are used as PWM outputs and 12 as analog inputs. Its crystal oscillator operates at a frequency of 16 MHz, ensuring adequate performance for various applications. Furthermore, it has 32 KB of flash memory for program storage, as well as a micro USB connector that simplifies connection and power supply.

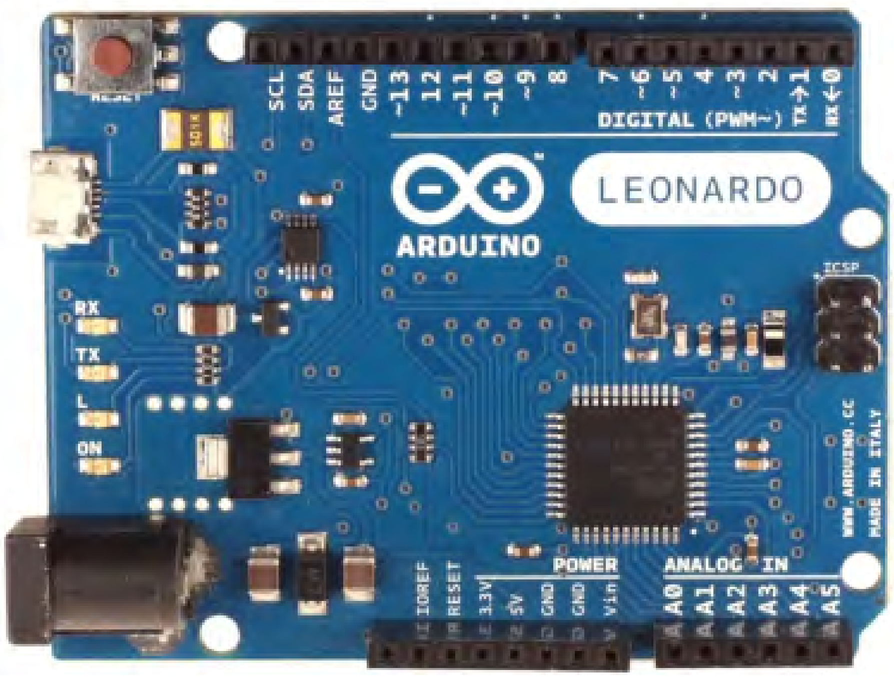

Figure 2. Arduino Leonardo Development Board

XBee S1 Module

The XBee S1 module, shown in Figure 3, is a wireless communication device designed for applications requiring connectivity in personal area networks. It operates in the 2.4 GHz ISM frequency band and uses the 802.15.4 protocol (Weatley, 2018), allowing low energy consumption and low latency connections. It provides a transmission power of 1 mW (0 dBm), achieving a range of up to 100 meters under direct visibility conditions, making it suitable to be implemented in industrial and urban environments. It is characterized by its ability to operate in an industrial temperature range, from -40°C to 85°C, guaranteeing its functionality in various environmental conditions. The module interface allows a data rate of up to 115.2 Kbps, facilitating efficient information transmission between devices. Furthermore, its compact design and variety of antenna options, including embedded antennas and connectors for external antennas, provide flexibility in system implementation.

Figure 3. Wireless Module Used

Wireless Controller Programming

The link programming was performed using the Arduino integrated development environment (IDE) in its version 1.8.2, which provides an accessible and versatile environment to develop applications based on microcontrollers. The network connection establishment is carried out via the XBee and XBee Arduino Library, which are fundamental to simplify the remote automation implementation, remote control, and the collection of relevant data about the surrounding environment.

The XBee library provides support for API mode, which enables the transmission of structured data and the handling of AT commands (Wang & Tang, 2011), in addition to allowing dynamic configuration of module parameters. This is particularly useful in applications where precise control over connected devices and effective network management is required. Moreover, it simplifies the programming of the wireless link, but also allows users to implement advanced features such as power management in battery-powered devices, which is crucial to lengthen the system lifecycle. The wireless link programming algorithm is shows in Figure 4.

