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Implementation of an app-controlled robotic arm to optimize loading processes in Callao-Peru

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ABSTRACT

Efficient handling of heavy loads represents a constant challenge for businesses, which traditionally rely on significant numbers of staff, involving considerable financial costs and occupational health risks exacerbated by the need for specialized infrastructure. Despite technological limitations and structural deficiencies, this solution has prevailed in practice. However, engineering has responded with innovations aimed at optimizing these processes. In this context, the study proposes to adopt an approach based on implementing a robotic arm supported by technologies such as Arduino, Bluetooth devices, servo motors, and remote-control software developed in App Inventor. This approach promises not only the reduction of labor costs and the improvement of job security but also a positive impact in social and economic terms. A preliminary prototype is presented that validates the basic functionality of the proposed robotic arm. This study presents a technically and economically viable alternative for managing heavy loads in enterprise environments, reducing dependence on a large workforce, and improving operational efficiency.

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1. INTRODUCTION

The transportation and logistics industry faces significant challenges related to high personnel costs and the need for adequate infrastructure for handling heavy loads [1]–[4]. The need for optimization and infrastructure in heavy cargo processes is a real problem that affects the efficiency and profitability of logistics and transportation companies [5], [6]. This generates delays, high operating costs, customer dissatisfaction, greater worker insecurity, and environmental impact; this problem has been solved using science [7]–[9].

Previous research has addressed various aspects of automation in cargo handling. One presents a study focusing on controlling a three-degree-of-freedom robotic arm to manipulate objects. It uses kinematic models and algebraic solutions implemented with MATLAB and user interface. This work offers a solution to design reality interfaces in robots, demonstrating its applicability in robotic arm control [10].

This study addresses optimizing remote controls to manually operate a robotic arm, looking for more intuitive strategies to replace traditional keyboards and joysticks. A proposed design includes a glove with flexible sensors to control the robotic arm's movements. Servomotors act as actuators. The electronic device detects manual gestures and transmits wireless signals. This solution offers a more natural alternative for manipulating the robotic arm, potentially improving efficiency and user experience in various industrial applications [11].

The performance of a Mitsubishi RV2-AJ 3-DOF robotic arm with a PID controller in a closed-loop system is compared to that of a model with a closed-loop only. Simulation is carried out using Solidworks and Matlab-Simulink. The results demonstrate that the model with the PID controller exhibits faster response times and lower overshoot compared to the model with a closed loop only [12].

In viticulture and mariculture, the HEKTOR project plays a pivotal role in addressing the challenges posed by non-rigid parts. It presents an autonomous robotic system tailored for each sector, utilizing collaborative robotic components and subsystems. Fielfd tests confirm the HEKTOR system's ability to operate autonomously in challenging environments, meeting the required quality and quantity standards [13]. The project's focus on addressing the complexity added by non-rigid parts during assembly is evident in its exploration of models, methods, and techniques for their handling and control, leading to the development of innovative solutions and improved efficiency and accuracy [14].

Efficient packaging of chocolates in small-scale operations is achieved by developing a robotic arm with PRR configuration and a universal vacuum gripper, which allows for precise handling of chocolates. Using materials such as PLA and TPU improves movement control, while electronic components complement the system. The programming includes a graphical interface to control arm movements. This underlines automation's crucial role in improving productivity and quality in food packaging [15].

An Android application with Bluetooth capability was developed to manually and automatically control a four-wheeled mobile robot in different areas. The MIT App Inventor tool was used to create the application. After conducting experimental tests, the accuracy and data transferability were validated [16]. Furthermore, a project showcasing a robotic arm with five servo motors capable of moving in four directions and a stand for gripping and transporting materials is presented. Control is facilitated through an Android app via Bluetooth, and the study explores the significance of robotic arms, their types, theories, components, and practical implementation, concluding with data and experimental results [17]. The study [18] involved designing an Android application with Bluetooth to efficiently control a mobile robot. Using MIT App Inventor, the application was developed, which includes three main sections, ensuring proper data transfer with the robot. Experimental tests confirmed the operation's success.

