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Next-Generation Exterior Painting: A Prototype Model for High-Rise Buildings with ESP32 Wireless Control

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ABSTRACT

This paper addresses the need for innovative solutions in exterior painting processes for high-rise buildings. The intention is to develop a prototype model that not only automates the painting procedure but also enhances efficiency, safety, and the overall quality of the process. The methodology involves the integration of ESP32 wireless control technology, allowing for automation through either Wi-Fi or cloud control. The key components of the model include a 240V, 1hp single-phase hoisted motor for vertical movement along the building façade and a 12V PMDC square geared motor for the operation of painting arms that apply paint to the wall. A contactless painting approach is adopted using a sprayer instead of traditional brushes or rollers. The results of the model's painting operations demonstrate significant reductions in time and costs compared to traditional methods, along with improvements in safety and overall painting quality. Notably, the model is designed to adapt to diverse climate conditions and accommodate various building sizes and shapes. This proposed automated exterior painting model holds immense potential for revolutionizing conventional practices, providing a safer, more efficient, and cost-effective solution for a wide range of building structures.

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1. Introduction

The development of automated exterior painting systems has gained significant traction in recent years, driven by the need to enhance efficiency, safety, and cost-effectiveness in the construction industry [1]. Traditional painting methods for high-rise buildings involve considerable human effort, time, and safety risks [2, 3]. As the demand for faster and more reliable solutions grows, researchers and engineers have been exploring advanced technologies to automate and optimize the painting process. Nowadays, High-rise buildings are on the rise globally owing to limited land in dense urban zones and their crucial function as key edifices in contemporary metropolises and capitals [4-6]. In recent years, because of intense global competition in construction, many new ideas and methods have been developed to create the best buildings possible. The idea of painting high-rise buildings can be daunting and risky, involving the use of ladders, scaffolding, and cranes. It is not only time-consuming but also poses significant safety risks to workers [7-9]. Continuous lifting, climbing up and down ladders [10], and applying paint can injure the knees, hips, shoulders, elbows, and neck of the workers. Exposure to certain, solvents, additives, pigments, and other materials that may contain asbestos can potentially lead painters to develop serious health problems, including lung disease and certain cancers. Painting work conducted at elevated structures [11] appears to carry the highest level of risk compared to other occupations under scrutiny. Therefore, preventive and control measures must be implemented within a timeframe of 1-2 days. Climate change is capable of having a negative impact on the materials that compose the facades of buildings, causing degradation and damage [12].

The task should not proceed unless the risk is assessed, and control options are chosen based on the Hierarchy of Controls. In the case of hazards related to painting work, it is necessary to apply appropriate rigid structures, establish proper access points for flexible platforms, provide suitable fall arresters/harnesses, and ensure the presence of secure safety ladders with paint-holding platforms and barriers. To ensure safe painting at significant heights, it is crucial to make paint mixing and transportation to the required height secure by providing adequate training and necessary equipment. According to the Occupational Safety and Health Administration (OSHA) in the United States [13], the construction industry has one of the highest rates of fatal injuries compared to other industries. In 2019, there were 1,102 fatalities in the construction industry in the United States, accounting for 20.7 % of all worker deaths by falling while hanging on a building [14].

To overcome these issues and challenges, an automatic painting system for high-rise buildings has been developed to automate the painting process and increase safety. The automatic painting system for high-rise buildings is a unique innovation that eliminates the need for manual labour by utilizing automated robotic systems [15, 16]. Studies have explored various wireless control mechanisms, such as Wi-Fi and cloud control, to streamline operations and reduce human intervention. Additionally, research highlights the importance of motor control systems in facilitating the movement of painting apparatus along the building façade. In the realm of automated painting systems, the integration of wireless control technologies has emerged as a key area of focus. The utilization of ESP32 wireless control, whether through Wi-Fi or cloud-based mechanisms, offers a promising avenue for reducing human involvement and enhancing the overall efficiency of the painting process.

This development background recognizes the potential of automation in addressing the challenges posed by manual painting methods, leading to improvements in both productivity and safety for personnel working on high-rise buildings. An automatic painting system is a highly efficient system that employs advanced technologies and techniques to ensure a uniform, high-quality finish [15]. The system has been designed to work in various weather conditions and can be used for a range of building sizes and shapes. The development of the automatic painting system for high-rise buildings has opened up a new chapter in the construction industry, providing a safer, more efficient, and reliable solution to painting tall buildings.

This paper is structured to provide a comprehensive exploration of the automated exterior painting system. The subsequent sections delve into the technical details of the prototype model, emphasizing the role of ESP32 wireless control, motor control mechanisms, and the application of a contactless sprayer. The results of the model painting works are presented to demonstrate its effectiveness in reducing painting time, costs, and improving safety and quality. The verification process of the highly efficient system, supported by advanced technology and techniques, is discussed. Finally, the paper concludes with insights into the adaptability of the model under diverse climate conditions and its suitability for a range of building sizes and shapes.

2. Literature Review

A substantial portion of painting tasks is essential to meet market demands, yet obtaining labour has become progressively expensive and challenging. Additionally, reliance on human labour proves to be time-intensive. The statistics underscore the necessity for the creation of autonomous painting machines capable of serving both individual consumers and established real estate entities [17]. Automatic wall painting [18] is an optimal solution due to its repetitive, stressful, and dangerous nature of rope over painting [19] as shown in Fig. (**1**).

The automotive industry has successfully implemented automation in painting; the construction sector is yet to adopt this technology. Automation in the painting would help to eliminate the loss of life due to the external factors acting when the workers are doing their jobs, such as high winds, storms, and falls. The craftsmanship [20] in manual spray painting was crucial for achieving consistent coating thickness on both flat and curved surfaces. However, computer-controlled spray guns have greatly minimized the need for such expertise. These automated processes not only enhance worker safety but also improve paint deposition efficiency and reduce appreciable time in painting [19]. Automation in painting gives good results scalability of the problem: it allows performing experiments with lower waste of raw materials [21].

