Robust PID Control of Piezoelectric Actuators with Internet of Things Integration Using Blynk Application

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Abstract.

The use of Arduino software to fine-tune piezoelectric actuators for achieving a fast response configuration is investigated. Achieving optimal performance from piezoelectric actuators in Internet of Things (IoT) applications remains a significant challenge due to the complexities involved in tuning and controlling these devices in real time. Traditional tuning methods often fail to meet the speed and accuracy requirements of dynamic IoT environments, necessitating the development of a reliable and efficient tuning process. The tuning procedure is examined with a focus on system performance using MATLAB software. The primary objective is to enable multiple tunings suitable for IoT applications. By employing an ESP32 microcontroller, the desired performance outcomes are achieved. The combination of MATLAB and Arduino allows for accurate real-time control and monitoring of the piezoelectric actuators. Experimental results demonstrate the system's capability for rapid and precise adjustments, enhancing its potential for various IoT applications. This study establishes a foundation for future investigations into advanced piezoelectric system tuning techniques for IoT applications, aiming to improve the overall functionality and potential of piezoelectric actuators by addressing the limitations of conventional tuning methods and leveraging advanced software capabilities

Keywords: PEA, Piezoelectric Actuator, ESP 32, Microcontroller, Arduino Software, IoT Internet of Things, PID Tuning, MATLAB Software

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1 Introduction

For precise engineering applications, piezoelectric actuators have attracted a lot of attention because of their outstanding accuracy, energy efficiency, and responsiveness. These actuators are perfect for applications requiring precise positioning control because they integrate electrical inputs into accurate mechanical movements. However, complex control systems are required to achieve optimal performance with piezoelectric actuators. The incorporation of Internet of Things (IoT) technologies into control systems has created new opportunities in recent years to improve the performance and efficiency of these actuators [1]. This research focuses on developing a robust Proportional-Integral-Derivative (PID) control system for piezoelectric actuators, integrated with IoT capabilities using the Blynk platform. By leveraging MATLAB and Arduino software for system tuning and employing the ESP32 microcontroller as shown in Figure 1, the study aims to achieve rapid response configurations suitable for various IoT applications.

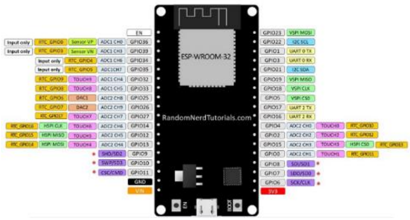

Figure 1 Pin description of ESP32

The objective of this research is to fine-tune piezoelectric actuators to obtain a rapid response and enhance system performance [2]. This is achieved through a combination of MATLAB for tuning process examination and Arduino for practical implementation.

1.1 Literature Review

Piezoelectric actuators are widely used in various high-precision applications due to their ability to produce small, accurate movements in response to electrical signals [3], [4]. They are employed in fields such as robotics and nanotechnology. The unique properties of piezoelectric materials allow these actuators to deliver high resolution, repeatability, and quick response times, making them essential components in precision positioning systems [5], [6]. Proportional-Integral-Derivative (PID) control is a widely adopted technique in the control of piezoelectric actuators. By fine-tuning the proportional, integral, and derivative gains, the PID controller can minimize the error, leading to improved accuracy and stability of the actuator [7]. Various studies have demonstrated the effectiveness of PID control in enhancing the performance of piezoelectric actuators, particularly in applications requiring precise and rapid movements [8].

The advent of the Internet of Things (IoT) has revolutionized the way control systems are designed and implemented. IoT integration enables remote monitoring and control, enhancing their efficiency and functionality. In piezoelectric actuators, IoT integration can provide real-time feedback, facilitate remote tuning, and enable the implementation of advanced control strategies. Platforms such as Blynk offer user-friendly interfaces for developing IoT applications, allowing seamless integration with microcontrollers and sensors [9]. MATLAB provides an extensive suite of tools for modeling and simulation. Arduino, on the other hand, offers a flexible and easy-to-use platform for implementing control algorithms on hardware. The combination of MATLAB and Arduino allows for the precise tuning of piezoelectric actuators, ensuring optimal performance in real-world applications [10].

