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DESIGN AND IMPLEMENTATION OF A FPGABASED MOTOR DRIVE CONTROL SYSTEM FOR E-SCOOTERS

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Abstract: The increasing demand for eco-friendly and sustainable transportation systems has made Electric vehicles to be a popular alternative to hydrocarbon-based transportation systems. E-vehicles provide many advantages like higher efficiency, zero tail emissions, low noise, and higher reliability. However, the performance of Electric vehicles relies mainly on the stability of the Motor drive control system.

The paper proposes a simple, cost-effective motor drive control system that can individually manage two DC motors using closed-loop PWM control. The design also offers an electronic differential control to ensure the optimum performance of the connected motors. The proposed system is implemented on a Cyclone® V FPGA device, offering high-speed concurrent performance ensuring fasterresponse to the connected sensors. The motor operation is controlled through the inputs from a twist throttle system, speed mode buttons, and direction control buttons. Three-speed modes, Off, Low, and High are defined that change the PWM control of the system catering to the rider's need. The direction control ensures the drive is either in forward or reverse which can be controlled through F and R buttons in the twist throttle itself. The differential control loop detects the movement of the handle towards the leftor right. Depending on the handle direction, the left and right motor speeds are adjusted to ensure a smooth and stable turn. When the handle is turned left, the left motor speed reduces, and the right motor speed increases. A complementary action takes place when the handle is turned towards the right.

The proposed Electric vehicle control system is implemented on a prototype tricycle chassis. Overall, the paper proposes a cost-effective motor drive control system for electric vehicles, with closed-loop PWM control and an electronic differential control loop. It offers efficiency, reliability, and a smooth driving experience, making it an ideal solution for sustainable transportation and a significant contribution to the field.

***Index Terms* - Motor drive control, E-vehicle, FPGA design, PWM control, Electronic Differential control system**

I. INTRODUCTION

The widespread use of electric vehicles (EVs) presents an excellent opportunity to design and implement various technical features, ranging from basic drive control systems to advanced autonomous driving systems. Developing an efficient and effective motor drive control system is crucial for achieving better performance and ensuring stable wheel control. Although the fundamental principle for motor drive control depends on motors such as BLDC, Hub motor, etc. DC motors offer superior speed/torque characteristics which are easily controllable through the PWM signal generated from the controller.

The controller used is the Altera DE0 Nano SoC FPGA board which is a development board based on the Cyclone V SoC FPGA from Intel. This board offers a low-cost and compact solution for developing motor control systems based on FPGAs. The DE0 Nano SoC board includes a range of peripherals such as Ethernet, USB, and SD Card interfaces, as well as a 2x20 GPIO header, making it easy to interface with other components of the motor control system. Additionally, the DE0 Nano SoC board includes a range of development tools such as Quartus Prime software and SoC EDS software that make it easy to develop and debug FPGA designs. Overall, the Altera DE0 Nano SoC FPGA board offers a low-cost and integrated solution for developing motor control systems based on FPGAs. FPGA-based motor control systems are preferred over other types of controllers for several reasons. FPGAs are highly versatile and can be customized to meet the specific requirements of the motor and application. They offer high performance and can process large amounts of data in real time, making them suitable for applications that require precise timing and fast response times. Many FPGAs, such as the Altera DE0 Nano SoC FPGA board, include integrated processors that can run control algorithms and interface with other components of the system. While FPGAs can be more expensive than other types of controllers, they can reduce the overall cost of the system by eliminating the need for separate components. Ultimately, the choice of a particular controller or development board depends on the specific requirements of the motor control system and the expertise of the designer.

II. General System Description

The vehicle has been designed to be controlled by an FPGA board, which uses PWM control to adjust the acceleration based on the accelerator output. Figure 1 depicts a complete block diagram of the system. The vehicle has two-speed modes: mode 1 and mode 3. Mode 1 is set to 25 percent of the motor's capability, while mode 3 is set to 75 percent. Each speed mode has two additional speed levels, one for lower speed when the throttle is not engaged, and another for higher speed when the throttle is fully engaged.