Figure 1: Painting with rope at high-rise buildings.

Painted wall quality hinges on factors like the painting process, tool trajectories, speed, paint flow, paint type, dilution, air pressure, and distance [21]. Flood *et al*., [22] have successfully developed a painting machine designed specifically for painting surgical tubes. This innovative device incorporates a chain-driven track assembly that efficiently transports the tube pieces, securely held on paint fixtures, into a designated paint chamber for the painting process. Subsequently, the painted tubes are moved into an oven where the paint is dried thoroughly. Based on the aforementioned discussion, it is evident that the utilization of automated spray painting technology is highly viable and applicable for a wide range of finishing tasks. Painting at high-rise buildings [23] utilizes wireless sensor networks and cloud platforms, comprising a sensing network, data acquisition, data transmission, and condition evaluation components, and looks like a future trend in high-rise wall painting.

Permanent magnet DC motors (PMDC) are quite suitable for controlling the joints as they are more efficient and most importantly they can be battery operated up to 10 HP. PMDC motors are most suitable for intermittent and light-to-moderate duty. The integration of IoT technologies in the painting process, exploring potential benefits such as remote monitoring, data analysis, and optimization. IoT-based implementations and demonstrations, the target application for painting is an industrial scenario, and this environment has stricter requirements in terms of quality, operating conditions, and reliability, so not all types of sensors used in IoT prototypes are suitable for industrial applications. Thus, the usage of IoT-based solutions for monitoring the painting process in an industrial environment, and evaluating the continuous operation and performance of the system as part of a long-term solution [24].

Construction sites, with their vast, dynamic, and cluttered nature, demand efficient positioning of materials, tools, and vehicles. Various wireless tracking technologies, each with distinct characteristics, infrastructure, and device requirements, present challenges and opportunities in this unique environment [25]. The choice of technology depends on specific functionalities, capabilities, and application scopes. For instance, RFID may offer different features in local construction crew monitoring compared to a nationwide construction procurement system. Wireless technologies are widely used in many areas of the economy, including the construction industry [26].

Spray painting involves coating surfaces by spraying paint through the air, often using compressed gas. While painting robots were once perceived as costly, today's reality is different. They are affordable and versatile for various industrial applications, offering precise control over spray parameters. This robotic system delivers high performance at a fraction of the cost of complex robotic arms [27]. The performance of the robot was tested by five different tests which were DC motor testing, Stepper motor testing, Paint testing, liquid level sensor testing, and efficiency testing. The designed project can paint an area of 0.270 m2 in 26.760 minutes which has an accuracy of 96.476%. The efficiency of the painting system has an efficiency of 96.296% in terms of the painted area. The painting efficiency increased by decreasing the separation distance between the wall and the robot and fixing a pressure to 4.5 bars. The overall efficiency of the entire system has been obtained which was 83.987%. The system has a strong mobility system for reducing the vibration generated by the stepper motors. A simple approach to hardware design, coupled with very precise machines enables productive and safe operations [28]. The modularised and simplified painting setup made the system more approachable and robust.

Technology and innovations have fuelled the evolution of the fourth industrial revolution (Industry 4.0). Therefore, construction practitioners should partner more with researchers in the ICT industry to enhance the automation of work processes and managerial activities in the engineering and construction industry [29]. In conclusion, the literature review highlights the evolving landscape of automated exterior painting systems in high-rise building maintenance. The subsequent section presents a detailed block diagram illustrating the components and functionalities of the proposed prototype model.

3. Methodology

In developing the intricacies of the automated exterior painting system for high-rise buildings, it is essential to understand the overall structure and functionality of the system. The methodology of this model is explained with a block diagram [30] presented in Fig. (**2**) and it provides a visual representation of the key components and their interconnections within the system. This model uses two microcontrollers such as Arduino Uno and an ESP 32 blue tooth model microcontroller. The ESP32 is designed to provide wireless connectivity for a wide range of applications [31, 32]. The Arduino Uno effectively drives a 4-channel relay due to its GPIO pins and low-voltage compatibility. This enables easy control of multiple devices such as lights or appliances, enhancing automation and flexibility in various projects while offering a cost-effective solution. It includes Wi-Fi and Bluetooth functionality, making it suitable for IoT (Internet of Things) projects, home automation, wearable devices, and more. The Arduino drives a 4-channel relay, in which two channels are used for driving a 1.3 hp hoister motor to move the sprayer gun arrangements over the wall surfaces through bobbin-rope arrangements.

This single-phase induction motor works at 230V, 50Hz AC supply, and other channel runs to drive a suction pump driven by motor runs with a 12V DC supply supplied through a lead-acid battery. This suction pump draws paint from a 5-litre capacity paint storage tank. Paint from the suction pump through a pipe reaches the sprayer gun, and a square-geared motor with an L298N driver controls it with a 12V DC supply. Sprayer gun painting offers swift, even coverage, reducing painting time and labour costs. Its precise application minimizes drips and streaks, achieving a professional finish, and making it an ideal choice for efficient and high-quality wall painting projects. The sprayer gun can project an optimum 86˚ on the wall and provide a good finish on the first coating itself using this model.