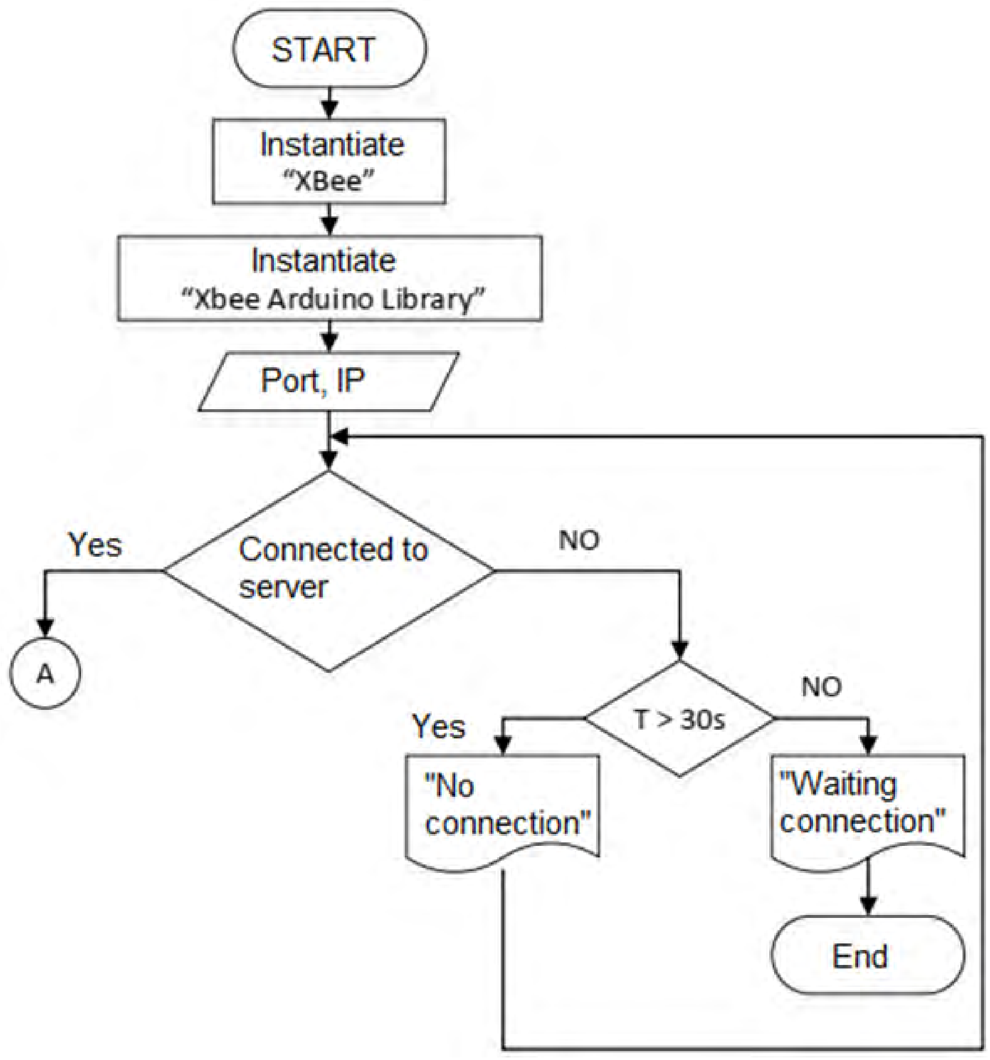

Figure 4. Wireless Link Programming Algorithm

Management and Control Application

In the development of the management and control application was taken into account the possibility of wireless connection via

WiFi or wired over Ethernet, as well as cross-platform with the aim of installing it both from a desktop computer with Windows OS® or Linux operating system, and on mobile devices with Android operating system. That is why, the QtCreator5.7 framework (Qt Creator, n.d.) was selected. This research is limited to describing only the application development process in Windows ® and Android, differing only by the inclusion of the corresponding compilation tools. In (Touil *et al.*, 2020), the relevant configurations in the framework options to perform the compilation for the Android operating system are explained.

