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Design and Implementation of Pid-Based Intelligent Control on a Microcontroller Platform

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ABSTRACT

This research details an experimental setup for applying PID (Proportional-Integral-Derivative) control and other intelligent control algorithms on a microcontroller platform. A high-performance microcontroller, a number of sensors (e.g., temperature, pressure, position, and acceleration), a number of actuators (e.g., motors, valves, and relays), and a number of communication interfaces (e.g., UART, SPI, and I2C) are all part of the setup that can support real-time control applications. Integral to the system's functionality is the microcontroller's ability to operate with appropriate programming environments and neural network-based control algorithms. The output of a system may be controlled using PID control by constantly reducing the error between the actual output and a desired setpoint. Each of the three parts that make up the control signal—proportional, integral, and derivative—contributes in its own special way to the dynamic response of the system. Findings from the experiments prove that the PID algorithm is capable of producing precise and steady control. To reduce oscillations, the control signal is adjusted by the proportional term according to the present error, by the integral term according to the sum of all errors, and by the derivative term according to the trend of future errors.

Keywords: Microcontroller, Neural network, Proportional term, Control Signal

I. INTRODUCTION

The incorporation of AI approaches into embedded systems has become a game-changer in the dynamic world of contemporary control systems, altering the way control operations are thought of, planned, and executed. Neuronal network algorithms are exceptional among various AI methods for modeling nonlinear systems, learning from data, and real-time adaptation to changing surroundings. An excellent example of this integration is the intelligent control of microcontroller-based systems via the use of neural networks, which provides hitherto unseen levels of autonomy, resilience, and precision. These smart algorithms are best implemented on microcontrollers since they are the building blocks of embedded systems that are ubiquitous in modern technology, from home appliances to factory automation. Proprietary-Integral-Derivative (PID) controllers and other rule-based control schemes have historically dominated microcontrollers. Complex, nonlinear, or time-varying systems are typically too much for these techniques to manage, even though they perform admirably for linear and well-modeled systems. An effective substitute for conventional control techniques, neural networks may learn on their own and approximate complicated input-output correlations.

Neural network algorithms mimic human cognitive processes, which is the fundamental premise of using them for intelligent control. Layered networks of linked processing components (neurons) mimic the architecture and operation of the human brain. To learn to identify patterns, categorize data, and make predictions, these networks may be trained using either historical data or learning processes that operate in real-time. Neural networks, when integrated with microcontroller systems, allow for self-adjusting control techniques that take into account input from the surrounding environment or changes in system dynamics. In situations when conventional control rules may not be applicable or feasible to derive analytically, this capability to learn and modify control parameters dynamically greatly improves the system's performance and adaptability.

The widespread availability of intelligent automation in a wide range of disciplines is one of the most encouraging features of control systems that integrate neural networks with microcontrollers. Intelligent controllers optimise temperature regulation, motor control, and fluid dynamics in industrial automation without much human involvement. Such controllers are used in smart thermostats, adaptive lighting systems, and intelligent voice assistants, among other consumer gadgets, to learn the user's preferences and provide individualized performance. Adaptive cruise control, lane-keeping assistance, predictive maintenance, and other ADAS features are made possible by neural-network-based microcontroller systems, which are crucial in the automobile industry. In addition, smart microcontroller-powered wearables may improve healthcare by monitoring vital signs and using learned patterns of physiological data to tailor alarms or therapeutic actions, thereby increasing patient safety.

Although there are many potential benefits, there are also many technical hurdles to overcome when putting neural networks on microcontrollers. This is mostly because embedded systems have limited resources. The creation of efficient and lightweight neural network topologies is necessary since microcontrollers usually operate with limited memory, processing power, and energy resources. Neural networks must be trained to match the tight requirements of microcontroller settings using techniques like quantization, pruning, knowledge distillation, and model compression. Additionally, frameworks like as TinyML and TensorFlow Lite for Microcontrollers have been developed to facilitate the implementation of machine learning models on these platforms. These frameworks include libraries and tools that are specifically tailored to embedded AI applications. Thanks to these advancements, it is now much easier to incorporate neural networks onto inexpensive microcontrollers that don't drain the battery or slow down the system.

Training the neural network using a learning algorithm is another important part of the intelligent control architecture. Depending on the situation, supervised, unsupervised, and reinforcement learning all have their advantages. Unsupervised learning may be used to discover hidden patterns or anomalies in system behavior without established labels, while supervised learning works best with labeled data and a well stated control aim. Adaptive and real-time control situations are ideal for reinforcement learning, which places an emphasis on learning by interaction with the environment and getting feedback in the form of incentives or punishments. With the help of these learning processes and the real-time data from sensors and actuators, the microcontroller can do more than just make smart control choices; it can also adapt its behavior to become better at what it does.

