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ANALYSIS ON MODIFIED ULTRASONIC DISTANCE METER USING ULTRASONIC SENSOR, ESP32 AND PLX_DAQ SOFTWARE

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Abstract

Most of researchers and hobbyists who measure the distance between observer and object are used the ultrasonic sensor and then, they determined the distance by using the speed of sound wave of 340 ms^{-1}. They assumed that the speed of sound is constant at any time and at any local weather situations. But, in the point of view of Physics, the speed of sound is not constant and it depends on some parameters of weather conditions such as temperature and humidity. In this research, the distance between the observer and the obstacle is observed by programming with constant speed of sound as well as with the speed of sound depending on the temperature and humidity. The ultrasonic sensor, DHT22, OLED and ESP32 are mainly used to determine the distance. The calculation of the current speed of sound is based on the temperature and the humidity obtained from DHT22. The distance measured with constant speed of sound and that with calculated speed of sound are displayed on the OLED. The values of distance measured are directly uploaded to Excel spreadsheet using PLX_DAQ software. The comparison of distance measured with constant speed of sound and that with the speed of sound varied due to temperature and humidity is observed on Excel.

Keywords: ESP32, ultrasonic sensor, DHT, OLED**,** speed of sound, PLX_DAQ.

Introduction

Ultrasonic sensor HC_SR04 can measure the distance between observer and object. For this ability, it can be used in robotic avoidable vehicles, car parking system, in-out counter and so on. Most of hobbyists and inventers used ultrasonic sensor HC_SR04 to measure the distance. In determining the distance, the speed of sound is used to calculate the distance. Most of them assume that the speed of sound is constant at anywhere and at any time. For the aspect of Physics, the speed of sound is dependent on some weather conditions. The speed of sound can be varied with temperature and humidity which are changed in time to time. The more precise value of distance can be obtained by using the calculated speed of sound at present temperature and humidity. DHT22 is a sensor which can produce the accurate temperature and humidity. The speed of sound is calculated by knowing these two parameters. ESP32 is a series of low-cost, low-power microcontroller with integrated Wi-Fi and dual-mode Bluetooth. The ESP32 consists of dual-core microprocessor, built-in antenna, switches, power amplifier, low-noise receive amplifier, filters, and power-management modules. The obtaining the temperature and the humidity from DHT22, the getting time of flight from HC_SR04, converting it to the distance and the displaying data on OLED are processed by ESP32 using C++ language. The block diagram of the system is illustrated in (figure 1).

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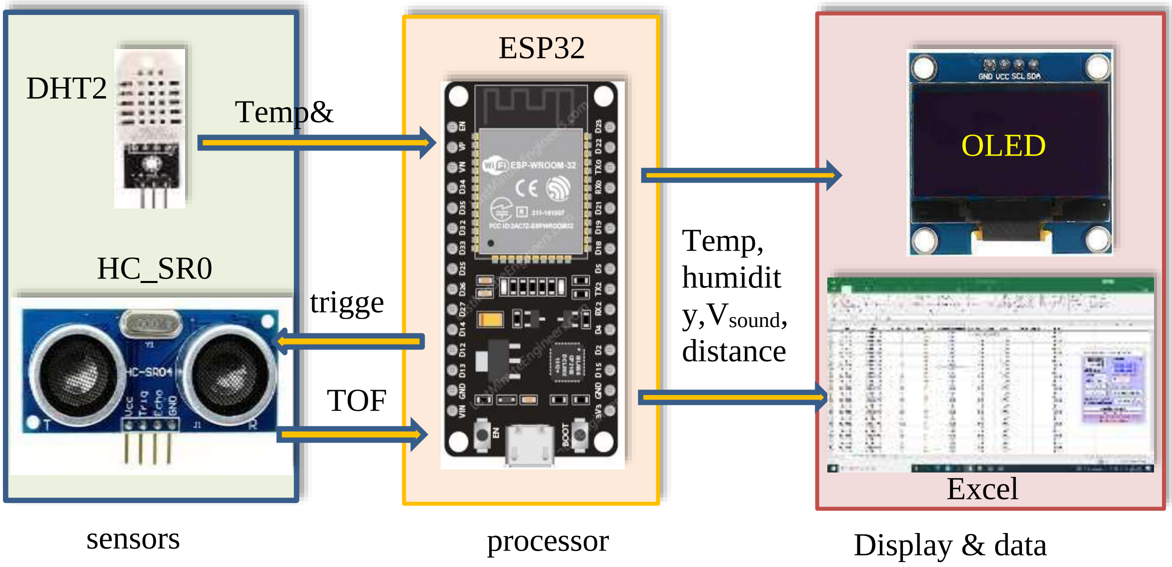

Figure 1. The block diagram of ultrasonic range measuring system

Materials and Method

DHT sensor can produce the temperature and humidity which are used to calculate the speed of sound. When HC_SR04 ultrasonic sensor is received the trigger signal from ESP32, it transmits ultrasonic pulses and receives the reflected sound. The time duration is received by ESP32 and it is converted to the distance. These measurable quantities are displayed on the OLED display.