Considering the hardware architecture, the client-server model was used for application programming, where the Arduino Leonardo board operates as the client and the management and control software is the server. The protocol used in the transport layer of the architecture was TCP, as being connection-oriented, it provides a reliable means for bitstream between applications (Penttinen, 2013). Considering that large volumes of data will not be transmitted, the package delivery will not imply a significant delay. For server development, the QTcpServer and QTcpSocket libraries were used. The proposed programming algorithm is shown in Figure 5.

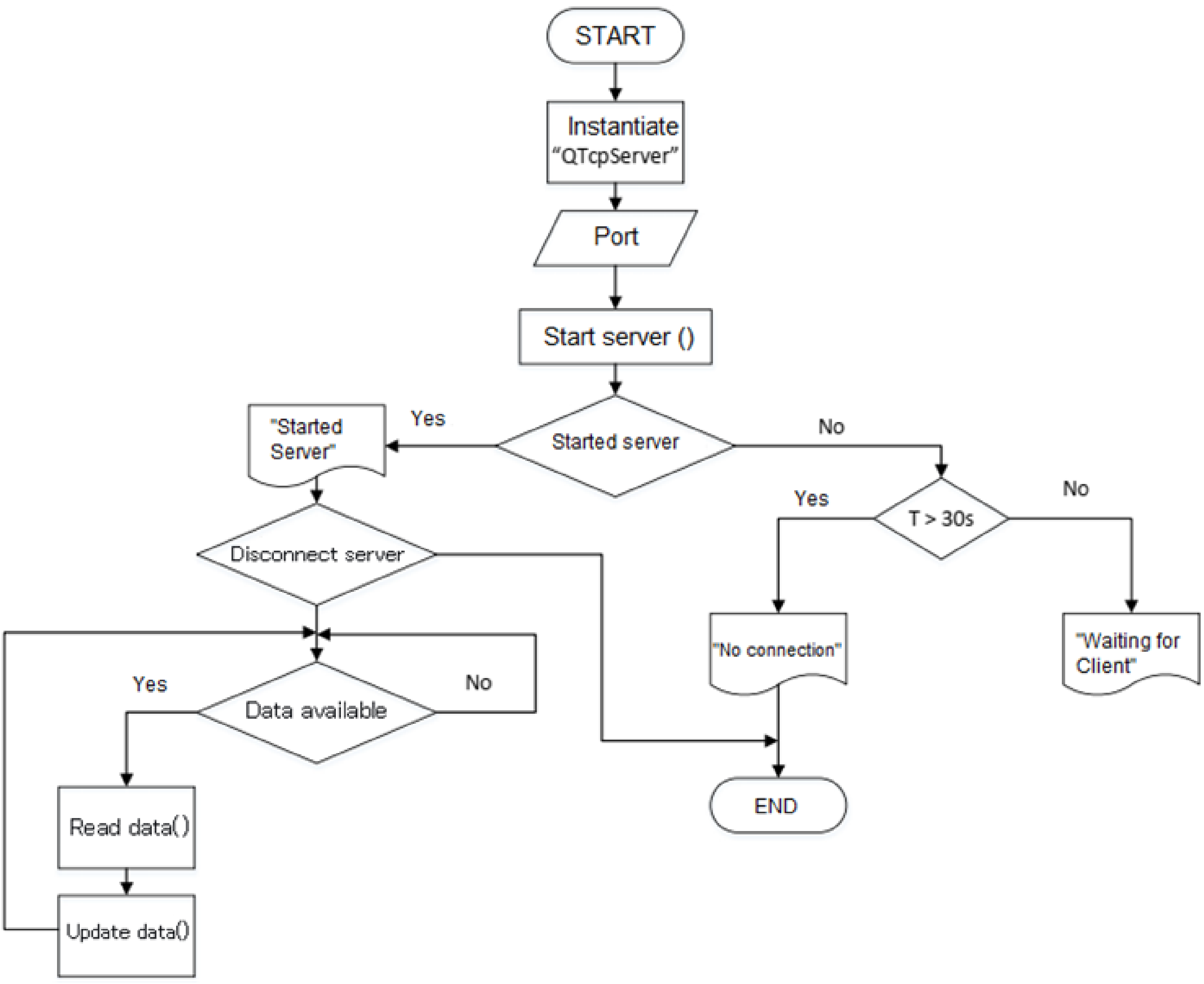

Figure 5. Programming Algorithm implemented in QtCreator

Control Technique Implementation

The implemented control technique is a PID controller - Proportional, Integral and Derivative - which is based on the regulation of