Design and Development of Robotic End Effector for Screwing Operations

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***Abstract*—This research investigates the creation of an intelligent robotic end effector that uses a collaborative robot to carry out automated screwing tasks. The primary objective was to develop a method that could function with more accuracy and consistency in order to lessen the effort and inaccuracy frequently associated with manual screwing. The robot was able to install components rapidly and securely thanks to a specially designed mechanism that held and drove screws. Industries that require speed and dependability that frequently involve repetitive assembly processes would find this method particularly helpful.**

***Keywords*—Robot End Effector, Automated Screwing, Collabrative Robot, Industrial Automation, IoT integration, Human Robot Collabration**

I. INTRODUCTION

This project focuses on the design and development of a custom-built end effector specifically for automated screwing operations in industrial environments. The end effector is equipped with a screw punching mechanism that accurately positions and holds the screw, followed by a motor-driven drill bit that performs the screwing action. To enhance control and flexibility, the motor is integrated with an IoT-based system using the Blynk platform, allowing the rotation of the drill to be managed remotely through a mobile application.

The design is made modular so that the end effector can be mounted on any type of robotic arm, making it a universal solution for various automation setups. For testing and validation, the end effector was mounted on a Hanwha collaborative robot, where it successfully demonstrated its functionality and efficiency in performing consistent screwing tasks.

The primary goal of this project is to create an end effector that can execute automated screwing tasks with extreme precision and versatility. Any robotic arm can be used with the end effector, making it simple to integrate into a variety of industrial automation configurations. In manufacturing settings, the objective is to reduce the amount of manual intervention, speed up assembly, and enhance screwing operation accuracy.

The project combines embedded systems, IoT technology, and mechanical design. Screwing is done with a motor-driven drill bit, and the screw is fed and held in place by an integrated screw punching mechanism. The drill motor is controlled remotely via a smartphone using an Internet of Things module built on the Blynk platform. This wireless control system increases the solution's practicality for industrial application by adding flexibility and user-friendly operation.

II. LITERATURE SURVEY

In recent years, robotic end effectors have gained significant traction in collaborative industrial environments, particularly for repetitive tasks like screwing. Yazici and Kirisci (2020) emphasized the importance of torque-controlled screwdrivers in human-robot collaboration, highlighting the need for compact, torque-sensitive tools that prevent thread damage while improving fastening precision. Similarly, Zhu et al. (2018) proposed a side-mounted screwing mechanism tailored for constrained environments, which improved spatial efficiency by minimizing the need to reposition either the robot or the component. These works collectively underscore the growing emphasis on ergonomic, task-specific design for improved operational flexibility.

The integration of screw feeding and alignment systems was demonstrated by Kobayashi et al. (2017), whose work enabled fully automated screw selection, positioning, and driving in a single motion, thereby increasing both speed and consistency. Yokoyama (2019) further explored the application of dual-arm manipulators with integrated force and vision sensors, showcasing how real-time adjustments based on contact pressure can enhance screwing precision. While sensorless systems remain more cost-effective, these sensor-integrated approaches serve as benchmarks for achieving balance, alignment, and consistent tool pressure—goals also attainable through physical guides in simpler setups.

On the mechanical side, Patel and Shah (2021) developed a high-torque end effector using a brushless DC motor and reduction gears to maintain torque stability under prolonged usage. Müller et al. (2019) proposed a modular robotic gripper with a lead-screw mechanism, promoting ease of tool replacement and cross-platform compatibility. Singh (2020) and Han et al. (2022) further contributed to the trend of designing compact, application-specific tools with universal mounting capabilities, supporting efficient operation within collaborative workspaces without interference.

In terms of system control and connectivity, Rawat et al. (2021) and Mehta (2022) demonstrated the use of IoT platforms such as Blynk and NodeMCU for remote and real-time control of motor-driven devices. Their findings showed that even low-cost, non-industrial components could achieve reliable and scalable control, contributing to improved industrial safety and convenience. Kumar et al. (2021) extended this approach by integrating cloud-based diagnostics and predictive maintenance features, laying a foundation for future system enhancements. Lastly, Bose (2023) advocated for task-specialized, plug-and-play end effectors, reinforcing the value of focusing on single-function tools—like dedicated screwing systems—to maximize efficiency and reliability in industrial automation.

III. METHODOLOGY

The suggested approach for creating a robotic end effector for automated screwing operations combines web-based IoT control, embedded technologies, and mechanical design into a cohesive and effective solution. Functional needs were first identified, with a focus on the necessity of flexibility across various robotic platforms, especially collaborative robots (cobots). A modular design approach was used, allowing the end effector to perform screw insertion and tightening duties with little assistance from humans.

