Ultrasonic Radar and Detection System

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***Abstract*—This report goes over the design and functionality of an Ultrasonic Radar and Detection System. This system is capable of detecting objects within it's range of view using an ultrasonic sensor mounted on a stepper motor. The sensor is continuously scanning it's surrounding area, displaying in real time on an LCD screen. When an object is detected, the corresponding location on the LCD screen will light up. There will also be a buzzer that goes off at certain frequencies, based on the objects distance. This project is intended to be used in real time scenarios/fields such as in security, automated monitoring, and detection.**

I. Introduction

In modern technological applications, real time detection and monitoring systems are essential for safety and automation. The HC-SR04 Ultrasonic sensor provides an affordable and versatile solution for shorter range detection. It's able to measure distance by outputting sound waves from it's transmitter and recording how long it takes to get back to it's receiver once it's been reflecting of off the object. This project implements a 180 degree radar system using the ultrasonic sensor mounted on top of a stepper motor to scan within its' range of vision. The system provides visual feedback using an LCD screen to map out where the object is. It's also accompanied by audio feedback from a buzzer to let the user know how close the object is. This system can be setup in multiple fields. Some include military use at foreign territories, simple house security, and naval/aerial navigation. Combining these certain components, it provides the user with real time data on objects or obstacles within it's effecting range of vision.

II. Model

This ultrasonic radar detection system works by using a concurrent Finite State Machine (FSM) model. This controls the rotation of the stepper motor as well as monitoring the object detection system. This design separates the system into 3 subsystems represented by 3 different FSMs:

- The rotation control,
- The display management, and
- The object detection.

This allows for the concurrent actions to be run smoothly.

The first FSM controls the rotation of the stepper motor. The two states that it's made up of are called "Backward" and "Forward". The system switches between the two based on the current step the motor is at and pre-defined boundaries for the right and left . The stepper motor either increments or decrements based on which state it is. This is then used to calculate the bar on the LCD screen.

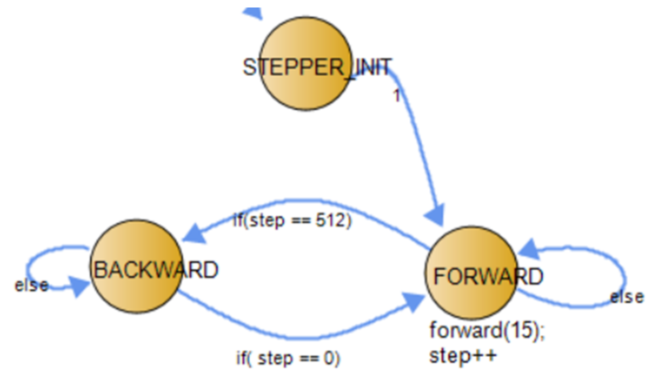

Fig. 1. Stepper Motor FSM

The second FMS describes the characteristics of the ultrasonic sensor. The sensor measures the distance. If it's below the threshold, it sets a flag high. Otherwise, the flag is set low. It then goes to measure again to update the system.

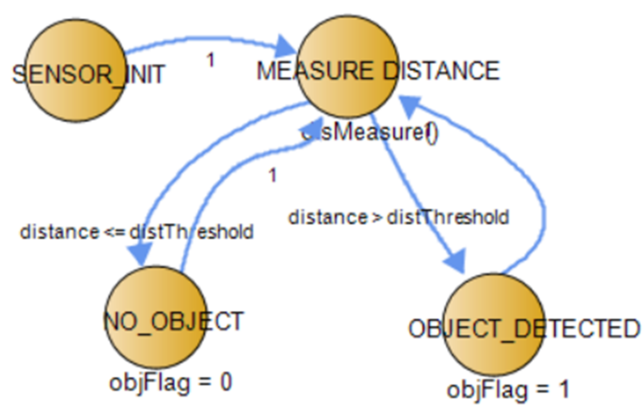

Fig. 2. Ultrasonic Sensor FSM

There are 2 FSMs incorporated with the LCD. The first one helps characterize the movement of the bar, going left and right based off of the current step the motor is at. it shows the bar on screen, and then moves to the next pixel, clearing the spot where it was just at.