Today, computing plays a fundamental role in engineering, business, and communications. This study proposes to use an Android application to develop a gesture control system for a 3D-printed robotic arm. A gesture control algorithm was created with MIT App Inventor. Using a smartphone's accelerometer, it is possible to control the arm via Bluetooth. The accelerometer captures hand movements, and a servomotor in the arm replicates these gestures. The project consists of a hardware part (3D printed arm and electronic components) and a software part (developed in App Inventor). The results confirm that the arm can be controlled wirelessly via the Android application [19]. Despite these advances, significant challenges remain in effectively integrating robotic technologies in traditional logistics environments, optimizing the user-robot interface to improve operational efficiency, developing specific robotic solutions for handling heavy loads in industrial environments, and improving safety and ergonomics in automated loading and unloading operations.

In response to these challenges, this study aims to develop a robotic arm controlled by a mobile application to optimize heavy lifting processes in the Callao area, Peru. This approach seeks to improve operational efficiency, reduce labor costs, and increase worker safety in industrial environments. The specific objectives of this research include designing and building a prototype robotic arm using technologies such as Arduino, servo motors, and Bluetooth modules, capable of handling heavy loads with precision and safety; develop a mobile application based on App Inventor that allows remote control of the robotic arm through a Bluetooth connection, providing an intuitive and functional user interface; implement a control system that allows precise and programmable movements of the robotic arm in multiple axes, facilitating the manipulation of loads in various industrial scenarios. Therefore, the research seeks to contribute to industrial automation, offering an innovative solution that combines robotics, remote control, and mobile technology to address critical challenges in handling heavy loads. The study not only aims to demonstrate the technical feasibility of the proposed solution but also explore its potential to transform working practices and improve the competitiveness of companies in the logistics and transport sector.

The following sections of this article will detail the design and development of the robotic arm, including its technical specifications and mobile control application. The methodology used for the implementation and testing of the system will be presented, followed by the results obtained in terms of operational efficiency and security. The implications of this technology for the logistics and transportation sector are significant, as it has the potential to transform working practices, improve the competitiveness of companies, and enhance safety and ergonomics. The article will be concluded with recommendations for future research in this field. This study contributes significantly to the advancement of automation in logistics, offering a practical and viable solution to the current challenges of the sector.

2. METHOD

Figure 1 shows the robotic arm's development method, which follows a cascade structure. Each phase must be completed before advancing to the next. This methodology ensures that each component is reviewed in detail and errors are minimized. The process includes several stages, such as the work area's delimitation, the prototype's design and implementation, and experimental validation.

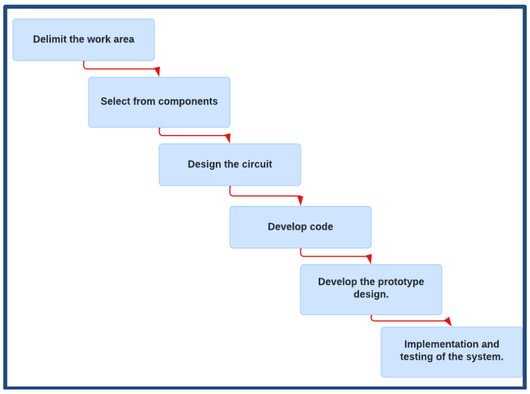


Figure 1. Project development stages

2.1. System architecture diagram

Below is an architecture diagram showing the relationships between the different components, including controlling movements in the arm joints using a combination of servomotors to optimize their performance. For joints with heavy movements, MG84 servomotors were used, while FG90 servomotors were used for lighter joints. This allows an efficient balance between cost and performance. An HC-06 Bluetooth module was integrated for the user interface, controlled via a mobile application, and an Arduino Uno microcontroller that processes user instructions and controls the actuators. This approach ensures precise management of robotic arm movements and smooth interaction with the user. A 9-volt battery powers the system, minimizing cable clutter and ensuring stable operation, as seen in Figure 2.