In order to do this, the design had to include a punching mechanism for screw insertion and a rotating drive system for the screwing operation. Compact components and a straightforward, dependable frame were chosen since the mechanical design of the structure needed to be both lightweight and strong enough to withstand repeated screwing operations.

Because of its high torque and efficiency under load, a 12V Johnson DC motor was chosen to provide the necessary actuation. In order to retain and rotate the screwdriver bit used for the screwing procedure, this motor was connected to a drill chuck. In order to control the motor's power supply, a relay module was added; it functions similarly to a microcontroller-controlled switch. The central control unit was the ESP8266 NodeMCU board, which provided Wi-Fi connection and computational power. The NodeMCU was interfaced with a 5V single-channel relay module to allow motor switching via digital I/O pins.

The Arduino IDE was used to create the software control, which configured the ESP8266 to understand user commands and remotely operate the screwing mechanism. By using its web interface to configure the Blynk IoT platform, the program logic was created to react to digital signals. This removed the need for mobile devices and allowed the system to be accessed from any computer or 4 tablet with internet access. The screwing process could be toggled on the Blynk dashboard, which triggered the relay and supplied electricity to the screw driving motor.

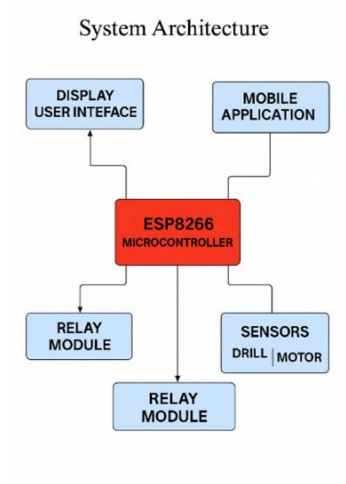

FIG 1. System Architecture

Following the system's assembly, a number of functional tests were carried out to confirm each part's functionality and overall integration. The relay's switching dependability was verified by repeated cycling, and the motor's ability to rotate consistently under varied loads was evaluated. To guarantee real-time responsiveness and low latency, the communication between the ESP8266 and the Blynk online dashboard was tested over a variety of networks. The end effector was installed on a Hanwha collaborative robot for application-level validation following successful bench testing. In order to enable the user to remotely engage the screw-driving function, the cobot was programmed to place the end effector exactly above predetermined screwing spots. This final integration proved the suggested system's adaptability, dependability, and industrial applications.

IV. DESIGN PROCESS & PROCESS WORKFLOW

SolidWorks was used in the design of the end effector's mechanical framework. Axial force application while screwing is ensured by the alignment of the punching guide, drill chuck, and motor in this vertical-axis configuration. 5 mm thick laser-cut acrylic plates, which provide rigidity while maintaining the assembly's lightweight, made up the structural framework.

The central housing, which was installed using a specially made bracket, was sized to suit the Johnson 12V DC motor vertically. The punching mechanism, which lines up with the screw insertion path, was placed in a circular chamber above the motor. Standard screwdriver bits could be used with the drill chuck, which was fixed directly to the motor shaft. Every effort was made to prevent the chuck and punch from interfering with one another during the cycle.

To accommodate components like the NodeMCU, relay module, buck converter, and OLED display, side plates were made with precise slots and holes. CAD simulations were used to model and confirm the fit of each component's unique mounting platform or cutout. The base plate's mounting flange was made to fit the Hanwha cobot's tool interface, making it simple to connect or remove the end effector.

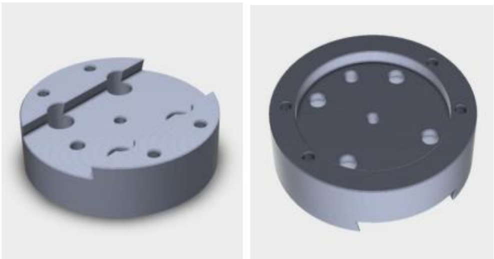

FIG 2. Mounting CAD Design Top & Bottom view

The end effector's electrical layout was intended to be safe for continuous operation and modular. A 12V rechargeable battery serves as the power source, supplying the motor directly and the control system through a buck converter. This dual-voltage configuration guarantees that the microcontroller's performance is unaffected by high-current loads.

The regulated 5V output of the buck converter powers the NodeMCU. It is configured to interface with the Blynk web interface, which allows users to operate the motor by sending ON/OFF signals. The NodeMCU reacts to these commands by turning on the digital output pin that is attached to the relay input after receiving them over Wi-Fi.

The Arduino environment's constant loop structure serves as the focal point of the screwing end effector system's primary execution logic. All components, including the OLED display, Blynk server link, Wi-Fi connection, and relay's GPIO pins, must be initialized via the setup() function. After completing these 25 initializations and verifying a successful connection to the internet and Blynk cloud, the system enters the loop() function, which serves as the system's continuous execution cycle.

