Electronic Hardware Development Assignment: Design of a Smart Electronic barrier system

551789: Electronics and Microcontrollers
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Abstract

During lectures and practical labs, we've learned basics of electronic circuits, laws of physics applicable in designing them as well as how to perform all calculations necessary to design them. We've learned how individual components are build, how they function, what role they have in circuit and how to use them in practise. On top of that we've learned about microcontrollers and their role. This assignment consists of all above put in practice.

Introduction

The goal of this assignment is to showcase our skills by designing a smart barrier system utilising various components like ultrasonic distance sensor, stepper motor with its controller, microcontroller, keypad and lcd display. Finished system should detect a vehicle approaching barrier and only allow access when correct password is entered. This task is divided into 4 separate subtasks focused on each individual functionality:

- Sonar working with UNO R3
- Stepper motor directional control
- LCD interface with keypad
- Complete working of barrier system

Task 1 – Sonar working with UNO R3

Ultrasonic sensor works by emitting ultrasonic wave at 40 kHz which is silent for humans and waits until it bounces from the object and returns to the receiver. Knowing the time that passed between emitting the wave and return and knowing the speed of sound we can calculate the distance from the sensor to the nearest object. This type of sensor has advantage of being cheap, easy to use, requires low computational power to interpret results and has very fast refresh rate. It only uses 4 pins, out of which 2 are used for power. The remaining 2 are trigger pin and echo pin. Former sends signal to transmitter and latter reads signal from receiver. One of the disadvantages of this type of sensor is low resolution of its reading. Due to sound waves spreading in spherical pattern, we know that object is x distance from the sensor somewhere at a concave part of the sphere of radius x, but we won't be able to tell where exactly in 3-dimensional space this object is located. We will not be able to estimate size of the object as well without adding multiple sensors or manoeuvring single sensor in space. With one sensor in fixed position, we won't be able to determine if the object in front of it is a wall or a single blade of grass. This sensor relays on sound wave bouncing from the target object. Some materials can absorb the soundwave or deflect it away from sensor which will result in it not returning to the sensor giving false reading. Other soundwaves of the same frequency in the environment may cause similar issue if they interfere with receiver during operation. Despite its limitations its commonly used thanks to its cost and ease of use in simple applications like this project. Here this sensor will be able to reliably tell if something is or is not in front of the barrier therefore more complex solutions are not required. Due to its ability to read distance very fast it can be successfully used on fast moving robots to avoid collisions, application where we need to know if something is in front of the robot or not to avoid it. In this case spherical pattern of wave can be even advantageous providing wider FOV with increased distance. Robots that operate in simple environments that can be simplified to 2D space are perfect application as well. For example, robot vacuum cleaners and robots found in warehouses to move goods around. Here fast readings offer significant advantage when for example person walks in front of the robot, it can react quickly. These robots usually have low profile and operating in simple environments these sensors provide enough information to avoid any potential obstacles. Using multiple sensors can provide awareness around the robot, estimate at what angle robot is approaching the wall or even SLAM.

In this project sensor was successfully integrated into the circuit using HCSR04 library and was able to detect object in front of it as well as distance from object to the sensor. This will be useful later as we will be able to tell if the object passed open barrier and it's safe to lower it again.

Task 2 – Stepper motor directional control

Stepper motors are very useful components that share features of both DC motors and servomotors. Like DC motors they can spin continuously in both directions and like servos they can precisely move in "steps" allowing user to set them exactly in desired position. Compared to DC motors or servos they are more complex. DC motors have two terminals and will spin continuously clockwise or counterclockwise depending on how we apply power. Servomotors are usually DC motors paired with gearboxes, potentiometers and control circuits with usually three pins. Two for power and one for signal. Stepper motors have 5 pinouts. One for power and four to operate each coil separately. Usually, stepper motors come equipped with reductor and need external control circuit for proper operation. Thanks to precision of movement they can be often found in high precision application like robotic arms where added complexity is accepted as controllability and precision takes priority.

We are using ULN2003 stepper driver. It allows connection to motor with convenient connector, external power supply and 4 control inputs that allow appropriate logic levels for use with UNO 3 boards. Driver board is equipped with 4 indicator LED's which allows us to see which coil is activated in real time.

