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Integration of Ultrasonic Range Finder Technology with IoT for Smart Automated Door Control Systems

Joe Essien
Department of Computer and Information Technology
Veritas University, Abuja, Nigeria

Abstract:- Integration of Ultrasonic Range Finder Technology with Internet of Things (IOT) for Smart Automated Door Control Systems is an innovative strategy that integrates two potent technologies to create intelligent and effective door control systems. The integration enables the automation and real-time monitoring of door operations, thereby augmenting security, convenience, and energy efficiency. By integrating ultrasonic range finder technology, which utilizes sound waves to measure distances, with IoT, automated door control systems can be enhanced with advanced capabilities. This paper presents the integration of ultrasonic range finder technology with smart automated door control systems. The work is grounded on the principles of sound wave propagation and the measurement of the time it takes for sound waves to travel and reflect back from objects. The work leveraging on the benefits of enhanced security, efficiency, data-driven insights, and integration possibilities with other IoT devices using Arduino Uno microcontroller, Ultrasonic Range Finder, Ultrasonic sensors, motor driver and integrated circuits. Ultrasonic sensors are deployed as the main medium for sensing users of the system. The methodology adopted include a user interface prototype that can be simulated to allow monitoring and control of the automated door system. The study contributes towards the potential for developing intelligent and responsive door control systems, thereby augmenting the overall smart building ecosystem. The contributions of this work demonstrate the versatility and wide-ranging impact of Ultrasonic Range Finder Technology across various domains, enhancing efficiency, safety, and functionality in numerous applications.

***Keywords**:- Sensing and Measurements, Real-Time Data Acquisition, Data Processing and Analytics, User Interaction, Security and Access Control.*

I. INTRODUCTION

The implementation of automatic entrance/exit door control is prevalent in various public settings, including hospitals, commercial establishments, transportation hubs, airports, and wholesale retailers, with the primary objective of eliminating the requirement for manual opening and closing operations. Presently, automatic door control technologies that rely on sensors are common and include techniques such as infrared, ultrasonic/radio, or other wireless sensing methods. The initial category can be subdivided into active and passive methodologies [1]. In active wireless sensing, the sensor or transmitter actively emits signals or energy into the environment to sense and gather information. The sensor actively generates and transmits a signal, and then analyzes the received signal to extract the desired information. Some common active sensing techniques include radar, sonar, Active RFID and Wireless Sensor Networks (WSNs) [2]. In passive wireless sensing, the sensor does not actively emit any signals or energy. Instead, it relies on capturing and analyzing existing signals or energy in the environment to extract information. Some common passive sensing techniques include Passive RFID, Wireless Energy Harvesting and Wireless Power Transfer (WPT) [2]. Passive sensing techniques often require reduced power consumption and may be more appropriate for extended monitoring or scenarios where the sensors must be inconspicuous or have minimal upkeep demands. The passive method is also a commonly employed technique due to its ease of use, efficiency, and affordability, as it involves the detection of infrared signals emitted by individuals. Both active and passive methodologies offer distinct advantages and are employed in various scenarios depending on the specific sensing requirements, power limitations, and environmental conditions [3]. The selection of active or passive sensing is contingent upon various factors, including power consumption, range, data accuracy, and cost considerations specific to the given application.

A similar technique is the ultrasonic/radio approach, which on the other hand, emits ultrasonic or radio waves to scan the environment and analyzes the returned signals for door access control. Although these techniques are effective at detecting objects, they are incapable of comprehending the nature and intent of the detected objects. An inadvertent opening event may occur when a door is inadvertently activated by a puppy or a pedestrian passing by. Repetitive incorrect operation can shorten the equipment's lifespan in addition to being inconvenient and causing wasteful energy utilization. Consequently, a technique for controlling automated doors that relies on tracking and analyzing movements and intents is necessary.