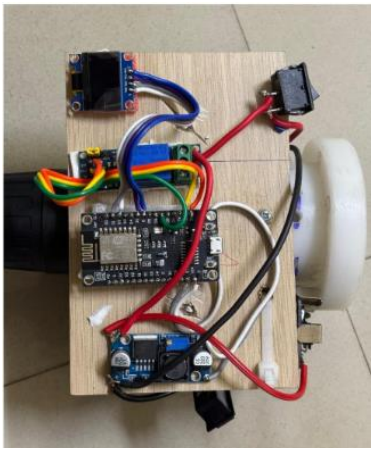

FIG 3. Circuit Setup

The first and most crucial operation in the loop() method is invoking Blynk. The function run(); looks for any commands coming in from the Blynk app. Virtual pin instructions are continuously monitored and responded to in real time thanks to this feature. Immediately following this, timer.run(); is frequently used to control repetitive processes, such auto-shutdown logic once a screw operation is finished, updating the OLED display, and managing time-based operations. Since responsiveness and performance are essential in embedded systems, this nonblocking method of time management is essential.

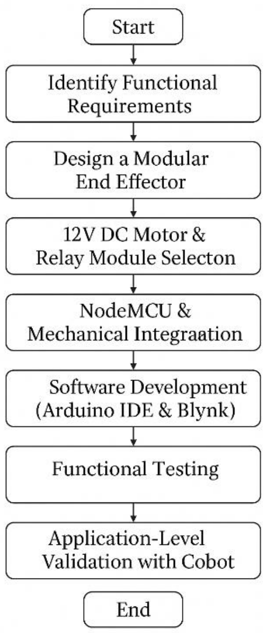

FIG 4. Workflow of the Process

The system receives a signal on a designated virtual pin (e.g., V1) when a user taps the motor activation button in the Blynk app. The value of the button is read by a virtual pin handler function, such BLYNK_WRITE(V1), which is triggered (1 for ON, 0 for OFF). The digital output pin that is attached to the relay module is controlled by this value. The OLED display is simultaneously updated with a message such as "Motor ON," and the system keeps listening for more input during this process. The motor is turned off and a fresh message such as "Motor OFF" appears on the OLED when the user hits the button once more or after a certain amount of time. Additionally, the main program flow includes error handling.

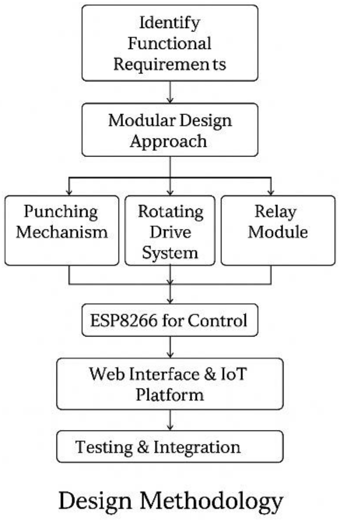

FIG 5. Design Methodology

In the event that the Wi-Fi connection is lost or Blynk becomes inaccessible, the system is designed to try to reconnect and alert the user via the OLED screen. In a robotic system that can be a component of a larger manufacturing line or testing platform, these 26 procedures are especially important for guaranteeing uptime and dependability. Overall, the software flow guarantees that the system responds rapidly, communicates clearly, and performs efficiently—all essential characteristics of an intelligent, networked robotic instrument.

FIG 6. IoT Control

V. RESULT AND CONCLUSION

During testing and integration with the collaborative robot, the created end effector showed dependable performance, meeting all design and functional requirements. Its small size and modular design made it possible for it to operate mechanically smoothly within the Hanwha cobot's payload limitations. A punching mechanism greatly enhanced screw stability and alignment, resulting in precise and reliable insertions.

Effective communication between the hardware and the web-based control system was demonstrated by the motor-driven screwing system, which was remotely controlled via an Internet of Things interface. It reacted to commands quickly and with little delay. Furthermore, no 38 significant alignment or torque-related problems were seen, and the system maintained its structural stability even after repeated operation. Improved ventilation resolved minor temperature issues with the motor, demonstrating the design's flexibility for improvement. All things considered, the prototype turned out to be a dependable, effective, and remotely controlled screwing tool appropriate for industrial settings needing accuracy and consistency.

Both operational safety and user convenience were improved by the end effector's incorporation of electronics and Internet of Things control. A NodeMCU microcontroller and Blynk interface allowed for smooth remote activation, which minimized possible risks during repetitive tasks and decreased the need for user intervention. Electrical safety was guaranteed by separating the power and control circuits using a relay module, and future improvements and simple maintenance were made possible by the modular housing design. Despite varying climatic circumstances, the system maintained consistent output and dependable communication across lengthy trials. This affirms that the project was successful in producing an intelligent, automation-ready tool that connects mechanical precision with digital control, demonstrating the strength of both the mechanical and electronic systems.