proportional, integral and derivative parameters to manage system dynamics. This approach allows an effective response to variations in the reference signal, ensuring precise control over the process. The digital system design is carried out using the multidomain simulation platform Simulink, proprietary to MATLAB. This tool offers a set of libraries that allow the model to be exported to C language, enabling its implementation in embedded environments. The resulting scheme for validation is shown in Figure 6.

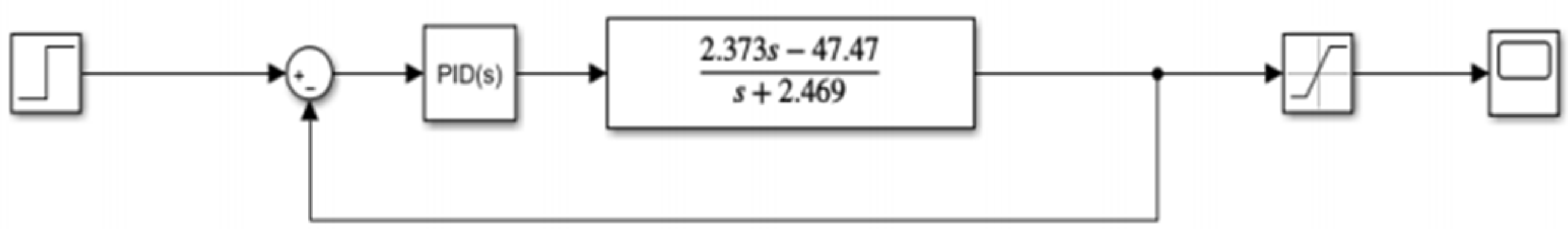

Figure 6. Simulink Scheme of the PID Controller

The system introduces the PID controller parameters to calculate the proportional, integral and derivative components of the error. This allows generating the control signal applied to the analog input of the frequency drive. The programming algorithm in Arduino corresponding to the PID controller is shown in Figure 7.