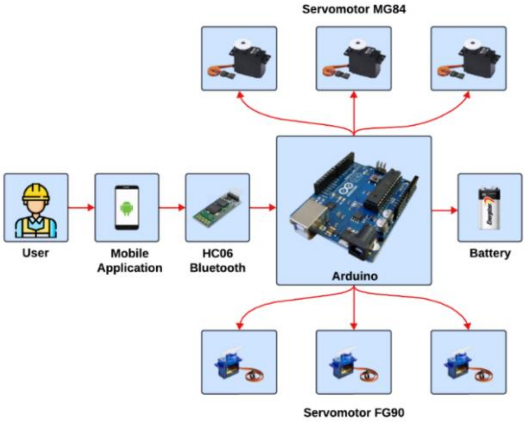


Figure 2. System block diagram

2.2. Components

2.2.1. Servomotor Mg 84/Fg90-45

A servomotor is an electric motor that controls a mechanism or device's precise position and movement [20]. It comprises a DC motor, a gear system, and an integrated control circuit. Servomotors can receive a control signal and rotate to a particular position, even under load conditions [21]. It is widely used in applications that require precise motion, such as robotics, positioning systems, industrial automation, and model-making [22], [23].

2.2.2. Bluetooth Hc-06

The HC-06 Bluetooth module is a device that operates at the 2.4 GHz frequency band [24]. This module, widely used in electronics and robotics projects, allows short-range wireless connections between various devices, such as microcontrollers (Arduino, Raspberry Pi), smartphones, and other sensors [25]. Thanks to its classic profile and simple configuration, the HC-06 facilitates integration into embedded systems, allowing bidirectional data transmission and the creation of simple wireless networks.

2.2.3. Arduino Uno

Arduino UNO is a hardware development board designed to create interactive electronic projects easily. Due to its ease of use and versatility, it is widely used in electronics and programming. Here are some typical applications using Arduino UNO [26]. One of the great features of Arduino Uno is its ease of programming. It allows users to load programs or “sketches” on the board to control various devices and perform actions [27].

2.3. Table of components

After a thorough review of the proposed system design and operation, a detailed analysis was conducted to determine the minimum essential characteristics required for system start-up. This evaluation process allowed us to carefully identify a number of critical specifications that are indispensable to ensure optimum performance and operational stability of the system under all conditions [28], [29], as shown in Table 1.

Table 1. Technical specifications of electronic devices

Components	Characteristics			
	Dimensions	Feeding	Speed	Weight
Servomotor MG 84/FG90-45	40.7×19.7×42.9 mm	4.8-6.6 v	0.20sec/60degree (4.8v); 0.17sec/60degree (6.0v)	55 g
Battery	2.65×1.75×4.85 cm	9 v	-	0.045 kg
Bluetooth HC-06 RF	26.9×13×2.2 mm	+3.3VDC50 mA	Asynchronous: 2.1 Mbps (max)/160 kbps, Synchronous: 1 Mbps/1 Mbps	3.5 g
Endurance	0.8×0.5 mm	4 w - 220 V	-	4.8
Arduino Uno	68.6×53.4 mm	5-20 V	16 MHz	25 g

2.4. Circuit design

The robotic arm controller, implemented on an Arduino and a breadboard, is responsible for managing the control logic and coordinating the actions of the actuators. Through the Bluetooth interface, the controller receives user instructions and translates them into pulse width modulation (PWM) control signals for the motors. The power unit, composed of a motor driver and a switching power supply, supplies the necessary current to the motors, ensuring adequate torque and dynamic response. As seen in Figure 3, this configuration allows the robotic arm to perform smooth and precise movements, adapting to the different demands of the manipulation tasks.