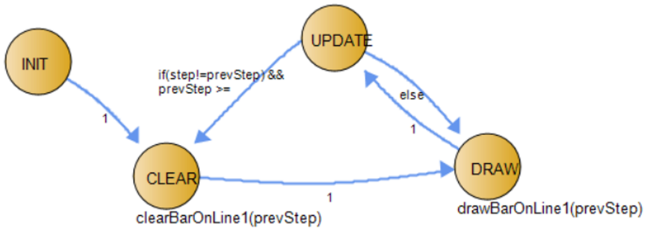

Fig. 3. LCD Screen FSM

The second FSM is based off of whether object flag was set high. If we're at the same pixel block, nothing happens until we leave that section/is finished being scanned, displayed by line 1. Once we leave, it either set that block high if object flag is high, or low based on the object flag.

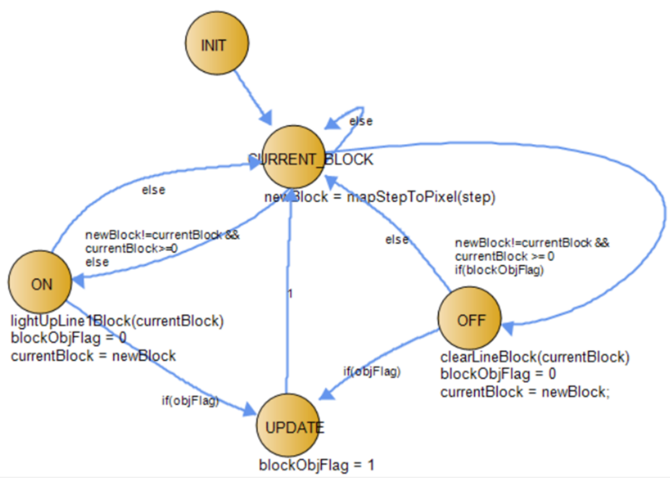

Fig. 4. LCD Screen FSM

This final FSM captures the behavior of the buzzer. It starts off as low, but when an object is within range, the buzzer will calculate the frequency at which it beeps based off the distance of the object. The closer it is, the more frequent and vise versa.

III. Design

A. Construction of System

The physical construction of the system is a lightweight basic structure. a 3D printed cut-out was designed so it could be mounted onto the stepper motor. It then had 2 cutout holes where the ultrasonic sensor would fit right into. To help keep the motor grounded, electrical tape was added connecting the two. This made sure the motor wouldn't end up tilting while it was in motion or if pressure was applied via wires or any outside force. As for the rest of the system, there was no real construction needed rather than just the basic connections to the raspberry pi 3b and breadboard.

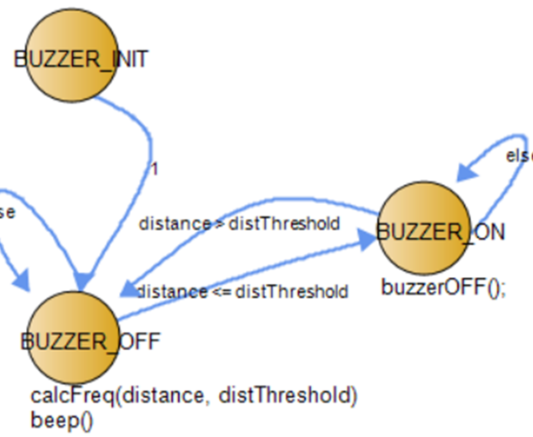

Fig. 5. LCD Screen FSM

B. Components

As was previously mentioned, to make the current system, several different components were needed.

1) Stepper Motor: The stepper motor rotates the HC-SR04 sensor around a single point, allowing for a full 360 degrees of motion. To be more specific, this type of motion is called yaw, where there is rotation parallel to the ground. It needs more voltage supplied to it, so it's paired with a ULN2003 board.

2) LCD Display: This specific LCD screen has a 16x2 grid of pixels blocks, each of which is 5x8 pixels. Custom characters are created in order to visualize a bar moving across each pixel block, going back and forth across the screen. We do this on one line, while on the second line, we display the whole pixel block as on or off to show whether or not an object is there and is within range. Unfortunately, there is a max limit of custom characters one can create, which is 8. This limited us to the 5 custom characters create for the bar movement, and 3 for any other. With such a limited amount, it is not feasible to have any better resolution than a 5 pixel width. This is because the minimum amount of custom characters needed is 9, thus our use of the alternative option. After each pixel block is left by the bar, it is the updated on the second line, either clearing or turning on that block, depending on whether the object is still there. Like for the stepper motor, an extra board was used to minimize the amount of pins that were used. In order to calculate the position of the bar, we need to know the total step range, the current step, and the pixel width of the screen.

$$\text{Pixel Column} = \frac{\text{current step}}{\text{MAX STEP}} \times \text{MAX PIXELS}$$

This equation helps characterize the bar's behavior.