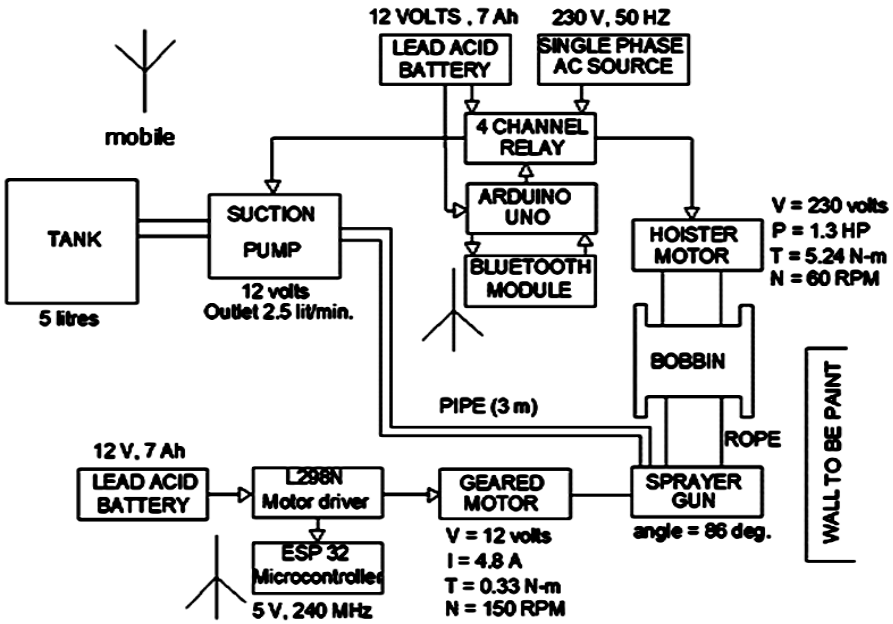

Figure 2: Block diagram for the proposed painting system.

4. Hardware Description

This hardware description chapter focuses on the tools, equipment, and materials needed for efficient wall painting, outlining essential components and their roles in achieving the best outcome for high-rise building painting results.

4.1. Hoister Motor

An electric hoist is lifting equipment that is powered by an AC single-phase induction electric motor. The electric motor is a key component of the hoist, as it is responsible for providing the power needed to lift heavy loads. Electric hoist motors come in a variety of sizes and power ratings, depending on the specific application and load requirements. The motor is typically rated in watts or horsepower, with larger motors providing more power and torque for lifting heavier loads. This model uses a 1020W, 60 rpm motor. Fig. (**3a**) shows the motor is connected to the hoist mechanism, which consists of a cable that is wrapped around a drum. When the motor is activated, it turns the drum, which causes the cable to move and elevate and de-elevate the load. The rope is designed with steel wires and length is about 6m long and each rope is given to the two bobbins and coupled with this moving system. In this model, an AC motor is used for the convenience of power supply, but in many sites, AC supply may not be available. In such circumstances, a DC motor may be used with batteries.

4.2. Permanent Magnet DC Motor

A square-geared PMDC motor (Fig. **3b**) is a type of electric motor that is commonly used in a variety of applications and gets its name from its square shape, which is designed to make it easier to mount in tight spaces. The motor is powered by a 12-volt DC power source can be a battery or a DC power supply. It includes a set of gears that help to increase the torque and reduce the speed of the motor. This gearing mechanism is essential for applications where high torque is required. The advantage of the square-geared 12-volt DC motor is its versatility and this motor can be easily controlled using a motor controller, which allows for precise speed and direction control. This motor provides more torque and acts as an actuator to pull the trigger of the sprayer gun which needs more force to pull the trigger. This operation is done with wireless control via our mobile to control the sprayer gun. The motor is programmed to run forward and backward direction. The motor will turn OFF every 0.8 seconds at intervals for every operating direction in order to achieve the required angle to operate the spray gun.

4.3. Motor Controller or Driver

The L298N is a popular dual H-bridge motor driver integrated circuit (IC) that is commonly used in robotics and other projects that require precise control over the movement of motors. It can drive two DC motors or a bipolar stepper motor and can handle a maximum current of 2A per channel. The L298N (Fig. **3c**) is designed to be easy to use, with a simple interface that allows for easy connection to microcontrollers or other control circuits. It includes built-in protection features, such as over-temperature and over-current protection, to help ensure safe and reliable operation.