Ultrasonic Sensor HC_SR04

Ultrasonic wave is a high-pitched sound wave whose frequency exceeds 20kHz that is beyond the audible range of human hearing. Ultrasonic sensor HC_SR04 composes of two ltrasonic transducers: transmitter and receiver. Transmitter produces the ultrasonic wave of 8 pulses at 40kHz as soon as the trigger pin of HC_SR04 is HIGH at 10μs. Meanwhile, the echo pin goes HIGH and waits for the reflected ultrasonic wave to receive. When the reflected ultrasonic is received, echo pin goes LOW state. ESP32 receives the output pulse whose width is proportional to distance in front of it. This gives the time of flight (TOF) in microsecond (μs) which can be obtained by using “pulseIn” instruction of C++. Ultrasonic sensor HC_SR04 shown in (figure 2) can measure the non-contact range between 2cm and 400cm (about 13 feet) with 3mm accuracy. The working principle is illustrated in (figure 3). The pin assignment of Ultrasonic sensor HC_SR04 is tabulated in table 1. [1]

Figure 2. Ultrasonic sensor

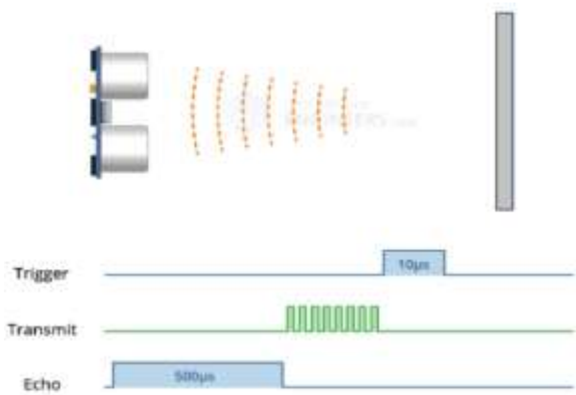

Figure 3. The working principle of Ultrasonic sensor

Table 1. Pin assignment of Ultrasonic sensor HC_SR04

Pin Name	ESP32
VCC	Connected to Vin
GND	Connected to ground.
TRIG	Pin 5 of ESP32
ECHO	Pin 18 of ESP32

ESP32

ESP32 development board composed of Tensilica Xtensa dual-core 32-bit LX6 microprocessor. This processor operates at **80 to 240 MHz** adjustable clock frequency and performs at up to **600 DMIPS** (Dhrystone Million Instructions Per Second). ESP32 integrates Wi-Fi transceiver and dual mode Bluetooth capabilities. It can not only connect to a Wi-Fi network and interact with internet but also it can setup an own network. It composes of 448KB of ROM, 520 KB of SRAM and 4MB of flash memory which are sufficient to implement web pages, JSON / XML (JavaScript Objects notation /Extensible Markup Language) data and everything used in IoT devices. ESP-WROOM-32 also contain a 4 MB SPI Flash IC, a 40 MHz Crystal Oscillator, PCB Antenna and some discrete passive components to make a working system. The pinout of a typical ESP-WROOM-32 Module shown in (figure 4). [2]

