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Design And Implementation of Ultrasonic Sensor-Integrated PWM Motor Drive System for Variable Load Transportation

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Abstract- The project presented is an ESP32 adaptive control system to regulate the speed of an A2212 BLDC motor via ultrasonic sensor feedback and PWM control using a lookup table for lightweight transportation applications. This system continuously monitors the fill level of a container using an HC-SR04 ultrasonic sensor and can also estimate the load on the motor via the sensor. The ESP32 will output PWM signals at a fixed frequency, with each respective signal's duty cycle being 30%, 60% or 90% based on up to 8 ranges defined in the lookup table as the motor will operate based on the averages of 8 measurements taken approximately every second from the ultrasonic sensor. The PWM output of the ESP32 will then be amplified by an IR2110 gate driver circuit to drive a 3-phase MOSFET-based custom inverter design that is the BLDC motor driver. Each PWM signal (30%, 60%, & 90%) will be sent to a 16x2 LCD display to display the distance measured by the ultrasonic sensor and the PWM being output by the ESP32 during operation. The method proposed eliminates the need for any closed loop control techniques to regulate the speed of the motor, thus reducing complexity and the expense associated with implementation.

Key Words: BLDC Drive, duty cycle, PWM, inverter

I. INTRODUCTION

The usage of motor drives in transports has been increasing in recent times. Compact electric drive systems have an extensive application in areas such as warehouse automation, conveyor systems, and carts with variable load. The applications require an efficient way of varying the motor speed according to the actual load it is carrying.

Conventional motor drive systems have traditionally used either manual adjustment of the speed or the use of a complicated closed-loop feedback system to control the speed of the motor. While manual speed control is not accurate enough, adding extra circuitry and computing power for feedback loops is costly and unnecessary in most cases that only require proportional speed response. Therefore, there is a need for a simple and effective method of controlling the speed of a motor that correlates directly to load variations.

BLDC motors are the motors of choice in applications where space and weight considerations are important due to their efficiency and power-to-weight ratio. The modern ESP32 microcontroller is another tool in this project that provides a dedicated hardware PWM, strong computation capability, and plenty of I/O resources to implement the necessary circuits. An ultrasonic sensor-based PWM motor drive using the ESP32 microcontroller for a variable-load cart application is presented in this project.

This Electric drive is connected to an HC-SR04 ultrasonic sensor to monitor the fill level of a container loaded on the cart. If the fill level increases it causes a reduction in the distance reading, and thus the ESP32 increases the PWM signal applied to the A2212 BLDC motor. In this way, motor speed is automatically varied according to the load.

II. BODY OF PAPER

2.1 Literature survey and the existing gap:
Previous research works on BLDC motor-drive systems mainly focused on advanced control strategies, sensor-less commutation techniques, and inverter-performance improvement. Shao (2006) proposed a microcontroller-based sensor-less BLDC drive using direct back-EMF sensing for automotive applications, reducing Hall sensor dependency and improving commutation performance. Xiaobo et al. (2011) developed a sensor-less BLDC motor-control

system for electric vehicle applications using rotor-position estimation and electronic commutation methods for stable speed control. Further, advanced motor-control approaches such as Fuzzy-PI and Model Predictive Control were proposed for improving dynamic response and reducing torque ripple in BLDC drives. Similarly, Gambhir and Mishra (2018) discussed variable-duty-cycle PWM techniques for improving inverter operational stability and reducing ripple current in switched inverter systems.

2.2 PROPOSED SYSTEM:

Since they enhance the performance of motor drive, these techniques do increase complexity of the operation and adjustment of the controller, and they raise the implementation costs associated with them. Additionally, most of the existing research has been performed using electric vehicles or large power industrial applications and not lighter-weight transportation systems that typically have predictable loading conditions.

The proposed system will utilize a lookup-table based PWM control method that is simple for a microprocessor (ESP32) and an ultrasonic sensor (HC-SR04). Therefore instead of using a sophisticated closed-loop control algorithm in order to create a motor drive output from a given input (e.g., using a given container fill level and a PWM Duty Cycle) this system will determine the loading condition, using the container fill level, and adjust the output by way of the PWM duty cycle to feed the BLDC with the appropriate amount of power through two MOSFET's and the associated gate drivers (IR2110's). Thus, providing a less complicated and costly adaptive motor drive suitable for lightweight waste transportation applications.

2.3 SIMULATION AND CONTROL STRATEGY:

Originally, the BLDC motor drive system was simulated using a closed-loop control architecture in MATLAB/Simulink and relied on Hall sensor feedback combined with PI-based speed control. The speed of the motor was continuously compared to the reference speed from the Hall sensors in the closed-loop system, and any error signal from the comparison was processed through a PI Controller to dynamically adjust the duty cycle of the PWM so that the motor operated stably under variable loading conditions. The simulation showed that the commutation of the inverter was performed correctly, had stable speed control, and had a satisfactory response time.

When trying to implement the closed-loop control system in hardware, the system had increased complexity in terms of computation, had difficulty in tuning the controller, required synchronization, and had an additional reliance on sensors. A simplified open loop control scheme using a look-up table to generate the PWM control signal was used because the intended application was for lightweight transportation systems that had predictable loading conditions, thus it also decreased complexity and cost of the hardware, while allowing for adaptive motor speed control using load estimations from ultrasonic sensors.