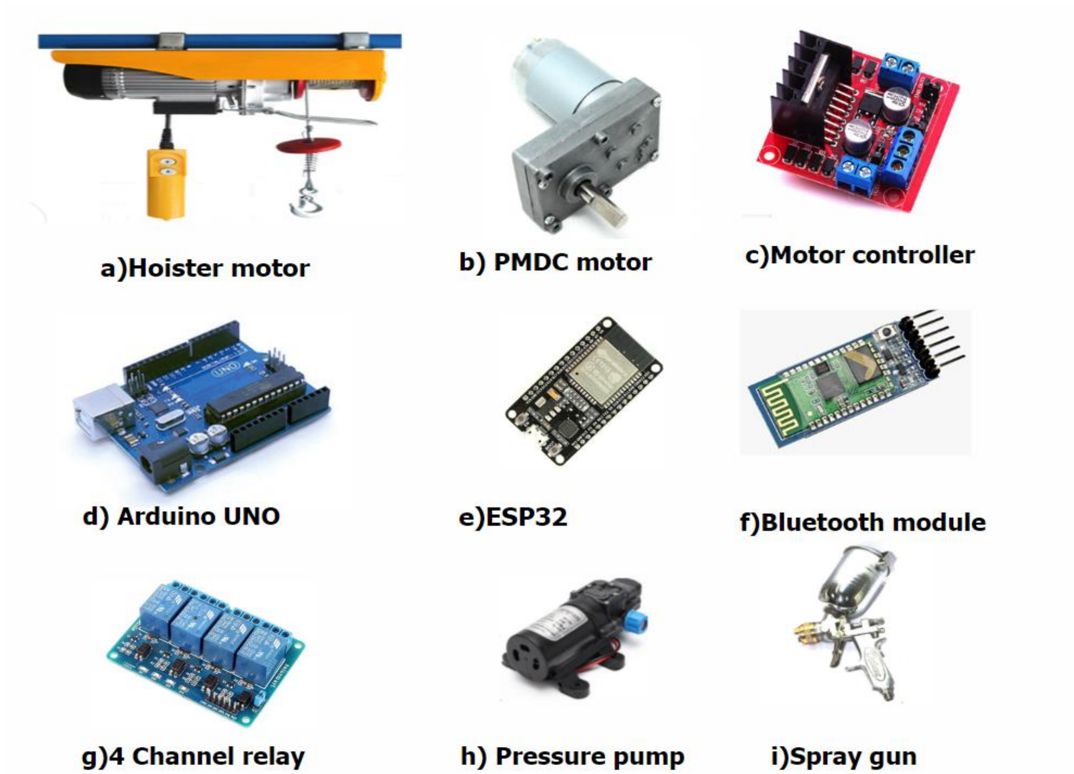

Figure 3: Hardware components of the proposed model.

One of the key advantages of the L298N is its ability to control the speed and direction of motors with precision. It supports both forward and reverse motion, as well as variable speed control using pulse-width modulation (PWM). The L298N is also compatible with a wide range of microcontrollers and other control circuits, making it easy to integrate into existing projects. It is commonly used in robotics projects, motor control applications, and other projects that require precise control over the movement of motors. Overall, the L298N is a versatile and reliable motor driver IC that is well-suited for a wide range of applications.

4.4. Arduino UNO

Fig. (**3d**) shows a microcontroller board based on the ATmega328P microcontroller. It has 14 digital input/output pins, 6 analogue inputs, a 16 MHz quartz crystal, a USB connection, and a power jack. The board is designed to be easy to use and is widely used for a variety of projects, including controlling single-phase AC motors [33]. Controlling a single-phase AC motor with an Arduino Uno typically involves using a relay module to switch the motor on and off. The relay module is connected to the digital output pins of the Arduino Uno, and the motor is connected to the relay contacts. By sending signals to the digital output pins, the Arduino Uno can turn the relay on and off, which in turn switches the motor on and off. To control the speed of a single-phase AC motor, a variable frequency drive (VFD) is often used. A VFD is an electronic device that can control the speed of a motor by adjusting the frequency of the AC power supplied to it. The VFD is connected to the Arduino Uno via a digital communication protocol, such as Modbus, and the Arduino Uno sends commands to the VFD to adjust the motor speed. Overall, the Arduino Uno is a versatile and easy-to-use microcontroller board that is well-suited for controlling single-phase AC motors. With the addition of a relay module and a VFD, it is possible to control the on/off and speed of the motor.

4.5. ESP32 Microcontroller

ESP32 (Fig. **3e**) is a powerful microcontroller and Wi-Fi-enabled system-on-a-chip (SoC) that is widely used in various applications such as IoT (Internet of Things) devices, smart homes, and wearable electronics. It is designed by Espressif Systems; a company based in China, and is the successor to the popular ESP8266 microcontroller. The ESP32 microcontroller is based on a dual-core Tensilica LX6 microprocessor with clock speeds of up to 240 MHz and it comes with built-in Wi-Fi and Bluetooth connectivity, making it easy to connect to the internet or other Bluetooth devices. The microcontroller also includes a variety of other hardware features, such as touch sensors, an analog-to-digital converter, and a low-noise amplifier. It can be programmed using a variety of programming languages and this flexibility makes it easy for developers to get started with the ESP32 and to develop a wide range of applications. In addition to its powerful hardware, the ESP32 also includes a variety of software features that make it well-suited for IoT applications [34, 35]. It supports a range of Wi-Fi and Bluetooth protocols, including Wi-Fi Direct and Bluetooth Low Energy, and it includes support for secure communication using SSL/TLS protocols. It also includes built-in support for a variety of cloud services, such as AWS IoT and Google Cloud IoT, making it easy to connect to cloud-based services and applications. In this system, we used ESP32 to control the sprayer gun with the 12-volt square-geared DC motor.

4.6. Bluetooth Module (HC-05)

A Bluetooth module (Fig. **3f**) is a wireless communication device that enables you to connect electronic devices such as smartphones, tablets, and microcontrollers like Arduino to other Bluetooth-enabled devices. In your project, you used a Bluetooth module to control a single-phase AC motor wirelessly from a smartphone and it provides a low-power, short-range wireless communication protocol that is widely used in consumer electronics, such as mobile phones, headphones, and wireless speakers. In this project, a Bluetooth module to establish a wireless communication link between the smartphone and the Arduino microcontroller that controls the relay. One advantage of using a Bluetooth module to control an AC motor is that it provides a convenient and flexible way to control the motor remotely without the need for wires or physical connections [36]. By using a smartphone app, you can easily switch the motor on and off and change the direction of rotation from a distance. Another advantage of using a Bluetooth module is that it is widely available and easy to use, with many modules and libraries available for Arduino and other microcontrollers. Bluetooth modules can also support advanced features such as encryption, authentication, and data compression, which can help to improve the security and reliability of your wireless communication link.