Typically, sensors are utilized to identify visitors to the building while electric motors operate the automatic doors. By eliminating the use of door handles, buttons, keypads, and intercoms, this touch-free entrance prevents the spread of contaminants, viruses, and infections. This study designs and simulates an automated door system based on an ultrasonic range finder for use in public spaces such as hospitals, malls and schools where controlled, medically safe, and practical entrance and exit are required. An ultrasonic rangefinder measures sensor-to-target distance. It transmits ultrasonic sound waves and receives a reflection of the transmitted signal from an obstacle. Some sensors used in modern automated door control include, infrared, ultrasonic/radio, and other wireless sensing methods. Active and passive tactics are two common approaches for deploying sensors in automatic doors [3]. The active technique emits signals from the controller and detects reflected signals to determine if an object is near the door. This approach accurately determines an item's location and velocity, but its high cost has made it unpopular [3]. In passive detection, ultrasonic/radio waves scan the surroundings and evaluate the returned signals for door access control. This method detects things but cannot understand their nature or intent [6]. Ultrasonic sensors can detect moving objects without touching them. It is generally considered to be low cost compared to other sensors. A control system theory, hardware, and control circuits for human body identification, automatic door position detection, and obstacle detection are described. Structured programming is used to model and simulate the main programme module, opening door subroutine module, and closing door subroutine module in this research [11].

II. REVIEW OF LITERATURE

Proximity Sensing and distance measurement is a crucial component of obstacle detection and avoidance systems. Ultrasonic rangefinders have been widely used for proximity sensing in robotics and automation [10]. Ultrasonic rangefinders are utilised for the purpose of detecting the presence or absence of objects within a specific range. This is achieved by measuring the duration of time it takes for ultrasonic sound waves to reflect off the target and return to the rangefinder. Ultrasonic rangefinders have proven to be advantageous in collision avoidance, object detection, and navigation within autonomous systems. Ultrasonic rangefinders have been utilised as a viable and economical approach to determine distances [11]. Ultrasonic rangefinders are capable of precise distance measurement between the sensor and an object through the computation of the round-trip duration of sound wave propagation. These sensors are deemed advantageous in various applications, including but not limited to level sensing, liquid level measurement, parking assist systems, and distance monitoring.

Ultrasonic rangefinders are commonly utilised in the domains of robotics and autonomous vehicles for the purpose of detecting and avoiding obstacles that impede their path. By continuously surveying the adjacent surroundings, these technological devices possess the ability to provide instantaneous distance calculations, thus enabling seamless manoeuvring around impediments and guaranteeing secure operation. Researches have been conducted aimed at improving the accuracy of ultrasonic rangefinders for obstacle detection [12,13]. Kim, & Do [5] proposed techniques to enhance the accuracy of ultrasonic rangefinders for obstacle detection in mobile robots. The research explores calibration methods, data fusion approaches, and filtering techniques to improve the reliability of distance measurements. Ultrasound signals have extensive application in robotics for the purpose of performing distance measurements and detecting objects.

The advancement of electronic technology, particularly in high-power semiconductor devices, has facilitated the progress of applied ultrasound technology in recent decades. The utilisation of ultrasonic systems has experienced a notable expansion in various domains, including but not limited to ultrasonic measurement of distance, depth, and thickness, ultrasonic testing, ultrasound imaging, ultrasonic machining encompassing polishing and drilling, ultrasonic cleaning, and ultrasonic welding [14]. The ultrasonic distance measurement principle relies on the established air propagation velocity. By measuring the duration between the emission and reception of the reflected signal upon encountering an obstacle, the distance between the transmitter and the obstacle can be calculated using the time and velocity. Many authors have posited that in terms of operation ultrasonic sensors emit sound waves or radio waves and measure the time it takes for the waves to reflect back from an object compared to wireless sensing systems which use wireless communication protocols such as WiFi, Bluetooth, or Zigbee to transmit and receive signals [15]. Consequently, Ultrasonic sensors use sound waves, while radio-based sensors use radio frequency signals. Wireless sensing systems can employ different types of sensors, including motion sensors or presence sensors, to detect the presence of individuals near the door. In terms of Obstacle Detection, Wireless sensing systems primarily focus on detecting the presence of individuals rather than specific objects [1]. They are suitable for automated door control systems that require human presence detection for opening or closing the door while Ultrasonic sensors are effective at detecting stationary or moving objects in the path of the door. They can trigger the door control system based on the presence or absence of obstacles [14]. The selection of either ultrasonic/radio-based sensing or wireless sensing for an Automated Door Control System is contingent upon a variety of factors, including but not limited to the particular application requirements, desired range, accuracy, environmental conditions, and budgetary constraints. The utilisation of ultrasonic or radio-based sensing is highly appropriate for the purpose of detecting obstacles and achieving precise distance measurement. On the other hand, wireless sensing is well-suited for detecting the presence of individuals and facilitating the operation of the door without physical contact.