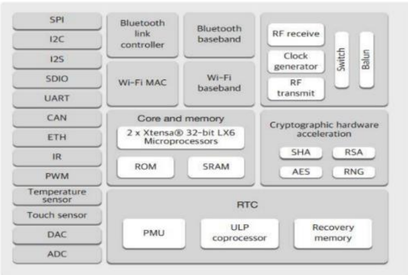

Figure 2 Internal Block of ESP32 System on Chip

The ESP32 microcontroller is a popular choice for IoT applications due to its powerful processing capabilities, integrated Wi-Fi and Bluetooth, and low power consumption. Its versatility makes it suitable for a wide range of applications, from home automation to industrial control systems. In the context of this research, the ESP32 microcontroller (refer from Figure 2) is used to implement the PID control algorithm and facilitate real-time monitoring and tuning of piezoelectric actuators. The integration of robust PID control with IoT capabilities represents a significant advancement in the field of piezoelectric actuator control [11]. Recent advancements in IoT have further expanded the capabilities of microcontrollers like the ESP32 in the realm of control systems and smart devices. The integration of Machine Learning and Artificial Intelligence with IoT platforms has enabled more sophisticated and adaptive control mechanisms [12].

2 Methodology

2.1 PID control tuning of Piezoelectric Actuator.

2.1.1 Experiment Setup

In this research, Arduino software collects data on overshoot by setting programmed setpoints, causing the piezoelectric actuator to reject disturbances. The primary goal is precision, requiring zero steady-state error. After addressing steady-state error, the focus shifts to peak and settling times. Peak time is when the setpoint reaches its target, with faster peak times indicating better performance. Settling time is when the setpoint stabilizes within its boundaries after oscillation. [13]. Through tuning of the PID control system, the research aims to minimize the steady-state error and optimize peak and settling times, ensuring precise and responsive control of the piezoelectric actuator.

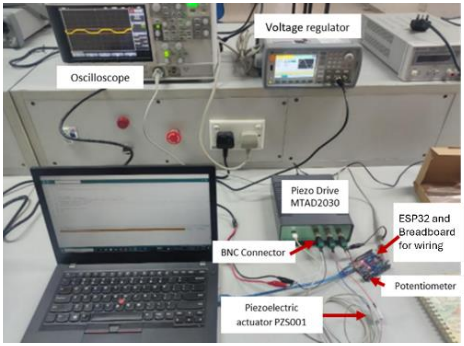

Figure 3 The Experiment Setup

The statically balanced position control system was tested under various conditions, demonstrating a quick response to changes in input, such as sudden load changes or external disturbances. The initial research phase involved determining the set point and overshoot produced by the piezoelectric actuator, using an experimental setup with an ESP32, Piezo Drive, and piezoelectric actuator (Figure 3). In PID control, overshoot refers to the extent the output exceeds the desired setpoint during the transient response phase [14]. Overshoot occurs when the control system's response initially goes beyond the target before stabilizing at the setpoint, often due to the inertia of the system or the dynamics of the PID controller's tuning parameters. Excessive overshoot can indicate that the system is too aggressive in its response, potentially leading to instability or prolonged settling times, while minimal overshoot is generally desired for precision and stability [15].