4.7. 4 Chanel Relay

A relay is an electronic switch that allows you to control high-power electrical devices with a low-power signal, such as those provided by a microcontroller like Arduino. This project used a relay to control a single-phase AC motor and PMDC motor. A relay consists of an electromagnetic coil and a set of contacts as shown in Fig. (**3g**). When the coil is energized by a signal from the microcontroller, it generates a magnetic field that pulls the contacts together, closing the switch and allowing current to flow through the relay. When the signal is removed, the coil de-energizes and the contacts open, breaking the circuit. Relays are commonly used to switch high-power devices, such as motors, lights, and heaters. This project used a relay to switch the power to the AC motor, allowing you to control the motor's direction of rotation by switching the polarity of the AC voltage. One advantage of using a relay to control an AC motor is that it provides electrical isolation between the low-voltage control circuitry and the high-voltage motor circuitry, helping to protect the microcontroller and other sensitive electronic components from voltage spikes and other electrical noise.

4.8. Pressure or Suction Pump

A 12V suction pump is a type of pump that uses suction to draw fluid or air from a container or other source. It is designed to be powered by a 12-volt DC power source from a battery. The Fig. (**3h**) typically consists of a motor, an impeller, and a suction inlet. When the motor is activated, the impeller rotates and creates a vacuum inside the pump chamber, which in turn causes fluid or air to be drawn into the suction inlet. One of the key advantages of a 12V suction pump is its versatility and portability. Another advantage of a 12V suction pump is its efficiency and low power consumption. It is designed to operate on a 12-volt DC power source, which is often provided by a battery or other portable power source. This makes it a cost-effective option for applications where electricity is not readily available. However, it is important to note that the performance of a 12V suction pump can vary depending on several factors, such as the type of fluid being pumped, the diameter of the suction inlet, and the condition of the impeller. It is important to choose a pump that is appropriate for the intended application and to follow the manufacturer's instructions for proper use and maintenance.

4.9. Sprayer Gun

A paint sprayer gun (Fig. **3i**) is a tool used for applying paint or other coatings to a surface. It works by using compressed air or high-pressure fluid to atomize the paint, breaking it up into tiny droplets that are then sprayed onto the surface. Paint sprayer guns come in a variety of types and sizes, ranging from handheld models for small projects to larger, more powerful models for commercial and industrial use. It is commonly used in the automotive, construction, and woodworking industries. One of the key advantages of using a paint sprayer gun is that it can provide a smooth, even coat of paint with minimal overspray [19]. This can save time and reduce the amount of paint needed for a project, making it a cost-effective option for larger jobs. Paint sprayer guns also offer greater control over the application of paint, allowing users to adjust the spray pattern and flow rate to achieve the desired results.

4.10. Battery

A 12V, 7Ah, battery is a rechargeable lead-acid battery commonly used in a wide range of applications such as uninterruptible power supply (UPS), emergency lighting, security systems, and portable electronics. As the name suggests it has a nominal voltage of 12 volts and a capacity of 7 ampere-hours, which means it can supply a current of 7 amps for one hour or 1 amp for 7 hours. The actual capacity of the battery may vary depending on the discharge rate and other factors, but in general, a 12V, 7Ah battery is capable of powering small to medium-sized devices for several hours [37]. One of the key advantages of a 12V, 7Ah battery is its compact size and portability. It is relatively small and lightweight, making it easy to transport and install in a variety of devices. It is also easy to recharge using a suitable charger, which makes it a cost-effective option for many applications [38]. Another advantage of a 12V, 7Ah battery is its reliability and durability. Lead-acid batteries are known for their long service life and ability to withstand heavy use, which makes them a popular choice for applications that require a reliable and long-lasting power source [39]. This model uses a 2, 12V, 7Ah battery; one is for the suction pump and another for the sprayer controller.

5. Torque and Spray-Angle Calculations

Torque calculation and appropriate spray angle calculation for automatic processes are pivotal for optimizing motor performance in painting applications [40]. It ensures precise brush movement and consistent coating, enhancing paint quality. Proper torque determination guarantees efficient motor control, contributing to flawless and professional paint finishes.

5.1. Torque Calculation of Hoister Motor

The torque equation [2, 41] for an electric hoist motor is given by,

$$T = (P \times 60) / (2 \times \pi \times N) \text{ N-m} \quad (1)$$

Where T is the torque in Nm, P is the power in watts, N is the speed in revolutions per minute (rpm), and π is the mathematical constant pi (approximately 3.14).

$T = (P \times 60) / (2 \times \pi \times N)$

$T = (1020 \times 60) / (2 \times \pi \times 60)$

$T = 30600 / (2 \times \pi \times 60)$

T = 5.34 N-m.

5.2. Torque Calculation of Sprayer Actuation System

The sprayer gun actuation to trigger the sprayer gun with the help of 12 Volts DC motor calculations is given below,

$$\text{Pulling Power} = \text{Torque} \times \text{Angular Speed} \quad (2)$$

$$\text{Force} = \text{Torque} / \text{Radius} \quad (3)$$

Where,

$$\text{Torque} = \text{Motor Torque} \times \text{Gear Ratio} \quad (4)$$

$$\text{Angular Speed} = \text{Motor Speed} / \text{Gear Ratio} \quad (5)$$

Radius = Distance from the centre of rotation to the point where force is applied

Let's assume the following values:

The force required to pull the sprayer gun arm = 10 N

Gear ratio of the motor = 60:1

Distance from the centre of rotation to the point where force is applied = 0.1m

Using these values, we can calculate the pulling power, force, and torque as follows:

Torque = 12 V x 10 A x 60 / (2π x 1000) = 0.57 N-m

Speed = 6000 rpm / 60 = 100 rpm

Pulling Power = 0.57 Nm x (2π x 60 / 60) = 1.79 W

Force = 1.79 Nm / 0.1 m = 17.9 N

As the calculated force required to pull the sprayer gun arm is 5 N, the motor is to provide enough force to pull the arm.