III. METHOD

In this work, Ultrasonic Range Finder approach is adopted. The choice of this methodology is based upon that assertion that Ultrasonic range finders can measure distances across a wide range of surfaces, including solids, liquids, and even transparent materials. This versatility allows for their application in diverse environments and industries. It also offers reliable and accurate distance measurements within their specified range. The method provides precise readings, enabling precise positioning or object detection. Ultrasonic rangefinders operate effectively in a variety of environmental conditions and are unaffected by ambient light, making them appropriate for both indoor and outdoor applications as well as dusty or dirty environments [8]. In terms of obstacle detection and avoidance, Ultrasonic range finders can accurately detect the presence or absence of objects in a given area, making them valuable in robotics, automation, and collision avoidance systems [9]. Ultrasonic Range Finder approach is implemented on flat panels as it can be set in a variety of ways. These panels can move in a horizontal and linear manner [3]. The automated sliding system has three components: the detecting mechanism, the primary controller circuit, and the motor. The circuit module is the primary controller for the door-sliding automation system [2]. Utilizing sensors enables the identification of individuals moving in close proximity to the sliding doors. Motors are employed to rotate in either the forward or backward motion to achieve open or close operation. The module's circuit comprises of two distinct activators (sensors), one of which is positioned outside the room and the other within the room. When the door's limit switches detect that it has been fully opened or closed, the corresponding action is executed [13]. Manual operation of the machine is feasible if there is a problem with the programming or the machine itself. Once a human crosses the threshold between the room and the sensors, the procedure commences [12]. Sensors such as ultrasonic range finders, photodiodes, phototransistors, and light-based resistors (LDR) are used to operate the control system for automatic sliding doors. These sensors sense light in order to work. There are two types of sensors: activation sensors and protection sensors for presence; each kind is employed for a distinct function. When a person approaches, a sensor activates and opens the door. The interference is recognized by the presence protection sensor, which prevents the door from opening or closing if a pedestrian is blocking its passage [3]. An electric circuit is linked with a mechanical motion using a device known as mechanical limit switch. One of the most common types of limit switch is a single-pole contact block, which has one normally open (NO) contact and one normally closed (NC) contact [1]. There are additionally limit switches available with a time-delayed contact shift. Limit switches are frequently used as input devices to indicate the presence or absence of a certain condition inside a system or process that is subject to monitoring and/or regulation [14]. A limit switch is a type of switch designed to detect when a system component has reached a certain location. Limit switches are a common component in a variety of industrial applications due to its ability to determine an object's maximum range of motion. The limit switches are developed to monitor the motion of a mechanical component. Limit switches are often employed in industrial control applications for the purpose of automatically monitoring and indicating whether or not a system's travel restrictions have been exceeded [4, 5].

In designing this automatic door, safety and usability were taken into account. This work employs an ultrasonic range finder connected to an Arduino uno microcontroller to determine whether a person is approaching the door. Once an obstacle is detected within a range of 300cm, the Arduino uno sends a Pulse Width Modulated signal to the motor driver to initiate the opening of the door. The door will remain open until no obstacle is detected within 300cm range in front of, and behind the automatic door. The automated door system is continually improved through repeated simulations until the required functionality has been attained. The Arduino Uno microcontroller unit deployed has a USB connection, a power connector, an ICSP header, a reset button, 14 digital input/output (I/O) pins and 6 dedicated analogue pins. 6 of the digital I/O pins are optimized for Pulse Width Modulated signals [10]. In addition, it is equipped with a 16 MHz ceramic resonator and a reset button. It has everything necessary to support the microcontroller, and all that is needed to get started is a USB connection to a computer or AC-to-DC converter or battery to give power. The absence of the FTDI USB-to-serial driver chip distinguishes the Uno from all boards that came before it. Instead, it employs an Atmega16U2 (Atmega8U2 prior to version R2) that has been developed as a USB-to-serial converter. During the process of closing the door, a sensor is engaged to determine whether a human or an object is in the door's center. This is a crucial safety component for preventing persons from colliding with one another and safeguarding the automatic door motor from overheating and burning out.