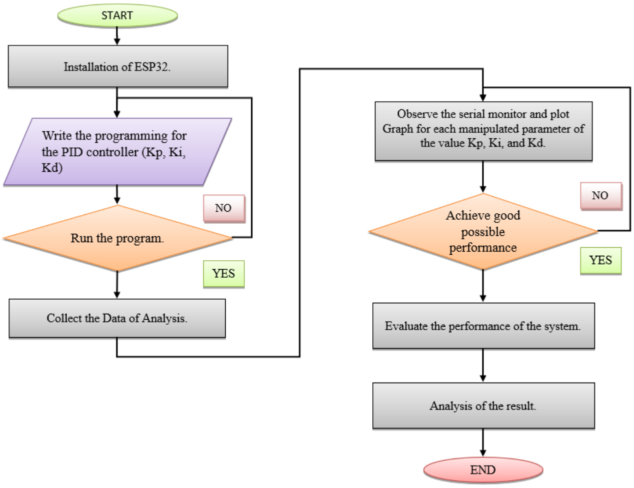

Figure 4 Flowchart of the Objective 1

2.2 Develop an Internet of Things (IoT) software system for the precise control of piezoelectric actuators.

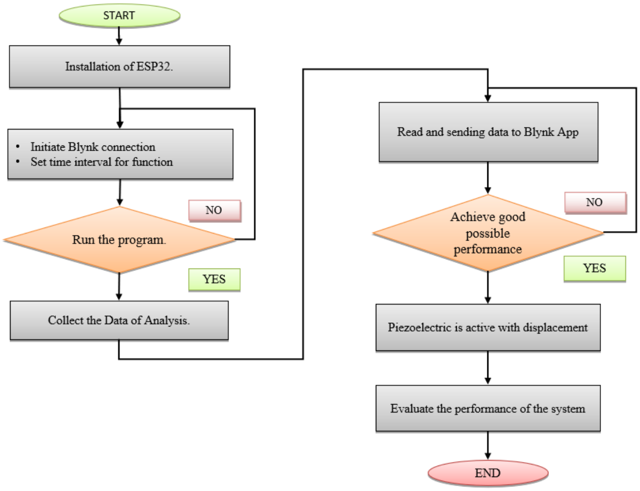

Figure 5 Flowchart of the Objective 2

The software implementation of the proposed system is outlined in the flowchart shown in Fig. 7. This system is designed to monitor and control the displacement and input voltage of the piezoelectric actuator in real-time. By leveraging the capabilities of the ESP32 microcontroller, the system continuously acquires data from the sensors attached to the actuator, capturing precise measurements of displacement and voltage [16]. This data is then processed by a robust PID control algorithm implemented within the Arduino software environment.

Figure 6 Blynk IoT Apps

The system, integrated with the Blynk platform, allows remote monitoring and control via internet-connected devices [17] Users can oversee actuator performance, adjust PID parameters, and receive real-time system status feedback from anywhere with internet access. The detailed flowchart in Fig. 6 illustrates the software implementation process, highlighting steps for monitoring, control, and data communication. Users can access cloud-stored data to evaluate performance and adjust PID parameters to enhance system responsiveness and accuracy [18].

3 RESULT

3.1 PID control tuning of Piezoelectric Actuator.

STATICALLY BALANCED PID SYSTEM

Table 1. PID value of statically balanced in each condition

Conditions	PID Value
1	Kp= 0.7, Ki= 0.035, Kd= 0.71
2	Kp= 1, Ki= 0.035, Kd= 0.61
3	Kp= 0.8, Ki= 0.035, Kd= 0.71
4	Kp= 0.7, Ki= 0.05, Kd= 0.61

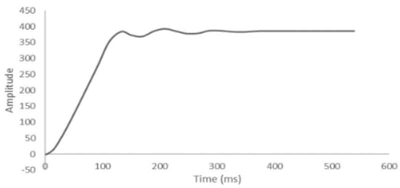

Figure 7 Condition 1 Graph

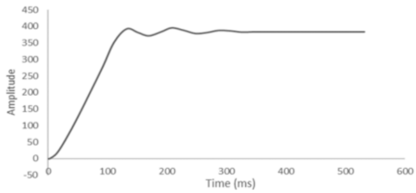

Figure 8 Condition 2 Graph

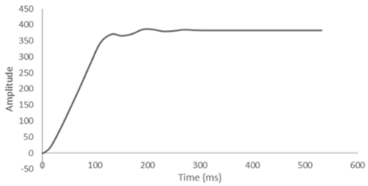

Figure 9 Condition 3 Graph

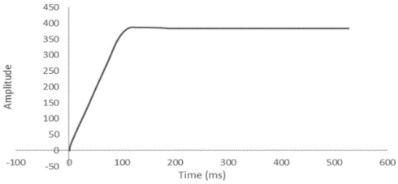

Figure 10 Condition 4 Graph

Table 2. Ranking of Statically Balance performance of each condition.