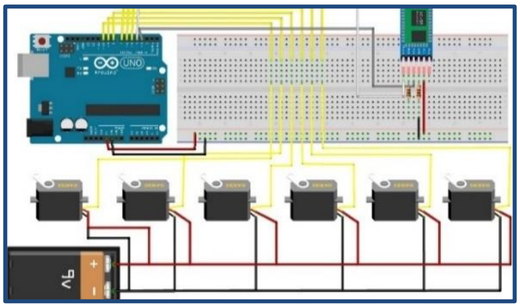


Figure 3. Robotic arm control system via bluetooth HC-06

2.5. Flow diagram

Figure 4 shows the start of the execution flow of the code programmed and stored in Arduino. Once started, the servomotors and the HC06 module are activated according to the established pins. Subsequently, the user verifies the successful connection of the mobile application with the project via Bluetooth and starts issuing commands. The robotic arm responds by executing a series of movements the user commands.

The user must verify that the arm is positioned correctly; otherwise, it must correct its position until it is as desired. Once the arm grabs the desired object and places it in its designated destination, the process is complete, and if the arm is not planned for future use, it is turned off.

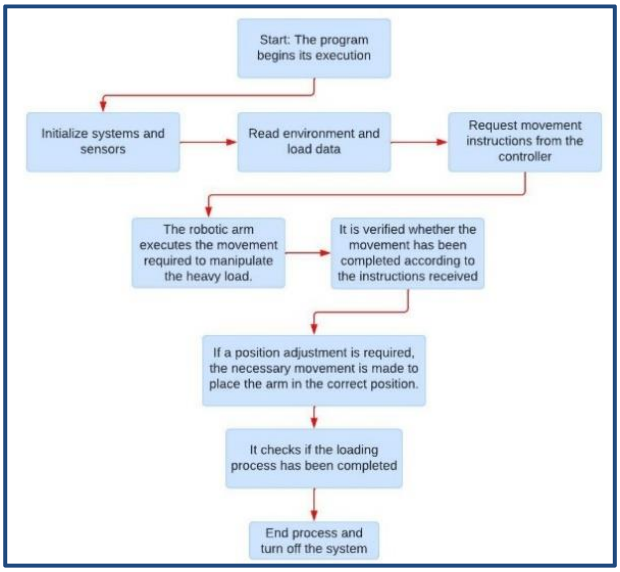


Figure 4. Operation flow diagram

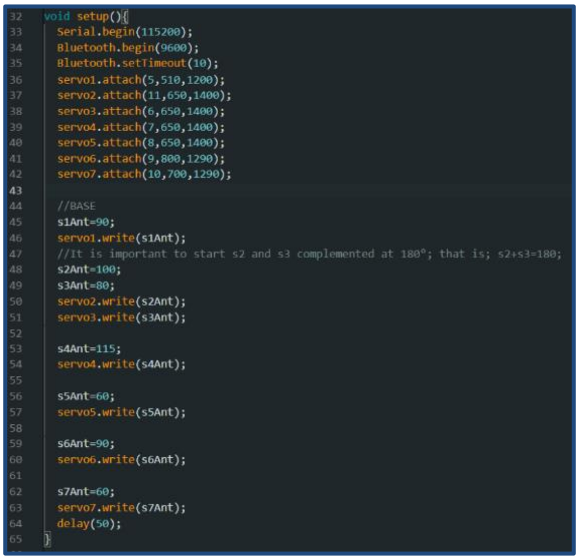
2.6. Circuit programming

First, as shown in Figure 5, the initial working environment of the system is defined by including essential libraries and declaring key variables. In this code, the Servo.h and SoftwareSerial.h libraries control the servo motors and serial communication over Bluetooth, respectively. A Servo object is defined for each of the seven joints of the robotic system, allowing precise control of each part. Additionally, variables representing each joint's speed of movement (s1Vel to s7Vel) are declared, ensuring smooth and controlled movement. The variables s1Act to s7Act store the current position of each servomotor, while s1Ant to s7Ant retain the previous position, allowing any change in position to be calculated. Matrices have also been defined to store up to 50 different positions of each servomotor, facilitating the registration and reproduction of complex movement sequences. Finally, the bt and btS character strings are used to manage communication data via Bluetooth.

```
#include <Servo.h>
#include <SoftwareSerial.h>
SoftwareSerial Bluetooth(3, 4); // RX, TX

Servo servo1;  //BASE
Servo servo2;  //SHOULDER1
Servo servo4;  //ELBOW1