5.3. Angle Calculation of Sprayer System

To calculate the sprayer angle [40] for your automated exterior painting system, you can use the following formula:

$$\theta = \tan^{-1}((2h) / d) \quad (7)$$

Where,

θ = sprayer angle (in degrees)

h = height of the building section being painted (m)

d = distance between the sprayer and the building section being painted (m)

Assuming a value of 30 meters for the height of the building section being painted and a value of 1 m for the distance between the sprayer and the building section, we can calculate the sprayer angle as follows:

$\theta = \tan^{-1}((2 \times 30) / 1)$

$\theta = \tan^{-1}(60)$

$\theta \approx 86.41^\circ$

Therefore, the sprayer angle for this scenario would be approximately 86.41˚. This means that the sprayer should be tilted at an angle of 86.41˚ from the horizontal in order to achieve optimal coverage of the building section being painted. It is important to note that this calculation assumes a few simplifying assumptions, such as a flat and uniform building surface, consistent paint flow rate, and consistent sprayer performance. In reality, other factors may come into play that can affect the sprayer angle, so it is important to carefully evaluate the specifics of your project to ensure that the sprayer is positioned and oriented correctly for optimal paint coverage.

6. Circuit Diagram

The circuit diagram and the pin configuration of different control mechanisms are important to understand the workings of this model. There are two important circuits and their pin configuration are essential to studying this work it is listed as follows,

1. Sprayer Control

2. Hoister Motor and Suction Pump Control

6.1. Sprayer Control

This Chapter delves into the pivotal aspect of the automated exterior painting system and it explores the sophisticated control mechanisms governing the sprayer, ensuring precision and efficiency in the painting process Fig. (**4**).

6.1.1. Motor Driver (L298N) to the ESP32 Connections

ESP32's 3.3V pin is connected to the VCC pin of the L298N. ESP32's GND pin is connected to the GND pin of the L298N. Connect two GPIO pins of the ESP32 to the IN1 and IN2 inputs of the L298N. These pins will control the direction of the motor [42, 43]. Similarly, Connect the ENA pin of the L298N to another GPIO pin of the ESP32 This pin will control the motor's speed. Connect the OUT1 and OUT2 pins of the L298N to the DC motor [44]. These pins control the rotation of the motor.

6.1.2. Power Supply to the Motor Driver Connections

The positive terminal of the battery or power supply is connected to the VCC pin of the L298N. Similarly, the negative terminal of the battery or power supply is connected to the GND pin of the L298N. Wi-Fi connections are initialized on the ESP32. Web servers are set up on the ESP32 that listens for commands from the mobile device. Necessary functions are defined to control the motor, such as forward, backwards, and stop.

When a command is received from the mobile device, the appropriate functions control the motor accordingly. ESP32 code is uploaded using the Arduino IDE. The mobile device is connected to the same Wi-Fi network as the ESP32. A mobile app or web page sends HTTP requests to the ESP32's IP address and triggers the motor control functions. Open the app or web page on the mobile device, enter the ESP32's IP address, and use the provided controls to send commands to the ESP32. When the ESP32 receives a command, it will control the motor's direction and speed based on the program.

6.2. Hoister Motor and Suction Pump Control

A DC and a single-phase motor are controlled using Bluetooth with an Arduino Uno, relay, Bluetooth module, and a battery Fig. (**5**). This control needs to be established with the necessary connections which are described as follows,

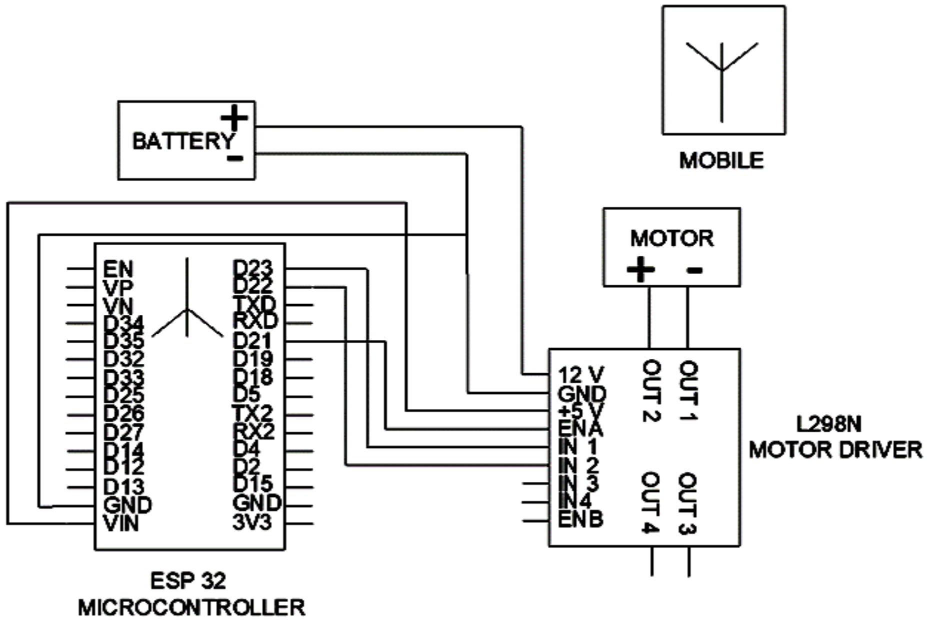

Figure 4: Circuit diagram for sprayer control.

6.2.1. Power Supply

The positive terminal of the battery is connected to the common power rail of the breadboard and the negative terminal to the GND (ground) pin of the Arduino Uno.

6.2.2. Bluetooth Module

TX (transmit) pin of the Bluetooth module connected to the RX (receive) pin of the Arduino Uno. Similarly, connect the RX (receive) pin of the Bluetooth module to the TX (transmit) pin of the Arduino Uno. VCC (power) and GND (ground) pins of the Bluetooth module [36] are connected to the appropriate power and ground rails of the breadboard.