IV. SIMULATION AND RESULTS

The primary component of the sliding door system is the door controller rack that is mounted to the ceiling above the door. A rolling track, an electric motor with a camshaft pulley, a timing belt, and an idler pulley opposite the camshaft pulley at the end of the electric motor are also included in the system. In addition, two ultrasonic sensors, one on each side of the door, and two limit switches, one at each end of the controller rack, are included in the installation. In order to accommodate the installation of doors of varying sizes, the position of the limit switch is adjustable across the breadth of the door opening. This enables a single-pane or double-pane door unit to be installed in the door space. The Complete circuit schematic diagram of the system is shown in Figure 1.

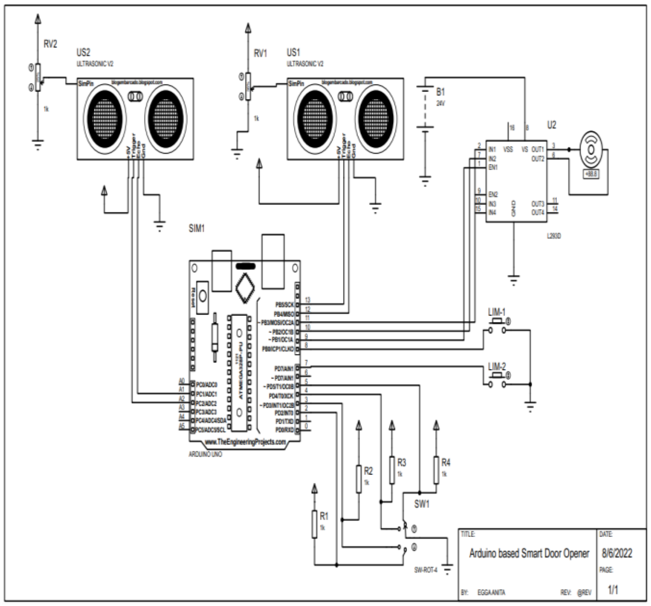

Fig 1. Complete circuit schematic diagram of the system

Design Implementation

Ultrasonic sensors are employed to perform a constant scan of the vicinity in front of the automated door, with the purpose of detecting the presence or absence of any obstructions. Upon reception of data from the ultrasonic rangefinder indicating a distance of 300 centimeters, the Arduino microcontroller commences the procedure for opening the door. Upon activation of the door-opening mechanism, the door will proceed to smoothly slide open at a velocity determined by the setting on the rotary switch. The sliding motion of the door will persist until it makes contact with one of the limit switches positioned at the remote end of the controller rack. Upon contact between the door frame and the limit switch, a signal is transmitted to the Arduino microcontroller to initiate a cessation of movement. The door will remain partially open if there is an obstruction within a range of 300 centimeters in front of it. When an obstruction is not detected within a range of 300 centimeters by the sensor, the Arduino microcontroller commences the door-closing procedure. In the event that the ultrasonic range finder identifies an obstruction within a 300 cm range during the door's closing operation, the process of closing is terminated and the door's opening process is resumed to allow the door to return to its open position. The sliding door controller has been designed to be compatible with both single- and double-pane doors. The positioning of the limit switch is modified to enable the Arduino controller to detect the conclusion of a predetermined door extent.

Power Section Analysis

A 9V power adapter is utilized to power the Arduino UNO microcontroller. Because software-configured power rails automatically account for the power source, this component is omitted from the virtual design. To make the Arduino microcontroller useable in everyday scenarios, the adapter is linked to a power connection on the circuit board. In order to exert control over the motor, a motor driver integrated circuit (IC) is utilized [4]. The L293D is a monolithic integrated circuit motor driver with four channels, high current, and high voltage Figure 2.