To control the direction of the vehicle, there are two buttons: F and R. The F button is for the vehicle to move in the forward direction, which is the default state. The R button is for the vehicle to move in the reverse direction. To control the speed levels of individual motors, a potentiometer is used to give input to the differential control circuit. The differential control circuit adjusts the speed levels of the motors based on the input from the potentiometer.

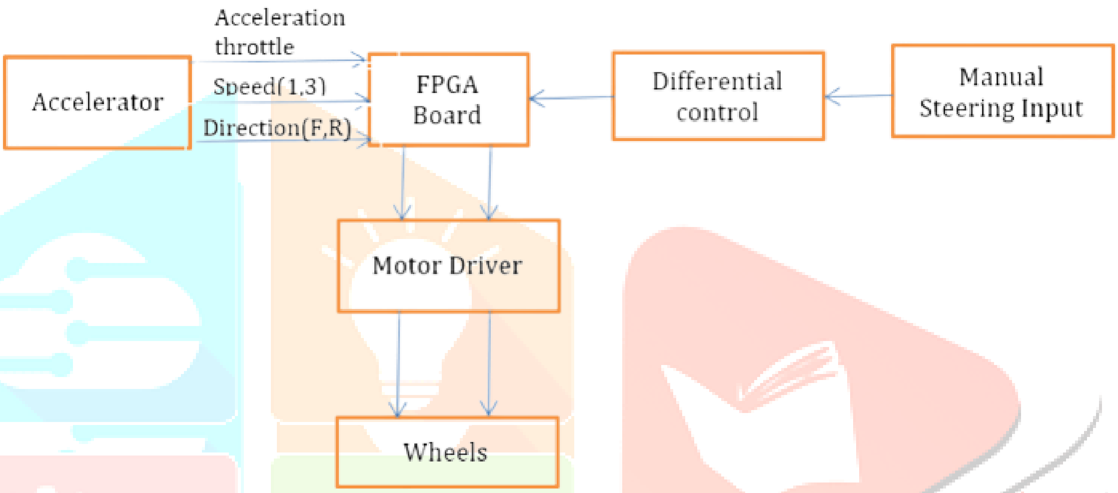

Figure 1: Block diagram of the control system in the Electric Scooter

The block diagram includes several components that work together to control the wheels of a vehicle.

The Throttle system provides input for controlling the direction and speed of the wheels. It includes buttons or switches that allow the user to select the direction of rotation (forward or reverse) and adjust the speed of the wheels. The accelerator is a device that provides a variable input signal that corresponds to the desired speed of the vehicle. As the accelerator is pressed, the input signal increases, and the speed of the wheels increases accordingly. The FPGA (Field Programmable Gate Array) is a programmable logic device that controls the motor driver and differentiator based on the input from the throttle system and accelerator. It generates the necessary signals to set the direction of rotation and adjustthe speed of the wheels based on the input from the Throttle system and Accelerator. The L298N motor driver receives signals from the FPGA and controls the power sent to the wheels. It includes pins for controllingthe direction of rotation (forward or reverse) and pins for controlling the speed of the wheels. The differentiator is a component that detects the direction of the wheels and determines if the vehicle is turning left or right. Itreceives input from the wheels, which can be used to generate signals that adjust the speed of the wheels to ensure a smooth and stable turn.

Finally, the wheels are the components that physically rotate and move the vehicle. They receive power from the motor driver, and their speed and direction are controlled by the FPGA based on the input from the throttle system and accelerator. Overall, the block diagram outlines the key components of a system that provides precise and efficient control of the wheels of a vehicle, allowing for smooth turns and variable speed control.

III. RESEARCH METHODOLOGY

The system has 3 operations namely speed control, direction control, and differential control.

- **PWM Control**

PWM stands for Pulse Width Modulation, which is a technique used to control the speed of motors, this is achieved by varying the duty cycle of a square wave signal, which is then sent to a motor driver that controls the voltage and current supplied to the motor. The PWM signal is typically generated by FPGA based on the input from the accelerator. The accelerator position determines the desired speed of the vehicle, which is then translated into a PWM duty cycle. The duty cycle is the percentage of time that the PWM signal is high compared to the total period of the signal. By adjusting the duty cycle of the PWM signal, the motor driver can vary the voltage and current supplied to the motor, which in turn controls the speed of the motor. This allows for precise control over the vehicle’s speed, as well as the ability to switch between different speed modes.