Servo servo5;  //ELBOW2
Servo servo6;  //DOLL
Servo servo7;  //GRIPPER

int s1Vel = 15; //BASE
int s2Vel = 25; //SHOULDER
int s4Vel = 20; //ELBOW1
int s5Vel = 20; //ELBOW2
int s6Vel = 15; //DOLL
int s7Vel = 15; //GRIPPER

int index=0;
int velG=25;

//current position of the servos
int s1Act,s2Act,s3Act,s4Act,s5Act,s6Act,s7Act;
//previous servo position
int s1Ant,s2Ant,s3Ant,s4Ant,s5Ant,s6Ant,s7Ant;
//arrays to store the positions of each servo
int s1[50],s2[50],s3[50],s4[50],s5[50],s6[50],s7[50];

String bt,btS;
```

Figure 5. Data disclosure

As shown in Figure 6, the necessary initialization tasks are defined within the setup() function. In this configuration, serial communications with the Bluetooth module are initialized, and the parameters required for correct communication are established. The corresponding pins are then attached to each of the seven servomotors using the attach() function, allowing them to be individually controlled via the microcontroller. The starting positions of each servomotor are also defined and sent using write(), ensuring that the robotic system starts in a known, safe position. This initialization process is crucial as it ensures that the servomotors are in the correct positions before any dynamic operations of the robotic system are executed. In addition, a short delay (delay(50);) is incorporated to allow the servos to reach their initial positions, avoiding sudden or incoherent movements.



```
void setup(){
  Serial.begin(115200);
  Bluetooth.begin(9600);
  Bluetooth.setTimeout(10);
  servo1.attach(5,510,1200);
  servo2.attach(11,650,1400);
  servo3.attach(6,650,1400);
  servo4.attach(7,650,1400);
  servo5.attach(8,650,1400);
  servo6.attach(9,800,1290);
  servo7.attach(10,700,1290);

  //BASE
  s1Ant=90;
  servo1.write(s1Ant);
  //It is important to start s2 and s3 complemented at 180°; that is; s2+s3=180;
  s2Ant=100;
  s3Ant=80;
  servo2.write(s2Ant);
  servo3.write(s3Ant);

  s4Ant=115;
  servo4.write(s4Ant);

  s5Ant=60;
  servo5.write(s5Ant);

  s6Ant=90;
  servo6.write(s6Ant);

  s7Ant=60;
  servo7.write(s7Ant);
  delay(50);
}
```