2.4 HARDWARE IMPLEMENTATION

The hardware architecture of the proposed system is designed to achieve adaptive BLDC motor control using ultrasonic sensor-based load estimation and lookup-table-based PWM control. The complete system consists of an HC-SR04 ultrasonic sensor, ESP32 microcontroller, IR2110 gate-driver circuits, MOSFET-based three-phase inverter, A2212 BLDC motor, LCD display, filtering circuits, and separate power-supply sections.

The HC-SR04 ultrasonic sensor continuously measures the distance between the sensor and the waste surface inside the container. The sensor operates by transmitting ultrasonic pulses and receiving the reflected echo signal. Based on the measured echo duration, the ESP32 calculates the distance using the speed of sound relation. The obtained distance value is then compared with predefined lookup-table ranges stored inside the controller memory to estimate the loading condition of the container.

The ESP32 microcontroller functions as the central processing and control unit of the system. It processes ultrasonic sensor data, performs lookup-table comparison, generates fixed-frequency PWM signals at 5 kHz, and controls the overall motor-drive operation. Depending on the detected loading condition, the ESP32 generates PWM duty cycles of 30%, 60%, and 90% to achieve adaptive motor-speed control.

The generated PWM signals are applied to the IR2110 gate-driver ICs, which perform voltage amplification and level shifting required for MOSFET switching. The gate drivers control the MOSFET-based three-phase inverter stage responsible for converting DC power into controlled switching signals required for BLDC motor operation. Bootstrap circuits consisting of IN4007 diodes and capacitors provide the boosted gate voltage necessary for high-side MOSFET switching operation.

The inverter stage drives the A2212 BLDC motor according to the selected PWM duty cycle. Simultaneously, the LCD display connected to the ESP32 continuously displays the measured distance and PWM level during operation. Separate regulated low-voltage supply circuits are used for the ESP32 and sensor modules, while a 12 V, 7 Ah battery powers the inverter and motor-drive stage to ensure stable operation of the overall system.

Fig -1: Figure

2.5 HARDWARE WORKING

The hardware block diagram includes an ESP32 controller, HC-SR04 ultrasonic sensor, IR2110 gate driver circuits, MOSFET based three-phase inverter, LCD display, and A2212 BLDC motor. The HC-SR04 ultrasonic sensor measures the filling level of the container through the transmission of ultrasonic waves and reflection of their echoes. Given that the speed of sound in air is 340 m/s, this time duration is used to compute the distance through the following equation Distance = Duration * 0.034 / 2

The constant 0.034 is the speed of sound in cm/µs, and 2 takes into consideration the double travel of the ultrasonic wave.

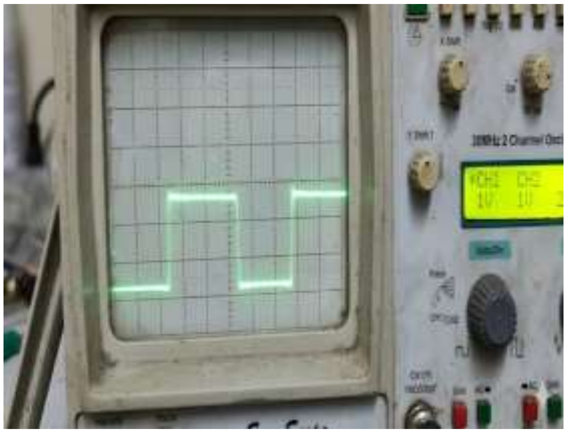
The ESP32 processes the obtained data and compares the readings with the stored values in the lookup table. The appropriate PWM waveforms of frequency 5 kHz with variable duty cycles of 30%, 60%, and 90% are generated by the microcontroller according to the detected loading conditions.

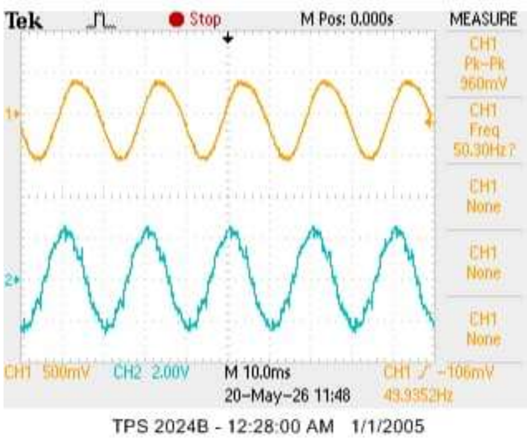
The motor control circuit adjusts the duty cycle of PWM to control the voltage applied to the A2212 BLDC motor to regulate its speed according to the loading situation.

The IR2110 gate driver ICs amplify the PWM signal to drive the MOSFET inverter stage. Meanwhile, the LCD displays the distance and PWM values during execution

Hardware

DSO and CRO output of the Inverter





CONCLUSIONS

The proposed ultrasonic sensor-integrated PWM motor-drive system was successfully designed and implemented using an ESP32 microcontroller and A2212 BLDC motor. The system utilized HC-SR04 ultrasonic sensor feedback and lookup-table-based PWM control for adaptive motor-speed operation according to varying loading conditions. A custom MOSFET-based three-phase inverter and IR2110 gate-driver circuits were developed for motor-drive operation.

The proposed approach reduced the complexity associated with conventional closed-loop BLDC control systems while providing a practical and cost-effective solution for lightweight transportation applications. Experimental validation through hardware implementation, LCD monitoring, and DSO waveform analysis confirmed successful PWM generation and motor-control operation. The project demonstrates that simplified open-loop adaptive control can provide reliable performance for applications with predictable loading conditions while minimizing computational overhead and hardware complexity.

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