6.2.3. Relay

The relay is used to control the single-phase motor [45]. The signal pin of the relay module is connected to a digital pin on the Arduino Uno. VCC (power) and GND (ground) pins of the relay module to the appropriate power and ground rails of the breadboard. Additionally, connect the input terminal of the relay module to a separate power supply.

6.2.4. DC Motor

The positive terminal of the DC motor is connected to a digital pin on the Arduino Uno, such as pin 9, using a suitable transistor or motor driver module. The negative terminal of the DC motor to connected to the GND (ground) pin of the Arduino Uno.

6.2.5. Single-Phase Motor

A single-phase motor requires an AC power supply and the Arduino Uno provides DC power, you'll need an external AC power source to run this motor. One terminal of the AC power supply to the COM (common) terminal of the relay module and the other terminal is connected to the NO (normally open) terminal of the relay module. Finally, one terminal of the single-phase motor is connected to the NC (normally closed) terminal of the relay module, and the other terminal of the motor is connected to the AC power supply's neutral terminal.

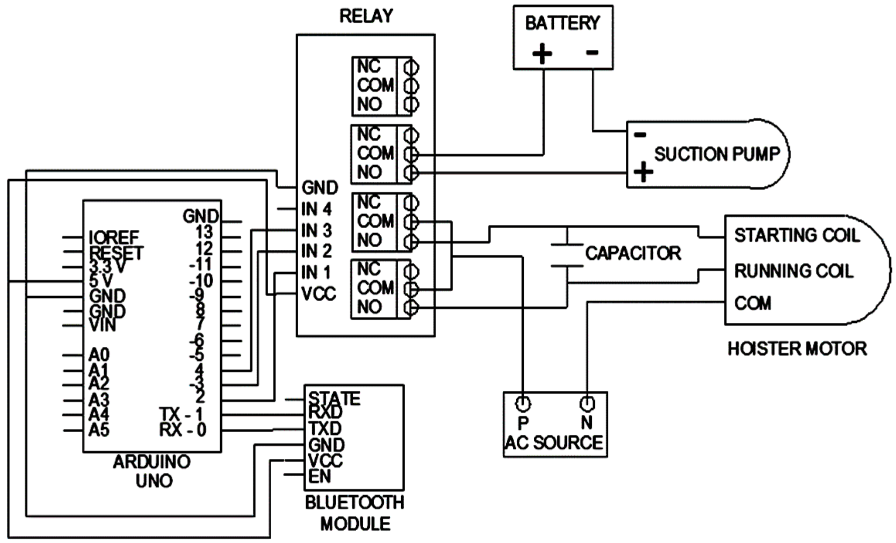

Figure 5: Circuit diagram for hoister motor and suction pump.

6.2.6. Arduino Uno

Arduino Uno [46] listens for commands received via Bluetooth and controls the motors accordingly. The Arduino IDE [36] or any compatible development environment is used to write the code in it. All the necessary library functions are built for Bluetooth communication and motor control. After completing all the connections and uploading the coding to the Arduino Uno, the mobile device with the Bluetooth module, the mobile device sends commands to the Arduino Uno, which will interpret the commands and control the motors accordingly. VCC (power) and GND (ground) pins of the Arduino Uno are connected to the appropriate power and ground rails of the breadboard.

7. Prototype Design

The automated exterior painting system for high-rise buildings is an innovative project aimed at improving the efficiency and safety of painting tall structures. This system shown in Fig. (**6**) combines robotics, automation, and advanced painting techniques to streamline the process and enhance the quality of exterior painting. The hardware prototype of the system consists of several key components. There is a robotic arm that is specifically designed to manoeuvre along the vertical surface of the building. The robotic arm is equipped with a high-performance paint-spraying mechanism. This arm can be adjusted to reach different heights and angles, ensuring uniform and consistent paint application across the building's exterior. The real-time setup consists of hardware and software components, including control systems, actuators, and communication devices.

The control system is another critical component of the real-time setup and it receives data from the sensor system and processes it using algorithms to determine the optimal painting parameters. These parameters include the painting speed, paint flow rate, and brush position. This control system must be highly responsive and able to adjust parameters quickly to ensure that the painting process is consistent and efficient.

Communication devices are also crucial components of the real-time setup. They allow the painting system to communicate with other systems, such as the building management system and the operator's control room. The communication devices include Wi-Fi, cellular, and satellite communication systems. These devices ensure that the painting system can be monitored and controlled remotely, enabling the operator to make adjustments as needed.

8. Discussion

The real-time setup for an automated exterior painting system for high-rise buildings requires a combination of hardware and software components, including sensors, control systems, actuators, and communication devices

[47]. These components must be highly responsive, precise, and reliable to ensure that the painting process is consistent, efficient, and of high quality. By using a robust real-time setup, automated exterior painting systems can provide significant benefits, including improved safety, reduced painting time, with increased quality.