3) Ultrasonic Sensor: The ultrasonic sensor was mounted onto the stepper motor using the 3D printed cut out. In order to measure the distance, a pulse is sent out for 2ms.

$$d_{\text{obj}} = \frac{\text{Time} \times \text{Speed of Sound}}{2}$$

This equation calculates the distance the object is from the sensor based on how long it takes for the sound wave to return. We divide by 2 because to only get the distance to, not the distance to and back. We then multiply by the rate at which it travels, which is the speed of sound. We have a set threshold range of 75cm. We also have a flag called objFlag. It's set high if the object is within range.

4) Buzzer: The buzzer is used in conjunction with an NPN transitor. When the raspberry pi set's it high, the transistor conducts allowing for noise from the buzzer. When set low, the transistor switches open, turning off the buzzer. We want the buzzer to beep more frequently when it's closer than when it's far.

$$f_{\text{buzz}} = f_{\text{min}} + \left(\frac{d_{\text{max}} - d_{\text{obj}}}{d_{\text{max}}} \right) \Delta f$$

This equation determines the frequency at which the buzzer goes off, based on the distance of the object.

C. Software

In order to have this system working properly, threading was needed. This allowed for more fluid actions from the stepper motor, LCD screen, buzzer, and sensor. 4 separate threads were created, one for each major component. For most of the threads, only one FSM was need, but to characterize the different behaviors of the 2 separate line on the LCD screen, two finite state machines were needed.

IV. Project Timeline

The timeline for the Ultrasonic Radar and Detection System project has been carefully laid out to make sure it's developed on time with enough time to work on each portion of the system. Each clear milestone was divided into those specific tasks due to the nature of how the different subsystems work with each other as well as their complexity.

A. Conceptualization

The project began with the concept of the development phase, in which the original idea for this system was established. This included identifying the different components, how they'll work together, and defining the system requirements.

B. Hardware Setup and Testing

During this stage, the initial components, which included the HC-SR04 sensor, buzzer, LCD screen, I2C module, stepper motor, and ULN2003A are assembled and have their basic functionalities.

C. Software and System Design

During this phase, the concurrent finite state machine was designed. This specific design was chosen due to the many moving parts that were already running in conjunction with one another. This design made it easier and simplified it down to it's basic parts. The basic equations and their software integration in c language were also implemented during this time.

D. Motor and Sensor Integration

The ultrasonic sensor and stepper motor are integrated into the system. At this stage, the sensor will start collecting data while the motor is moving, ensuring that the base of this whole project works correctly.

E. Sensor and Display Integration

Then sensors' data that's been collected will then be transmitted to the LCD screen. This will hopefully allow for a real time visualization of the scanned area. The system must be able to handle continuous scanning of the area as well as updates to the screen.

F. Alarm/Buzzer Integration

A basic alarm/buzzer system is added. This buzzer will adjust it's frequency based on the distance of the object. The closer it is, the higher the frequency. The further it is, the lower the frequency. This feature alerts the user of objects within it's range.

G. System Reset and Object Removal

This phase focuses on the previously established LCD mapping of the field of view. During this time, we must be able to implement a reset function for when the object that was in frame is gone. Once the object is gone, the position on the screen where it was displayed must be reset back to it's off state, thus resetting.

H. Debugging Edge Cases

At this time, the system is working. There were a few errors when it was first running. The bar wasn't always being cleared properly because step was being updated too soon. There were two ways in which this could've been solved, using mutex or have a longer delay. To not overload the system, adding a longer delay was the obvious choice. This allowed the sensor to also be able to measure at every pixel.

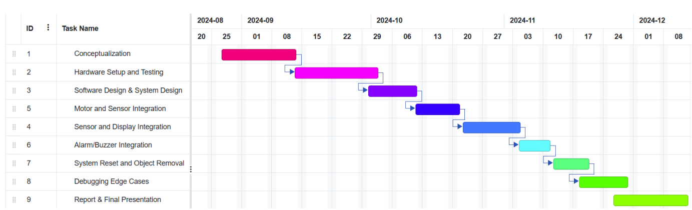

Fig. 6. LCD Screen FSM

V. Conclusion

In this project, we designed and started implementing an detection and radar system that's capable of providing visual and audio feedback. Integrating such components such as an ultrasonic sensor, motor, buzzer, and LCD screen, the system is able to detect objects and display them on a screen as well as alert the user using a buzzer. The concurrent FSM effectively and efficiently manages all the behavior of the different subsystems like the motors movement, the display behaviors, and the sensors characteristics.

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