- **Directional Control**

Directional control in an electric vehicle involves the ability to move the vehicle in both forward and reverse directions. This is typically achieved using a motor controller that regulates the amount of power delivered to the vehicle’s electric motor. When the driver engages the accelerator pedal or throttle, the motor controller sends a signal tothe motor to turn the wheels in the desired direction. Similarly, when the driver shifts into reverse, the motor controllersends a signal to the motor to turn the wheels in the opposite direction, allowing the vehicle to move backward. The ability to switch between forward and reverse directions is critical for safe and efficient vehicle operation, particularly when parking or maneuvering in tight spaces.

- **Differential Control**

Differential control is used in vehicles to allow for smooth and stable turning while minimizing tire wear and maximizing traction. A differential is a device that distributes torque to the wheels of a vehicle in a way that allows the outside wheel to rotate faster than the inside wheel during turns. This is necessary because during a turn, the outer wheel travels a greater distance than the inner wheel, and if both wheels were to rotate at the same speed, the vehicle would experience significant resistance and strain. Differential control allows the vehicle to navigate smoothly and efficiently turns, while also minimizing wear on the tires and maximizing traction on uneven or slippery surfaces. This is particularly important in off-road or high-performance driving, where precise control of the vehicle is essential for safe and effective operations.

IV. FLOWCHART

The flowchart outlines our methodology, which involves using Direction control, PWM control, and Differential control to control the motor. Figure 2 depicts the system flowchart. When power is turned on, the first step is to set the motor’s direction of rotation using the F and R buttons in the Throttle system. By default, the direction is set to forward. The motor driver has two sets of direction control pins - IN1 and IN2 for Motor 1,and IN3 and IN4 for Motor 2. During the forward condition, pressing the F button causes the FPGA to set IN1 and IN3 to a high state, and IN2 and IN4 to a low state. Similarly, during the reverse condition, pressing the R button causes the FPGA to set IN1 andIN3 to a low state, and IN2 and IN4 to a high state.

After setting the direction, the next step is to adjust the motor speed. The Throttle system includes a 3-way switch with Button 2 as the default off state or brake. Button 1 and Button 3 control the PWM signal for each motor. Pressing Button 1 sets the PWM to 30%, while Button 3 sets the PWM to 50%-75%. The Motor driver has two pins - EN1 and EN2 - for speed control. When Button 1 is pressed, the FPGA generates a square pulse with a frequency of 750Hz, and for Button 3, it generates a square pulse with a frequency of 763Hz. These changes in the PWM signal are sent to both the EN1 and EN2 pins of the motor driver.

In addition to the switch-based speed control, the PWM signal can also be adjusted using the Accelerator. Pressing Button 1 sets the motor to run at 30% PWM, but as the Accelerator is raised, the PWM gradually increases to 95%. Similarly, pressing Button 3 sets the motor to run at 50%-75% PWM, but as the Accelerator is raised, it increases to 95% PWM.

In the final stage, the differential control detects the direction of the handle and determines if the vehicle is moving toward the left or right. Depending on the handle direction, there is a change in voltage in the potentiometer, which is then compared in the comparator circuit. The output signal from the comparator circuit is sent to the FPGA, which slightly adjusts the PWM of the motor to ensure a smooth and stable turn. When the handle detects that the vehicle is turning left, there is a slight change in the PWM of the right motor while the left motor maintains its defined PWM. This change is also applied when the handle is turned towards the right.