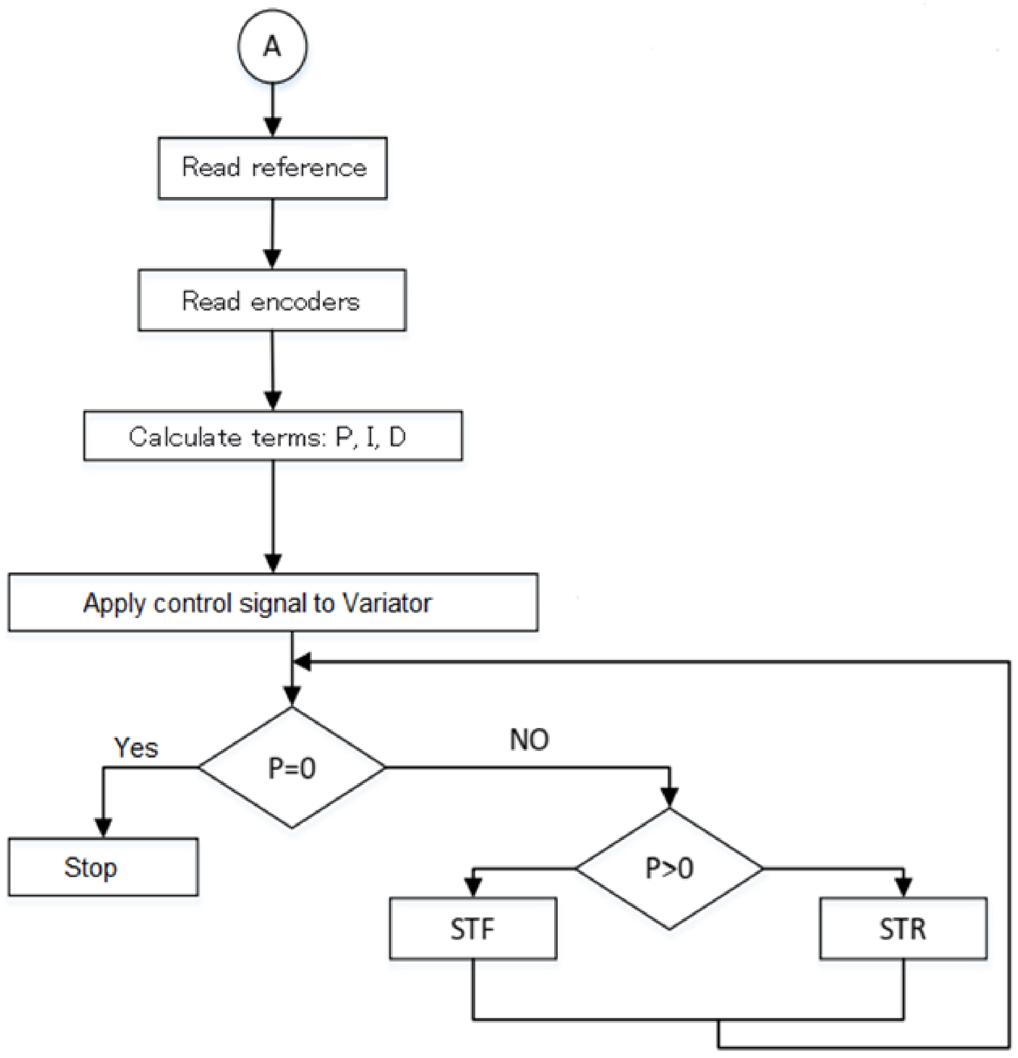

Figure 7. PID Controller Programming Algorithm

Results and Discussion

For the development of the experimental tests, the scheme shown in Figure 8 was designed. The sending of the data frame coming from the management and control server is performed at a frequency of 2.4 GHz. For the digital to analog conversion of the error signal, an AD 5626 converter with communication via Serial Peripheral Interface (SPI) and 12-bit resolution was used.