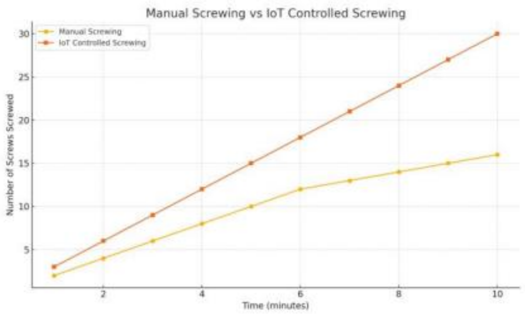

FIG 7. Manual Screwing Vs IoT Controlled Screwing Graph

The capacity of the motor to maintain a constant rotational speed during the screwing operation was one of the significant findings from the experiments. Even with fluctuating mechanical demands, the Johnson 12V DC motor, which was driven by a 12V battery and managed by a relay module, showed consistent performance. The motor's performance was assessed using rotational stability, torque generation, and response delay, and it was possible to remotely activate and deactivate it using the Blynk IoT interface.

Depending on screw size and material resistance, the system reliably finished screwing cycles in an average of 10 to 15 seconds. The motor was able to react to input commands with minimal latency, usually less than 200 milliseconds, thanks to the real-time control, which was well within acceptable industrial norms.

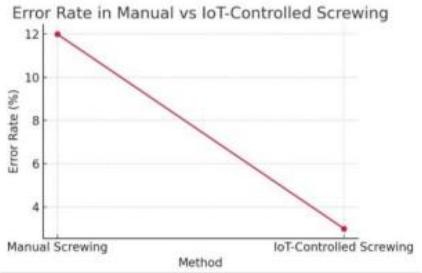

FIG 8. Error rate in Manual vs IOT Controlled Screwing

The durability and effectiveness of the power system, which included a DC-DC buck converter and a rechargeable 12V battery, were also assessed. The ESP8266's analog input was used to track voltage levels throughout continuous operation, and the Blynk dashboard displayed the data. The technology may effectively manage up to 50 full screwing cycles before needing a recharge, according to voltage drop patterns.

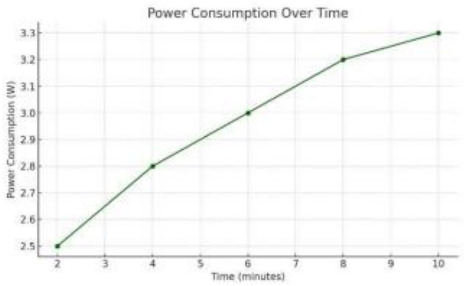

FIG 9. Power Consumption Over Time

Only during the high-torque screwing stages were there any discernible voltage dips, and the power consumption stayed within Fig 6.2 Error rate in Manual vs IOT Controlled Screwing Fig 6.3 Power Consumption Over Time 45 predicted bounds. An important component of industrial integration, these results validated the system's energy efficiency and capacity to function independently for prolonged periods of time without frequent recharge.

FIG 9. Finished Model attached to the Cobot

The study contains certain shortcomings in spite of its advantages. Torque flexibility was limited because the motor speed was managed in a binary fashion (ON/OFF) as opposed to using variable PWM. The battery may not be able to sustain prolonged continuous operations without frequent recharging, even when its capacity is adequate for short-term tests. Furthermore, the absence of torque feedback makes it impossible to precisely manage torque, which can be required for applications that call for delicate screwing conditions.

VI. FUTURE RESEARCH

Future studies can examine how adaptive screwing based on resistance levels and material qualities can incorporate AI-based decision-making. By putting machine learning algorithms into practice, the system may eventually learn the best screwing parameters. The end effector's performance under realworld circumstances could also be assessed by testing it with actual industrial workpieces in a collaborative robot (cobot) setting. Adding multi-axis motion and automatic screw feeding to the system's repertoire could help it develop into a completely self-sufficient screwing station.

Future iterations of the project could include a motor driver with PWMbased speed control, which would allow for variable torque and smoother operation while minimizing the constraints that have been observed. Adding a higher-capacity or swappable battery system to the power source can extend the system's operating time. Incorporating torque or current sensors would also provide feedback-based screwing control, increasing the system's adaptability to various screw and material kinds.

Despite the drawbacks, the study was able to produce a working proof of concept that showed the promise of inexpensive, Internet of Things-enabled robotic end effectors. The results offer a strong foundation for future research, 48 and because the system is modular, improvements like torque sensing or sophisticated motor control can be incorporated without completely redesigning the system.

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