Figure 6. initiation tasks

The code in Figure 7 is part of the Arduino loop() function, which runs continuously to control a servomotor based on Bluetooth inputs. This approach ensures that the system constantly responds to new commands. First, it checks if Bluetooth data is available, reads it as a string, and processes it if it starts with "s1". It then extracts a numeric value from the Bluetooth input (from position two onwards) and converts it to an integer, representing the target angle for the servo motor. The code uses two conditional structures to handle servo movement: increasing and decreasing the angle, allowing smooth, incremental movement in both directions. Finally, the servo's position is updated in small increments with short delays between movements, creating a sweeping motion. This gradual approach helps prevent sudden movements that could damage the servo or attached mechanism while providing more controlled and stable operation.

```
void loop() {

    if(Bluetooth.available()>0){
      // we read string
      bt = Bluetooth.readString();
      //SERVO 1 - BASE:
      //Checks if the string starts with "s1"
      if(bt.startsWith("s1")){
        //Let's extract the characters from position 2 onwards eg: "s1120" to "120"
         btS = bt.substring(2,bt.length());
         //Convert from string to integer
         s1Act = btS.toInt();
         //I MOVE THE SERVOMOTOR WITH A SWEEP
         if(s1Ant > s1Act){
            for(int j=s1Ant; j>=s1Act; j--){
                servo1.write(j);
                delay(s1Vel);}}
         else{
            for(int j=s1Ant; j<=s1Act; j++){
                servo1.write(j);
                delay(s1Vel);}}
        //The displaced angle (s1Act) becomes the previous position
        s1Ant = s1Act;}
```

Figure 7. Programming 1st part

2.7. Prototype design

The final design of where the circuit will go is shown in Figure 8, which represents the complete and optimized version of the design, which has gone through all the necessary design, testing, and adjustment stages. During the final design, all technical and functional aspects of the circuit, as well as the specific requirements of the project, have been taken into account. Extensive tests have been performed to ensure proper operation, and adjustments and optimizations have been made to meet the specifications and objectives. We implemented the final design in Autodesk software, which offers various solutions for managing architectural, engineering, construction, and design projects.