Furthermore, in mission-critical applications like autonomous cars, medical devices, and aerospace, the dependability and security of neural network-based intelligent control systems are of the utmost importance. Researchers have been investigating explainable AI (XAI) methods to decipher neural network architectures in an effort to guarantee openness and trust in decision-making. In order to improve user trust and make debugging or optimization efforts easier, these strategies try to provide human-understandable insights into decision-making processes. To guarantee that neural-network-driven controllers function securely in all anticipated scenarios, including edge cases and failure modes, comprehensive testing, validation, and verification frameworks are simultaneously being created.

At the periphery of artificial general intelligence (AGI) lies the confluence of neural network algorithms and microcontroller-based devices, which signifies a giant leap forward. The role of embedded systems is evolving from that of reactive tools to that of proactive agents with the ability to make decisions on their own as they gain intelligence, connectivity, and context awareness. Implications for intelligent system design philosophies such as edge intelligence, real-time analytics, and decentralized processing have resulted from this change. Many real-world applications rely on microcontrollers for intelligent control activities, and their ability to work autonomously, without relying on cloud infrastructure all the time, solves issues with latency, bandwidth, privacy, and dependability.

II. REVIEW OF LITERATURE

Huang, Zishan. (2022). The purpose of this research is to improve the automated intelligent control effect by studying the intelligent vector control method's performance with common power pulses and then obtaining an updated algorithm that is suited for current intelligent systems. If two adjacent vectors are not identical in time, meaning their difference is nonzero, then the vector can be rotated to a certain place. An automated intelligent control system based on artificial intelligence is also obtained in this work through the use of improved algorithms. This study concludes that the intelligent control system has an effect by confirming it via experimental research. The experimental results show that the proposed intelligent control system is superior to the state-of-the-art in terms of automated intelligent control.

Guan, Xiaochun et al., (2021) Purpose because they can lower power consumption and latency for data transmission, deep neural networks is finding widespread application on embedded devices. The goal of this research is to provide a way to install deep neural networks on a quad-rotor aircraft so that their application area may be further expanded. This study presents a design strategy for a quad-rotor aircraft that uses multi-sensor fusion to carry out its flying task. Among its many features are modules for acquiring attitude, GPS location, optical flow, ultrasonic, and Bluetooth signals, among others. The primary controller for the quad-rotor plane is a 32-bit microprocessor. When it comes to the design of quad-rotor aircraft control systems, this concept offers a straightforward and effective approach for further integrating AI algorithms. For the purpose of applying AI algorithms to UAVs or terminal robots, this technique serves as both an example of an application and a design reference.

Chang, Kuo-Chi et al., (2020) When an item is controlled by a mechanism that allows it to operate or maintain a condition without human intervention, this is called automated control. Intelligent control is an ideology that seeks to solve issues using human intelligence by relying on people's thought processes and problem-solving abilities. are all known to be included in the controlled object's complexity. Furthermore, uncertainty and change aversion are manifestations of the environment's complexity. According to this and other studies, intelligent control methods can be categorized into several broad categories, such as expert, fuzzy, neural network, hierarchical, anthropomorphic, integrated, combined, chaos, wavelet theory, etc.

Susnea, Ioan. (2012). It is stated in this research that any three-layer perceptron may be replaced with an equivalent distributed ANN by placing the neurons on communication network nodes and establishing connections between them during communication. This view holds that neurons are entities capable of processing and communicating. Given that an ANN's local and distributed implementations are functionally identical, it is possible to train a distributed ANN using the same set of synaptic weights. To prove that the concept is sound, two examples are given.

Rivera, José et al., (2012) In today's world, control is crucial for any job or business. Traditional control remains popular, but it's no secret that users need to know the ins and outs of the system to get the most out of it. In this study, we employ a single artificial neural network to construct a proportional integral derivative control, with the aim of making it more user-friendly and efficient while requiring less control expertise from the end user. The proposed control was tested using both real and theoretical first- and second-order physical systems. To increase confidence in the intelligent sensor control, the evaluation employed the time-honored method of testing the control response of a single step. A clever sensor equipped with a compact microprocessor put the suggested control into action. Additionally, the suggested control's performance was contrasted with that of a commercial control. In this case, we see an intelligent sensor that can regulate many different kinds of physical systems. The results of the testing proved that the suggested control works as intended; it is simple to implement and will cut down on setup time.