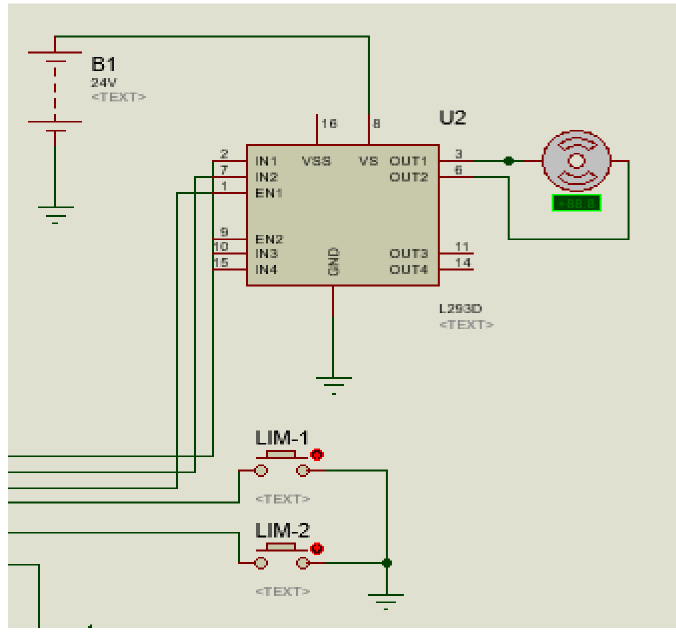

Fig 2. Schematic cutout showing DC Motor section with 24V battery power source

It can utilize power sources up to 36 volts and can deliver a maximum current of 600 milliamperes per channel (Figure 2). The L293D's power supply is located at pin 8 and is directly connected to a 24V battery. Therefore, the circuit will be able to supply the high starting voltage required for the DC motor.

Ultrasonic range finder section Analysis

The ultrasonic range finder component exposes the two ultrasonic range finders required to initiate the opening mechanism of the sliding door. The Devantech SRF05 rangefinder modules serve as the system's base [8]. If one of these two range finders identifies an obstacle within 300 cm, the door opening operation is initiated (Figure 3).

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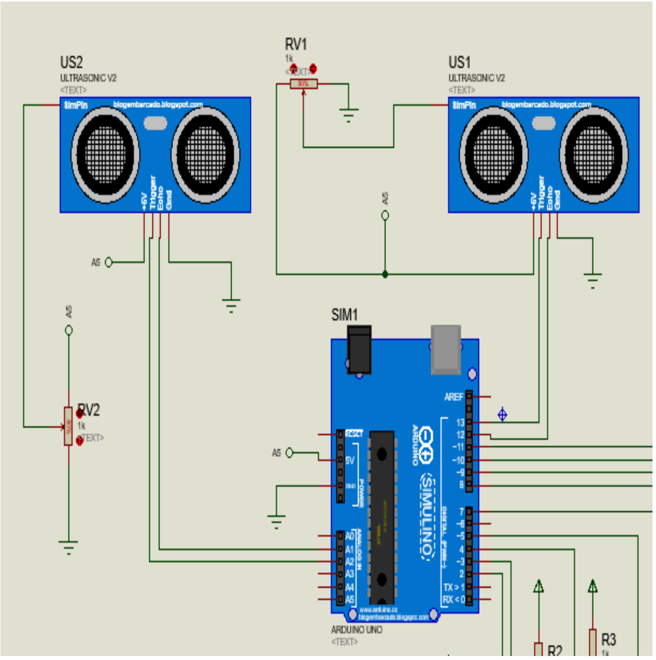

Fig 3: Schematic cutout showing the two ultrasonic range finders

Simulating Distance of the Ultrasonic Range Finders

In the proteus software environment, the process of distance detection using the SRF05 ultrasonic range finder is simulated through the utilization of a test pin that is connected to a high-resolution potentiometer [6]. Through manipulation of the voltage signals emanating from the potentiometer, it is feasible to reproduce the identification of objects situated at various proximities, as per source [8]. In order to carry out this simulation, a connection was established between the Arduino microcontroller and the Proteus virtual terminal instrument. Furthermore, the authors utilized a basic print function to communicate the distance measurements obtained from the ultrasonic rangefinder to the virtual terminal [11].