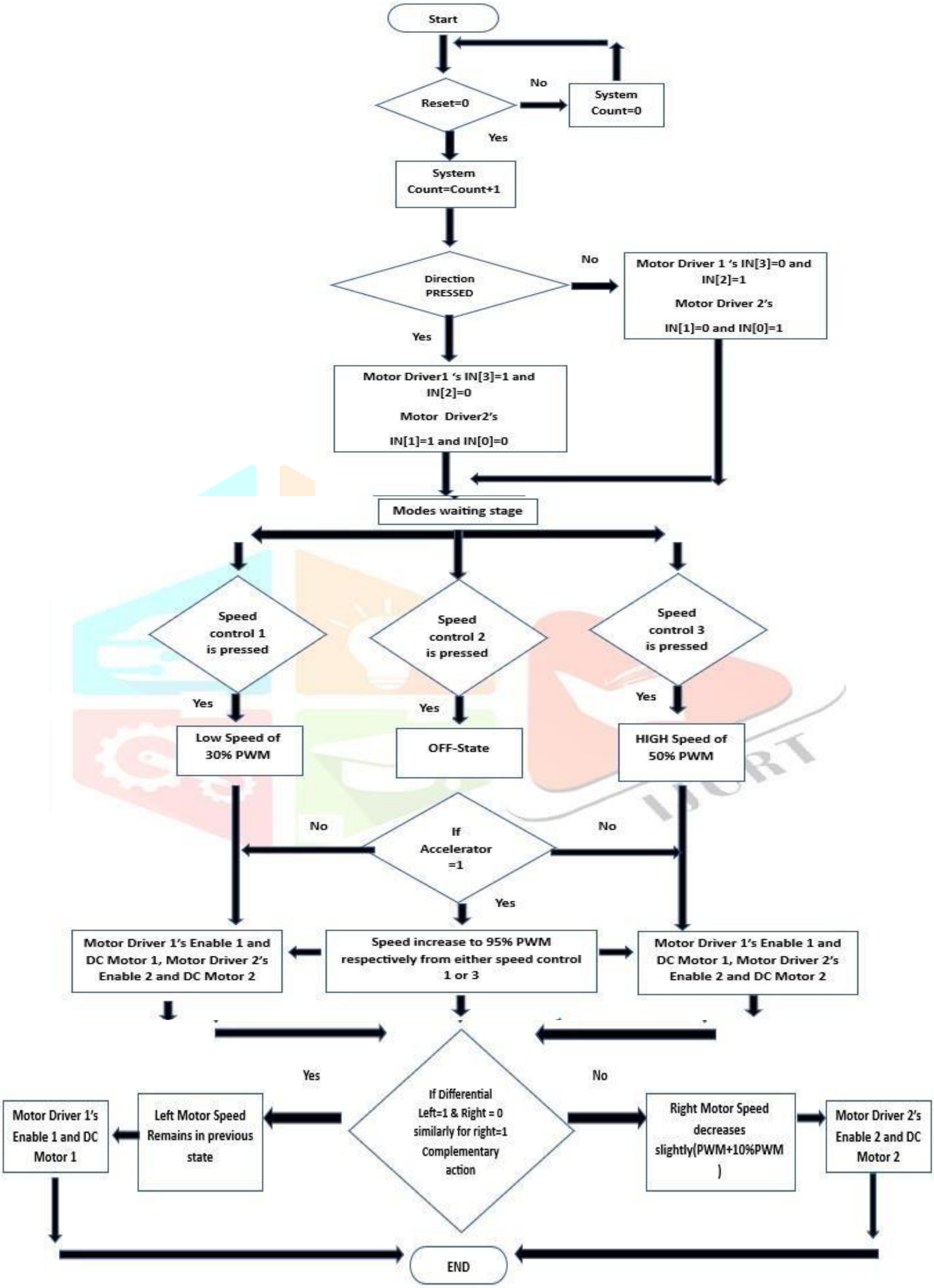

Figure 2: System Flowchart.

V. Result and Discussions

- **Model Design**

The vehicle body is built from scratch with a sturdy and durable 60x40 cm base with a load handling capability of 5-10kg utmost. Figure 3 depicts the model of theproject. The steering handle is attached to the base through a welded pipe to provide a stable and reliable connection. The vehicle has four wheels, with two free-running front wheels and two rear wheels that are controlled by the motor driver using the FPGA board. The rear wheels are individually controlled because of the differential control loop. This configuration allows for precise and efficient control of the vehicle’s movement.

Figure 3: E-Vehicle Model.