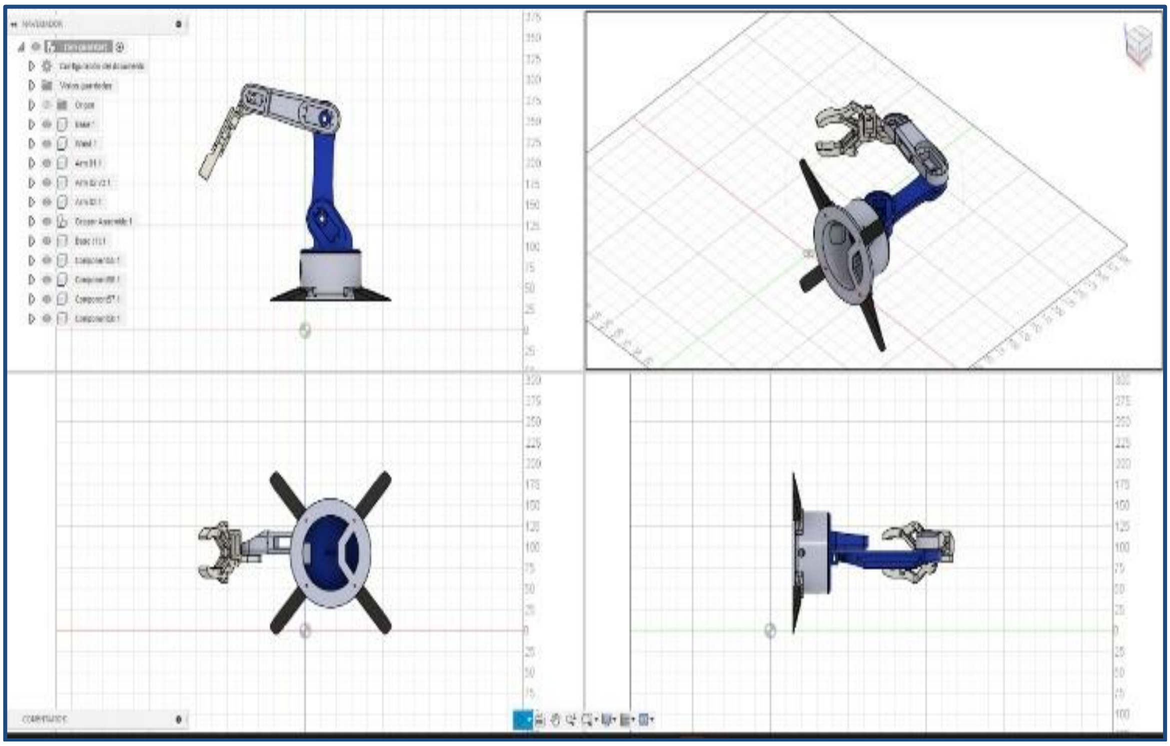


Figure 8. Final design in AutoCAD

3. RESULTS AND DISCUSSION

Implementing the robotic arm controlled by a mobile application yielded satisfactory functionality, precision, and efficiency results. The tests carried out on the prototype demonstrated that the system can handle heavy loads with stability and safety, which meets the initially set objectives. Combining servo motors and using a Bluetooth connection for remote control enabled precise manipulation of objects, overcoming common challenges in industrial automation. In addition, 3D printing of the structural components facilitated the construction of a robust prototype optimized for the industrial environment of the port of Callao. The following sections present the specific results of each project stage, from 3D printing of the parts to movement control and final implementation.

3.1. 3D Printing

We printed our project using a 3D printer, but first, we separated it into parts, as shown in Figure 9, to ensure the correct printing of the pieces. PLA (polylactic acid) filament was selected for manufacturing the scale prototype due to its optimal mechanical properties for this application. The inherent rigidity of PLA ensures that the model can withstand the expected loads during load testing, thus ensuring the functionality and durability of the design. In addition, PLA offers excellent adhesion between layers, which results in a final piece with high tensile and impact resistance, as we can see in Figures 10 and 11.

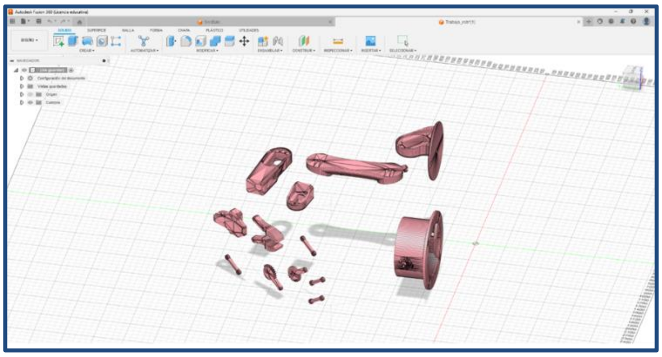


Figure 9. AutoCAD structure

Figure 10. Structure printing

Figure 11. Printed structure

3.2. Final assembled prototype

Figures 12 and 13 show the final result of the project implementation: an assembled and functional robotic arm. This robotic arm is built with 3D-printed parts, which form its main white structure. A servomotor controls the rotation movement at the base of the arm. The end of the arm is equipped with a pincer or claw designed to grasp objects. Several colored cables can be seen connecting the electronic components, indicating the integration of the control circuit. This assembly represents the culmination of the design, 3D printing, and assembly process of electronic components, resulting in a functional robotic device ready to be programmed and used in various applications.