Simulating the distance of ultrasonic range finders can be done using various methods. The approach adopted in this work starts by developing a mathematical model that represents the behavior of the ultrasonic range finder. This model takes into account the characteristics of the ultrasonic waves, such as speed and propagation patterns. Simulation environment is configured where the objects and their positions relative to the ultrasonic range finder is defined. The Proteus virtual terminal instrument environment is applied in this work for modelling and simulation. The objects in the simulation environment that will interact with the ultrasonic range finder are also defined. These objects consist of both simple geometric shapes as well as complex models to meet design specifications (Figure 4). A mathematical model is used to calculate the expected distance measurement from the ultrasonic range finder to each object in the simulation environment. This calculation takes into account factors such as the time of flight of the ultrasonic waves, reflection, and attenuation.

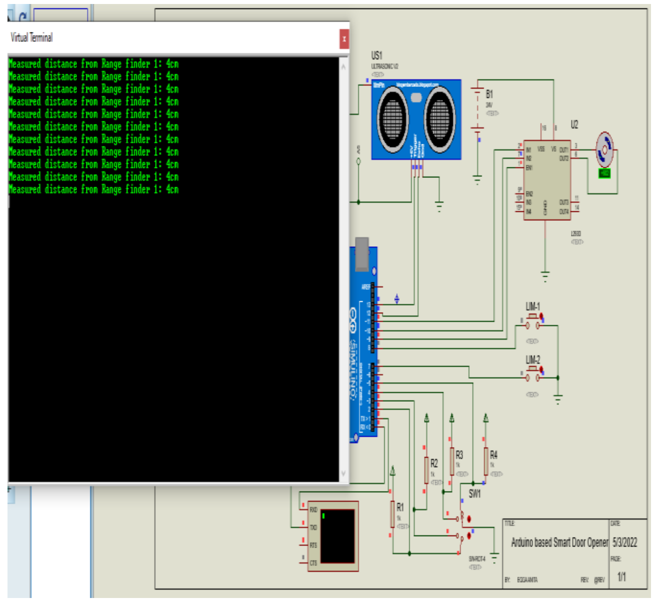

Fig 4: Measured distance printout of proteus virtual terminal instrument

The speed calculation for the 78rpm dc worm gear motor considering shaft diameter of 8cm is specified as;

The maximum speed of the motor at 100% duty cycle will be,
Note: Circumference of a circle is 2πr

Radius is 4cm (0.04m)

$$Smax = \frac{78 \text{ x } 2\pi r}{60}$$

$$Smax = \frac{78 \text{ x } 2 \text{ x } \pi \text{ x } 0.04}{60}$$

Smax = 0.327m/s

Or,
Smax = 32.7cm/s

the time it takes for the ultrasonic signal to travel from the range finder to the object and back is also calculated as: *Time = (2 * Distance) / Speed of Sound.* A simulation loop that iterates over time is set up. In each iteration, the positions and properties of the objects in the simulation environment is updated and the distance measurements from the ultrasonic range finder is recalculated. The simulated distance measurements are visualized in a graphical form depicted as real-time visualization. This allows observing the behavior of the ultrasonic range finder and validating its accuracy against the simulated objects.

Validation and Parameter Tuning

The simulated distance measurements are compared with the expected values based on the positions and properties of the objects in the simulation environment. This validation step helps ensure the accuracy and reliability of your simulated ultrasonic range finder. In order to operate the motor in either the forward or reverse direction during validation, the L293D motor driver is utilized. The L293D is an Integrated Circuit is a high voltage dual full-bridge driver with a high current, designed to handle standard TTL logic rates and drive inductive loads such as relays, solenoids, DC motors, and moving motors [7]. There are two active inputs that may be utilized to either make the system operate or deactivate it independently of the input signals. Using the matching external terminal as a contact for an external sensing resistor is achievable if the emitters of each bridge's bottom transistors are connected [14]. A second power input has been added to ensure that the logic will operate at a lower voltage.