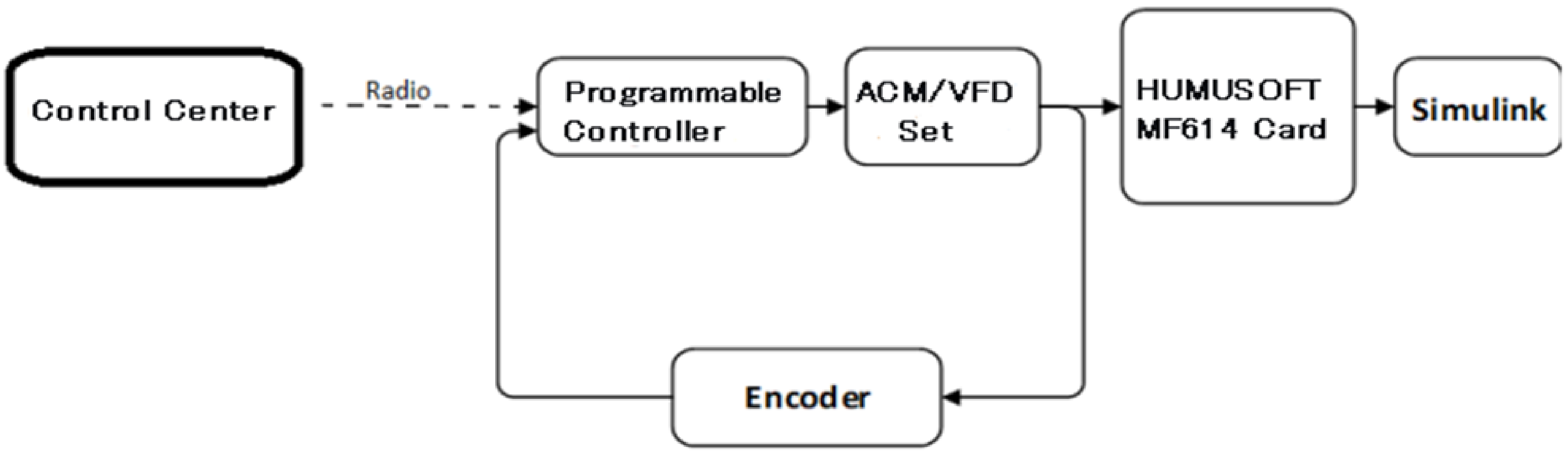

Figure 8. Wireless Controller Verification Scheme

The equipment used, in addition to the implemented controller, are listed below:

- Frequency drive and reference FR-A722 from Mitsubishi brand.
- Three-phase induction engine with 3 horsepower and nominal speed of 1500 rpm from ECCHOP brand.
- Incremental encoder with 12-bit resolution from DENMARK brand.
- HUMUSOFT MF614 acquisition card (Touil et al., 2020) to, via Real Time Target toolbox from MATLAB, check in Simulink the system output signal.
- PC with AMD E-300 Dual Core CPU 1.30 GHz processor, WINDOWS 10 PRO 64-bit operating system, 6 GB of RAM.

In the wireless connection, key parameters in link characterization are: the received power, the antenna gain, and the environmental noise level (Hongyim, 2019). Therefore, the system performance was assessed at different distances, using the antenna integrated into the wireless module. Table 1 shows the dependence of the received power against the distance to the server access point.

Distance (m)	Power (dBm)	Frequency (GHz)	Gain (dBi)
1	-35	2.4	10
5	-40	2.4	9
10	-45	2.4	7
20	-50	2.4	6
30	-55	2.4	5
40	-60	2.4	3
50	-70	2.4	2
55	-75	2.4	1

Table 1. Dependence of the received power on the distance

It can be noted that for distances greater than 50 meters the received power is significantly reduced, making the connection unstable. This measurement allows determining the maximum distance at which the control point can be located using the embedded access point. To improve the obtained results, a higher version of the wireless module can be used or add antennas with greater use of transmitted power.

A comparison was made of the results achieved on the platform with incorporated PID with the values established by the manufacturer in the original system manual. Measuring instruments used are the equipment's own parameter indicators. The obtained results are shown in Table 2.

Parameter	System	Measurement Plane	
		Horizontal	Vertical
Load Power (W)	Original	1200 ±500	1100 ±500
	With wireless control	1150	970
Dynamic Error (min)	Original	20±2	15±2
	With wireless control	18	13
Maximum Speed (rpm)	Original	1500 ±200	500 ±100
	With wireless control	1400	450
Full Rotation Time(s)	Original	20±5	12±5
	With wireless control	18	10

Table 2. Obtained Results

With the calculated value, an average of 1050 W of power necessary for the induction asynchronous motor was obtained, which describes the support capacity of the set combined by the alternating current motor and the frequency drive used, since they exceed that figure. The performance of the heavy platform was assessed, obtaining an improvement in compliance with the parameters established by the original system manufacturer, which corroborates that replacing the wired connection does not affect the platform control and increases the system capacity.

Conclusions

The results obtained show the fulfillment of the research objective by achieving the implementation of a wireless control system to ensure the control of a heavy rotating platform based on Xbee. Through the use of open hardware and software, high technological independence is achieved, lowering manufacturing costs. The adopted configuration allows above all flexibility and scalability, making its deployment possible in areas where a wired connection is impossible, as well as the addition of new nodes without significantly impacting the original design.

Even though the tests are satisfactory, if control distances greater than 50 meters are required, it is necessary to use another XBee module such as the PRO version or add a directional antenna to the RF connector embedded on the board.

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