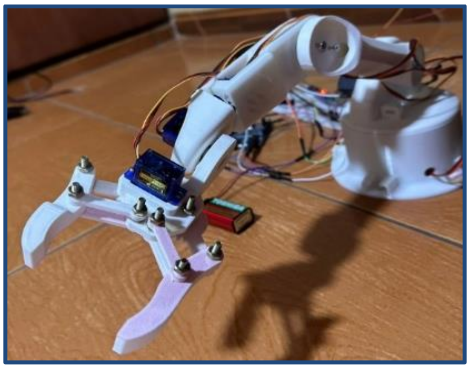


Figure 12. Final prototype

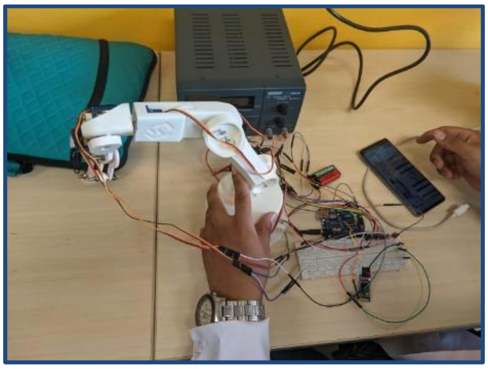


Figure 13. Operating robot arm

3.3. Bluetooth control application

Figure 14 shows that MIT App Inventor was the base where the application was created. This mobile application development platform allows the creation of applications for Android devices visually and without the need for advanced programming knowledge. The application can be connected via Bluetooth since the circuit has the Bluetooth module HC-06.

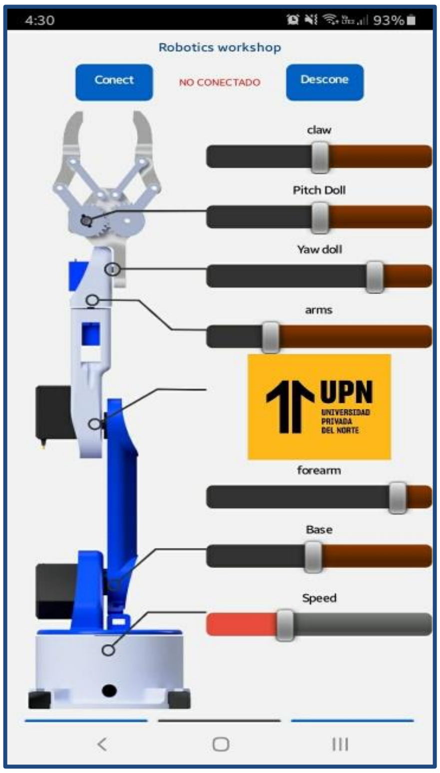


Figure 14. Application already running

3.4. Comparison with previous studies

The proposed system, which uses Bluetooth-controlled servomotors and a mobile application, proved to be highly efficient in handling heavy loads, achieving precise control of the robotic arm. This control optimizes the loading processes' safety and speed, meeting the initially set objectives. Unlike other approaches that use PID controllers, as observed in [12], this design simplifies the user interface, making it more accessible for implementation in various industries. Although the system does not include a detailed kinematic analysis similar to that presented in [10], the results are satisfactory for the industrial context of the proposed application. However, the absence of a deep kinematic analysis limits the precision of the arm movements, which could be improved in future prototype versions. This opens the possibility of integrating artificial intelligence, as the study in [19] suggested, to perform more advanced and optimized control in real-time. Additionally, it would be beneficial to conduct additional testing in other industrial contexts, as highlighted in [13], to validate the versatility of the proposed system. In summary, the results obtained demonstrate that the developed system has the potential to improve operational efficiency and safety in the handling of heavy loads, especially in port environments, reducing operating costs and improving worker ergonomics, in line with what was noted by previous studies [16], [17].

4. CONCLUSION

Implementing a robotic arm controlled by a mobile application to optimize loading processes in Callao represents an advance in the automation of port logistics. This system significantly reduces worker risks by automating repetitive and dangerous tasks while improving operational efficiency. The results suggest that adopting this technology could transform the industry's leading practices, positively impacting the safety and profitability of operations. Future research could explore incorporating more advanced algorithms to improve the system's performance and adaptability to other industrial environments.

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AUTHOR CONTRIBUTIONS STATEMENT
This study has been carried out with the contribution of the following authors, according to the Taxonomy of Collaborator Roles (CRediT):

Author Name	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
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Cristian Castro-Vargas	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT
The authors declare that they have no conflict of interest.

INFORMED CONSENT
This study does not involve the participation of human subjects or the use of personally identifiable information, so informed consent is not required.

ETHICAL APPROVAL
This study does not involve using humans or animals, so ethical approval is not required.

DATA AVAILABILITY
The authors confirm that the data supporting the findings of this study are available in the article.

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