The direct current motor is operated by a Pulse Width Modulated Signal (PWM) [9] at varying Sliding door speed levels (Table 1). The L293D motor driver is the first to detect and respond to these signals. The PWM signal is amplified by the motor driver, and this is done in line with the 24V that is delivered to it [3]. A PWM signal is formed by altering the amount of time that a continuous pulse signal is "on" and "off." This is done in such a way as to have an influence on the signal that is delivered to the motor on an overall average basis [11]. If the voltage signal is kept high for an average of 50% of the time before shutting it off for an equal amount of time that comprises 50 percent of the overall period, the motor will function at a speed that is comparable to 50 percent of its maximum potential. In the event of a pulsating signal, for instance, if the motor is maintained on for 20 percent of the time before being switched off for eighty percent of the time, then the motor will function at twenty percent of its usual speed.

Table 1: Sliding door speed levels

Door sliding speed levels	Speed (%)	PWM Duty Cycle (%)	Speed (cm/s)
Level 1	25	25	8.2
Level 2	50	50	16.3
Level 3	75	75	24.5
Level 4	100	100	32.7

The parameters of the mathematical model in the simulation environment are fine-tuned by varying the motor rotating at 50%, 75% and 100% speeds based on PWM signal of 50%, 75% and 100% duty cycles (Figure 5,6,7) to match the characteristics and performance of the real-world ultrasonic range finder. This may involve adjusting factors such as the speed of sound, environmental conditions, or the sensor's specifications. By following this method, the distance measurements of ultrasonic range finders in a controlled environment are simulated. This approach allows testing different scenarios, evaluate the performance of the range finder, and optimize its design or configuration before implementing it in real-world applications.

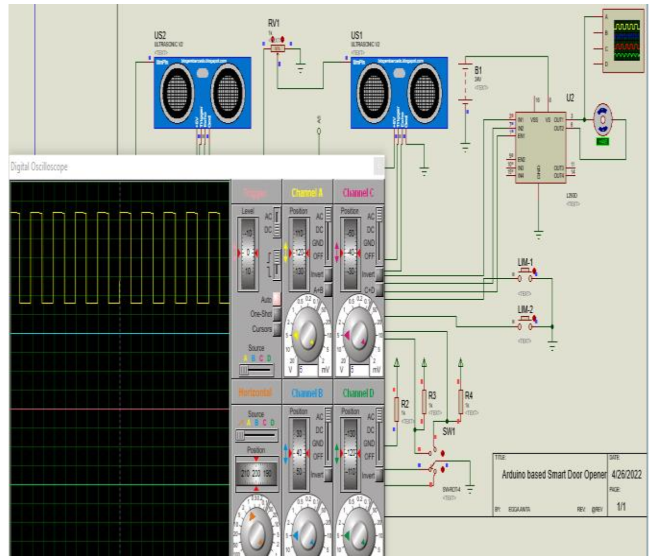

Fig 5. Speed 2 selection, with motor rotating at 50% speed based on PWM signal of 50% duty cycle.

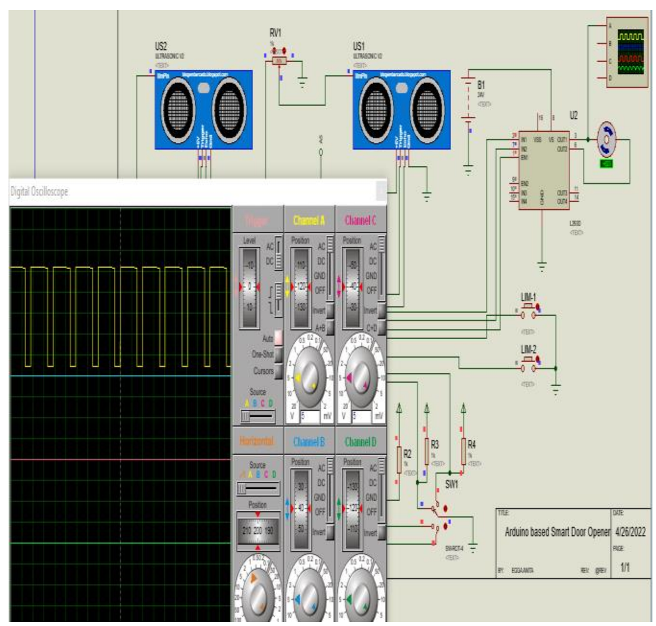

Fig 6. Speed 3 selection, with motor rotating at 75% speed based on PWM signal of 75% duty cycle.