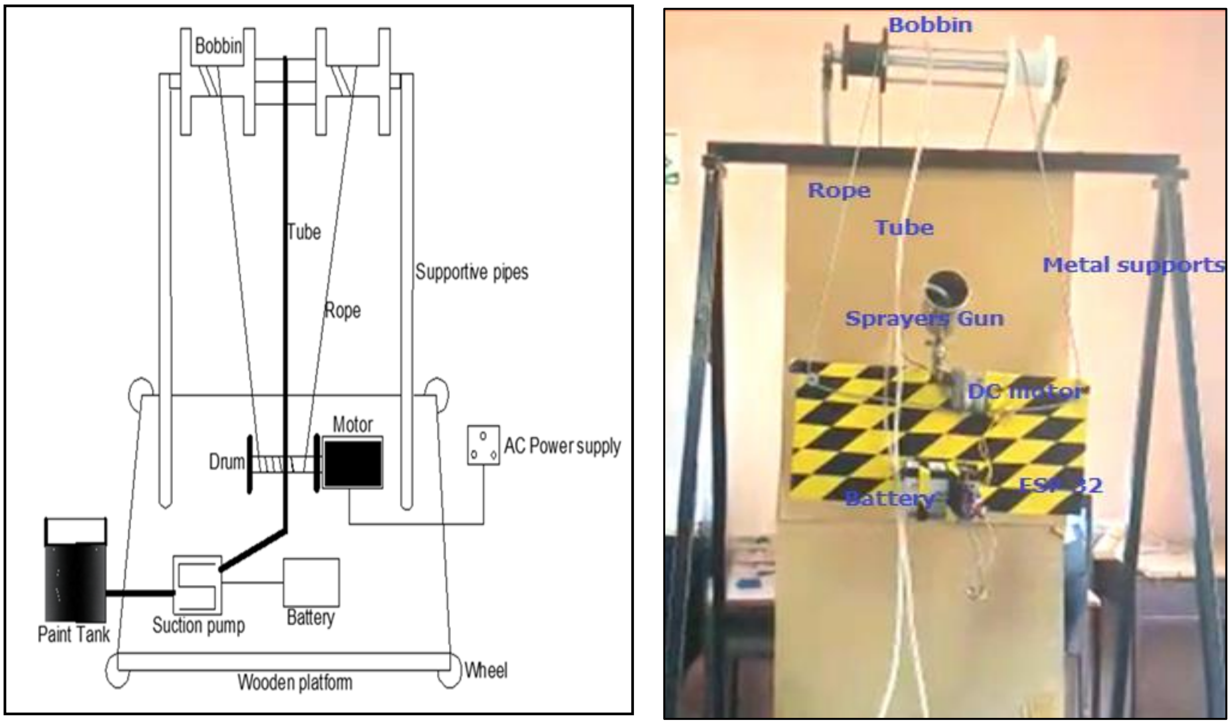

Figure 6: CAD drawings and its prototype model.

Table 1: Comparisons with Manual painting system.

Traditional System	Factors	Automated System
25-30	Manpower (crew person)	< 4
45-50	Duration (days)	4-5
5,62,500	Labor incentive (rupees)	5000-10,000
very high	Safety risk	low
very high	Mental and physical stress	less stress
low	Fine finishing	high accuracy
Avg. 5-10	Fatalities	No fatality

The field survey [48, 49] details shown in Table **1** are obtained by considering a 400-foot multi-housing apartment requires 25 to 30 workers and its exterior painting work of the building. The workers can complete the painting for the entire walls within 45 to 50 days and each worker may be paid an incentive of about Rs 500/day. So the company has to spend around Rs 5.625 lakh only for the workers' incentive which is excluding the materials used for painting and compared with our automation system, this model decimates the cost of incentives to just 1.7% of manual mode painting. Eventually, this model gives fine finishing on the walls with minimal paint usage also reducing the fatalities on construction site.

The proposed prototype model for automated exterior painting exhibits several notable advantages. Firstly, the system operates with high efficiency and precision, ensuring a more perfect finish on building surfaces. The automatic operation significantly reduces the need for manpower, contributing to increased productivity. The low maintenance requirements and cost-effectiveness make it a practical solution for long-term use. One key advantage is its user-friendly design, allowing even illiterate individuals to operate it conveniently. The simplicity of its construction facilitates easy transportation to different sites. The inclusion of Wi-Fi and cloud control not only enhances operational speed but also provides flexibility in monitoring and adjustments [50]. The replacement of traditional brushes and rollers with a sprayer gun ensures a flawless finish, improving the overall quality of the painting process. The system's adaptability is highlighted by its upgradability, allowing customization based on varying structures. Importantly, workers benefit from reduced exposure to health issues associated with painting reagents and physical strain, potentially lowering the death rate on construction sites.

However, there are certain limitations to consider [51]. Frequent maintenance is a notable downside, requiring regular attention to ensure the system's optimal performance. Complexities arise when dealing with uneven surfaces, such as balconies or windows, which may interrupt the painting process and require additional adjustments. Despite these drawbacks, the overall balance tips in favor of the proposed model, as its advantages significantly outweigh the identified limitations. The continuous improvement of maintenance protocols and addressing surface complexities in future iterations may further enhance the model's overall effectiveness and applicability in diverse construction scenarios.

9. Conclusion

The research issue addressed in this study revolves around the challenges posed by manual exterior painting processes, particularly in the context of high-rise buildings, where physical labor and safety risks are prominent. The research results present a solution in the form of an automatic exterior painting system that leverages advanced technology to eliminate the need for manual intervention. The system, operated by a robotic arm with multiple spray nozzles, ensures precise and uniform painting across diverse building surfaces. The successful testing of the system reveals a remarkable reduction in painting time by up to 50%, accompanied by consistently high-quality results. The research value lies in the system's cost-effectiveness, as it eliminates the requirement for scaffolding, thereby reducing labor and material costs.

In summary, the development of this automatic exterior painting system signifies a noteworthy advancement in the construction and maintenance industry. The system's ability to revolutionize high-rise building painting processes by enhancing safety, efficiency, and cost-effectiveness is a significant contribution. Looking ahead, future research directions could explore further optimizations and adaptations of the system for different environmental conditions and building types. Additionally, the integration of smart technologies for real-time monitoring and adjustments could enhance the system's adaptability and responsiveness, further cementing its position as a transformative innovation in the realm of high-rise building maintenance.

Conflicts of Interest

The authors declare no conflict of interest.

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