Attempt	Ranking	Disturbance Rejection (YES/NO)	Steady-state Error (Counts)	The Peak Time	Settling Time
1	3	YES	-1	209	120
2	2	YES	0	208	117
3	4	YES	-2	191	126
4	1	YES	0	141	120

STATICALLY UNBALANCED PID SYSTEM

Table 3.
PID value statically unbalanced in each condition

Conditions	PID Value
1	Kp= 0.5, Ki= 0.0, Kd= 0.9
2	Kp= 0.7, Ki= 0.0, Kd= 1.0
3	Kp= 1.5, Ki= 0.0009, Kd= 2.5

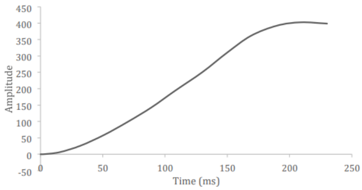

Figure 11 Condition 1 Graph

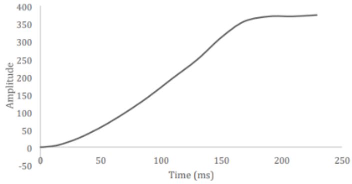

Figure 12 Condition 2 Graph

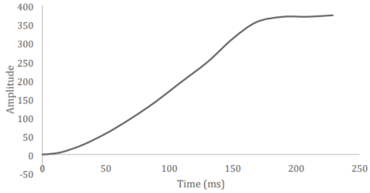

Figure 13 Condition 3 Graph

Table 4. Ranking of Statically Unbalance performance of each condition.

Attempt	Ranking	Disturbance Rejection (YES/NO)	Percentage of overshoot (%)	Rise Time	Steady-state Error (ms)
1	2	YES	20	200.00	-12
2	3	YES	29	188.73	-17
3	1	YES	9	244.80	-5

A statically balanced PID system refers to a control system utilizing a Proportional-Integral-Derivative (PID) controller to maintain a steady state or constant output without significant deviations or oscillations [19]. Proper loop tuning is crucial for optimizing the system's performance, ensuring it remains stable while effectively handling dynamic variations in operating conditions (Refer on graph 11,12 and 13). However, in real-world applications, several limitations and challenges may arise. For instance, the effectiveness of a statically balanced PID system can be compromised by external disturbances, such as environmental changes or unmodeled dynamics, which the controller may not fully account for.

3.2 Develop an Internet of Things (IoT) software system for the precise control of piezoelectric actuators.

Figure 14 Blynk Apps Output

The ESP32 microcontroller continuously updates data to the cloud, ensuring real-time synchronization and accessibility. This data, including displacement measurements, PID values, and input voltage, is displayed on the Blynk App platform (Fig. 14). The Blynk interface provides live updates, allowing comprehensive monitoring and real-time management of the piezoelectric actuator's performance. This enables prompt adjustments to maintain optimal performance, ensuring high levels of accuracy and efficiency. [20].

4 CONCLUSION

This research successfully developed an advanced IoT-enabled control system for piezoelectric actuators using the ESP32 microcontroller. Integrating real-time data monitoring and control through the Blynk platform, with precise PID parameter tuning, significantly improved system performance. Key findings highlight that a statically balanced position control system outperforms an unbalanced one by maintaining desired positions within a small tolerance and responding rapidly to input changes. This is crucial for high-precision applications in robotics, aerospace, and medical devices. Experimental results show that the balanced system reduces steady-state error, minimizes overshoot, and achieves faster settling times compared to the unbalanced system. While the unbalanced system may offer stability under certain conditions, it lacks the dynamic responsiveness and precision necessary for variable environments. This research lays a solid foundation for future advancements in piezoelectric actuator control, particularly through IoT integration, providing a flexible solution for remote monitoring and control in high-precision fields.

5 ACKNOWLEDGEMENT

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