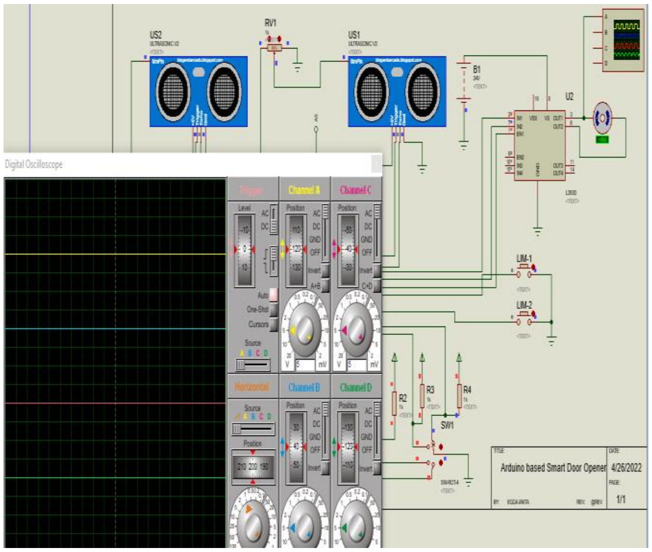

Fig 7. Speed 4 selection, with motor rotating at 100% speed based on PWM signal of 100% duty cycle.

V. FINDINGS AND DISCUSSION

The study's designed and simulated models have provided valuable contributions to mitigation efforts through various means. The utilization of Ultrasonic Range Finder technology facilitates contactless operation of doors, thereby reducing the need for individuals to manually engage with door handles or push buttons. Minimizing physical contact with door surfaces can considerably reduce the probability of virus transmission via contaminated surfaces. The Ultrasonic Range Finder has the ability to detect the presence of individuals in close proximity to the door and automatically activate the opening mechanism, resulting in a smooth and effortless entry and exit process without requiring any manual intervention. This strategy serves to alleviate traffic congestion at entry points and minimize the duration of close-range interactions. The system exhibits the ability to provide real-time surveillance of the entry and exit of individuals in a designated space. By implementing a centralized database or monitoring system, it is possible to capture information regarding the ingress and egress times of individuals. Ultrasonic Range Finder technology-based systems can be conveniently integrated into pre-existing door control systems. These devices possess the potential to be deployed on a variety of door configurations and can be easily scaled to include multiple entry points within a particular establishment. Whilst acknowledging the manifold benefits of Ultrasonic Range Finder Based Automated Door Control Systems, their constraints were also duly considered. Typically, ultrasonic range finders provide a measurement of distance at a specific location in the form of a single point. The aforementioned limitation was found to be insufficient in complex situations that require a more comprehensive spatial data. The limitations of ultrasonic range finders are evident in their detection range and angle coverage. The effectiveness of said devices is typically constrained by a specific distance threshold, whereby objects situated beyond said threshold may potentially evade detection. Furthermore, ultrasonic sensors generally demonstrate a more limited detection angle when compared to other sensing technologies.

VI. CONCLUSION

This work applied the Ultrasonic Range Finder Technology in the modelling and simulation of a smart automated door control systems and demonstrated accurate, versatile and distance measurement solutions with reliable performance and quick response times. The system when simulated presented a seamless and user-friendly experience. Ultrasonic range finders are widely preferred for distance sensing and object detection applications due to their cost-effectiveness, accuracy, and reliability, which render them a popular choice across diverse industries and environments. This research implements the fundamental principle of an automatic door control system by using an Arduino Uno microcontroller and motor driver integrated circuits to send Pulse Width Modulated signals to the DC motor to achieve door opening and closing operations at various speeds. Ultrasonic sensors are deployed as the main medium for sensing users of the system. The work contributes towards the advancement of research for control systems, taking into account both international automated door functions and appropriate safety standards.

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