In this project we used stepper motor to accurately control movement of the barrier in 90-degree intervals clockwise and anticlockwise. Stepper motor in this application has barrier mounted directly to output shaft and ULN2003 driver for control. This setup is powered by external power supply as Arduino I/O pins cannot provide sufficient current motor requires. Using this setup successful barrier mechanism was introduced to the project.

Task 3 – LCD interface with keypad

For this task we are using 16x2 LCD display and 4x4 keypad. Former allows us to display messages using dedicated library. 16x2 means we can display 16 characters in 2 rows. Integrated chip recognizes signal sent by microcontroller and translates them to corresponding characters for display. This device allows for controllable backlight. We can use potentiometer if that functionality is preferred or we can replace it with a resistor for fixed level of brightness. 4x4 keypad operates using 8 pinouts. 4 of them are connected to 4 rows of the keypad and remaining 4 are connected to the columns creating a grid. Depending on which button is pressed circuit will be shorted different intersection allowing microcontroller to read it from corresponding I/O pin.

Due to limitation in number of available I/O pins on UNO board in this project we are coupling inputs and outputs of our keypad with series of voltage dividers and reading the output with use of one analog pin. Analog pins contrary to digital pins read a value that's in range from 0 to 1023 or 0V to 5V instead of 1 0 value. Using voltage dividers each button will correspond to different voltage level at output therefore allowing us to understand which button is pressed.

This solution isn't perfect. Due to limited range of available resistors and internal resistances of components perfect match of resistors for voltage dividers wasn't possible. This resulted in some buttons returning very similar voltage output, therefore reading them reliably with analog input challenging, but sufficient for purposes of this assignment.

Another possible solution to this problem is using 6 available analog I/O pins and configuring them as digital pins, which is possible as they are equipped with pullup resistors, and the difference mostly comes from configuration. As we would need 8 pins in total theoretically, we could use TX and RX pins as digital I/O pins, but this is not recommended as any devices connected to these pins may interfere with data transfer between computer and microcontroller. To maximise chances of this solution to work we could unplug keypad from these two pins for duration of code upload and connect them again once USB is disconnected, but this will hinder ability to use serial monitor.

In this task we successfully used LCD screen to display information like confirmation from ultrasonic sensor that car approach barrier, prompt to input passcode and other supporting information in the process as well as proper integration of keypad allowing for passcode input.

Task 4 – Complete working of barrier system

Materials and components
-breadboard
-HC-SR04 ultrasonic sensor
-16X2 LCD display
-breadboard power supply
-4X4 keypad
-ULN2003 stepper motor driver module
-28BYJ-48 stepper motor
-UNO R3 board
- various resistors
-potentiometer

Construction and design

Stepper motor was secured to carboard fixture providing base for barrier. All electronic components were attached to breadboard with jumper wires. Ultrasonic sensor were held by "helping hand".

Software

Three dedicated libraries were used to provide required functionality. HCSR04 for ultrasonic sensor, Stepper to simplify stepper motor implementation and LiquidCrystal for LCD display. Code was written in C++ in dedicated Arduino IDE.

Functionality

Code starts in idle mode where barrier system message is displayed. Upon detecting vehicle LCD displays confirmation and prompts user to enter password. When incorrect password is entered system will prompt until receiving correct password. When correct password is entered barrier opens and relevant message is displayed. Barrier will stay open until vehicle stays in front of the sensor. When no presence is detected, barrier will close, and entire process will start over waiting for next vehicle.

Conclusion

Combining all above into one system we successfully created working barrier system. Ultrasonic sensor detects presence of vehicle. LCD screen displays relevant messages necessary to operate the barrier, keypad allows for password input and stepper motor opens and closes the gate as required. Overall using available components, I managed to create working and reliable device. All available work together well, but the design could be improved. Major are for improvement would be simplifying hardware. Of the shelf solutions like LCD and keypad with I2C interface would not only reduce number of wires used but remove need for use of voltage dividers along keypad. This way we could free large number of available pins and further improve design, for example by adding traffic light system, RFID card reader or speaker to generate sounds when interacting with keypad. Due to limitations of microcontroller, it would be hard to push this design any further but using SBC or microcontroller with WIFI card we could create a system with automatic number plate recognition using camera and computer vision with keypad or RFID card as backup.