- **Speed variation control using PWM**

The speed variation control of the vehicle is achieved using Pulse Width Modulation (PWM) control through the Accelerator. The Accelerator is a versatile control system that can be used to control the motor speed, motor direction, and the on or off state. The low PWM control button operates at a range of 30% PWM, and when acceleration is given, it can reach a maximum of approximately 95%PWM. Similarly, the high PWM control button operates at 50% PWM, and when acceleration is given, it can reach 95% PWM. This allows for precise control of the vehicle’s speed, making it easier tonavigate through different environments and situations. [3]

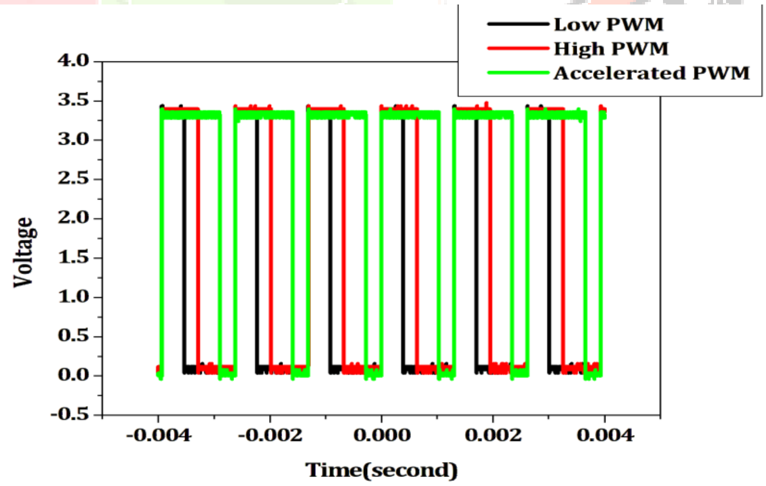

Figure 4: PWM of Low, High, and Accelerated states.

- **Individual wheel speed control while steering**

Individual wheel speed control is an essential feature of the vehicle, and it is achieved using a potentiometer and comparator circuit. Figure 5 depicts the Differential states. The potentiometer detects the direction of the steering handle and generates a differential signal that is compared to a reference voltage in the comparator circuit. Based on the change in voltage difference, the PWM control signal changes the motor's speed for the steering control's direction. This allows for individual wheel speed control while turning, ensuring a smooth andefficient transition between the two motors. The result is precise control over the vehicle’s movement, making it easierto navigate through narrow spaces, obstacles, and sharp turns. [5]

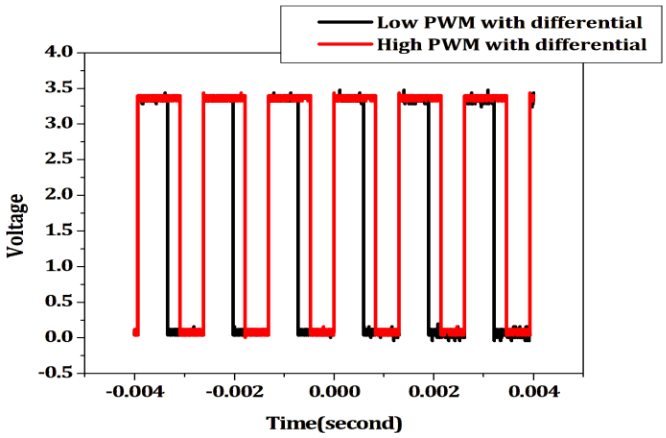

Figure 5: Low and High state with 10% Differential state.

VI. CONCLUSION

The e-vehicle motor driver control system designed in this project, using an FPGA with a differential control system, offers a cost-effective and efficient solution for controlling DC motors/BLDCs in electric vehicles. The closed-loop PWM control with speed andsteering wheel as loop control variables provides precise control of the motor’s speed and direction, ensuring reliable performanceand stability. The differential control loop detects handle movement towards the left or right and adjusts the left and right motor speeds to ensure a smooth and stable turn, providing a comfortable driving experience.

The user-friendly interface with twist throttle, speed mode buttons, and direction control caters to the rider’s needs and preferences, enhancing the driving experience further. The implementation on an FPGA device offers high-speed performance and fast response to the connected sensors, ensuring precise control of the motor’s speed and direction.

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