Kadam, Deepak et al., (2010) An ANN-based method for PM DC motor speed control is suggested in this work. The use of Neural Networks is the innovative aspect of this study. A comparison was made between the two systems' performance levels, namely between the ANN-based and PI-based approaches to speed control of a PM DC motor drive. The MATLAB 7.1 toolbox was used to simulate the complete system. Due to the ANN's ability to update its weights and biases in real time, the comparison findings show that the ANN-based system is much better, especially when dealing with parameter fluctuations and load disruptions.

III. EXPERIMENTAL SETUP

The experimental setup for applying artificial intelligence control algorithms on a microcontroller platform consists of several pieces and combinations. That it meets the requirements of the intended use and is compatible with the algorithms used for intelligent control, the choice of microcontroller platform is vital. The availability of input/output peripherals, processing power, memory capacity, and real-time capabilities are

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crucial factors to consider.

It is important that the microcontroller platform be compatible with languages and environments that may be used to construct control algorithms that are based on neural networks. The system's status variables may be monitored in real-time by a number of sensors that are part of the configuration. Accelerometers, temperature, pressure, and location sensors are some of the most common types of sensors.

The intelligent control algorithms create control instructions, which are then used to operate the system's actuators. Motors, solenoids, valves, and relays are among examples. The microcontroller and external devices may exchange data using communication interfaces like UART, SPI, or I2C.

One common feedback control technique used to govern systems and processes in engineering is PID control, which stands for proportional-integral-derivative. Through the manipulation of a control variable, it seeks to minimize the deviation from a target setpoint relative to the system's actual output. The three primary concepts upon which PID control is built are derivative, integral, and proportional. It may be expressed mathematically as:

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{de(t)}{dt}$$

Were,

u(t) is the control signal at time t.

e(t) is the error sign.

The percentage, integral, and derivative gains are denoted as Kp, Ki, and Kd, respectively.

This thorough grasp of the study's hardware design, control algorithms, and mathematical models is provided by this precise experimental setup, which is complemented by important mathematical equations.

IV. RESULTS AND DISCUSSION

There is a clear correlation between the present error and the proportionate term of the PID control algorithm. It provides a numerical value to the urgent course of action required to lessen the mistake. The product of the proportional gain (Kp) and the error (e(t)) yields the proportional term (P) in our case. For example, a larger proportional term indicates that the controller is taking a greater remedial action in the event of a big mistake.

Table 1: Results OF PID control

Time (t)	Error (e(t))	Proportional Term (P)	Integral Term (I)	Derivative Term (D)	Control Signal (u(t))
0	80º C	120	0	0	110
1	60º C	90	14	-2	90
2	40º C	60	22	-2	88
3	20º C	30	26	-2	60
4	0ºC	0	26	-2	22

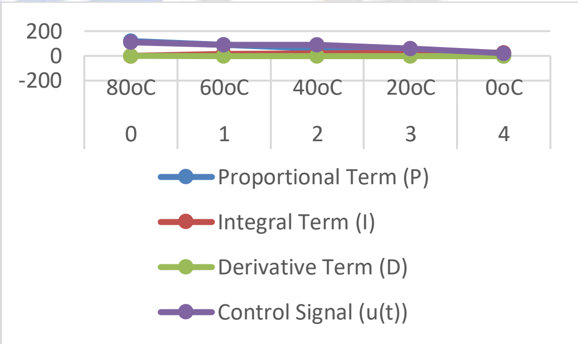

Figure 1: Results for PID

The integral term of the PID control algorithm accounts for the accumulation of past errors over time. It helps get rid of steady-state inaccuracy by constantly integrating the signal that represents it. Here, we integrate the error over time numerically to get the integral term (I). The rate of accumulation of prior errors is defined by the integral gain (Ki).While a greater integral gain speeds up error correction, it might cause instability or overshooting if not adjusted properly. By determining the error signal's rate of change, the derivative term of the PID control algorithm predicts its future trend. Its capacity to anticipate and counteract sudden changes in the error signal helps to reduce oscillations and enhance system stability. In this case, we may get the derivative term (D) by multiplying the error's rate of change with respect to time by the derivative gain (Kd). An increase in the derivative gain makes the system more sensitive to noise, but it also makes it respond quicker to changes in the error signal.

V. CONCLUSION

The system's design showcases a balanced approach to attaining precise, real-time control, with its meticulously chosen microcontrollers, sensors, actuators, and communication interfaces. The findings demonstrate how the PID controller's integral, derivative, and proportional components work together to stabilize the system and minimize error. The importance of fine-tuning parameters for improved control accuracy and instability prevention is highlighted in this work. Also, the fact that it worked shows how versatile microcontroller platforms can be for implementing smart control systems in many other kinds of engineering and manufacturing. The results of this experiment provide the groundwork for further research into learning-based and adaptive control mechanisms, which will ultimately lead to smart embedded system advancements.

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