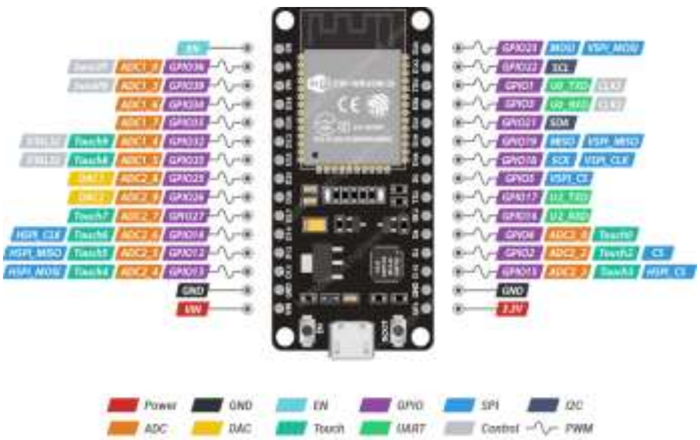

Figure 4. ESP32 module and its pin assignment

DHT22

DHT22 can measure temperature and humidity in terms of digital signal output. DHT22 includes a material whose resistance is varied with humidity and an NTC thermistor. It connects to a 32-bit ESP32 microcontroller so that its output has precise values, fast responding time and anti-interference ability. Among other temperature and humidity sensors, it is reliable and cost effective. The communication and synchronization between ESP32 and DHT22 sensor implement with Single-bus data format. Each temperature and humidity value consists of decimal and integral parts. One complete communication is about 4ms. A complete data transmission is **40bit**, and the sensor sends **higher data bit** first. The form of Data format is 8bit integral RH data + 8bit decimal RH data + 8bit integral T data + 8bit decimal T data + 8bit check sum. ESP32 transmits the data to OLED and uploads to Excel via PLX_DAQ software, if the check-sum is equal to the

Figure 5. DHT22 sensor

sum of 8bit integral RH data, 8bit decimal RH data, 8bit integral T data and 8bit decimal T data. As soon as ESP32 sends a start signal, DHT22 sends a response signal of 40-bit data that include the relative humidity and temperature information to ESP32. Overall communication process is shown in (figure 6). [3,4]

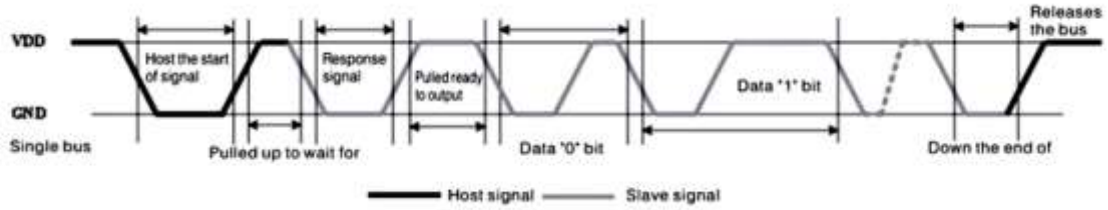

Figure 6. Overall Communication Process between DHT and MCU

OLED

OLED stands for Organic Light Emitting Diode, or Organic LED. It is a display technology consisting of OLED panels that emit their own light when an electric current is passed through them. As a result, OLEDs are super-light, have a true contrast ratio, wide color, deep color saturation and wide viewing angle. Although there are several types of OLED displays available in the market, the SH1106 1.3-inch OLED display in (figure 7) is used in this research. The main component of all different types of OLED displays is an SH 1106 controller which uses I2C or SPI protocol to communicate with the microcontrollers. The OLED performs faster in SPI communication but it is popular with I2C communication because of the lower number of pins. The OLED displays are available in various size, color, and shape but are coded in a similar way. Adafruit_ GFX library and Adafruit_SH110X library are required for 1.3-inch OLED display. [5,6]

Figure 7. I2C OLED

Variation of Speed of Sound

The speed of sound depends on how faster the vibrational energy propagate in the medium. For this fact, the derivation of the speed of sound takes into account the state of medium such as temperature, humidity. According to the kinetic gas theory, the speed of sound in gas (air) is;

$$v = \sqrt{\frac{\gamma R T_K}{M}}$$

Where, R= gas constant = 8.31 joule/mol K, γ =1.4, M=0.02897 kg/mol for air. If temperature is T_K= 20°C = 293 K, speed of sound is 343 m/s.

$$v = \sqrt{\frac{273\gamma R}{M}}\sqrt{\frac{T_K}{273}} = 331.4\sqrt{\frac{T_K}{273}} = 331.4\sqrt{1+\frac{T_C}{273}} = 331.4 + (0.6 \times T_C)$$

The speed of sound also depends on humidity. The density of humid air is less than the density of dry air. According to the equation of, $v = \sqrt{\frac{\gamma P}{\rho}}$ the speed of sound increases in the humid air. The speed of sound can be approximated as follow;

$$v = \{331.4 + (0.6 \times Tc)\} + \{0.0124 \times \text{relative humidity } (\%)\} \text{ [7]}$$

Operation

There are two main sections to measure the distance using ultrasonic sensor HC_SR04; hardware and software section. ESP32, DHT22 and OLED are used as hardware components. In software section, Arduino IDE and PLX_DAQ software are utilized. DHT library and SH110X OLED library are included in the code. Library for HC_SR04 sensor does not use in program. Knowing the operation of HC_SR04 sensor, code is written.

Hardware Preparation

Ultrasonic range meter is constructed by using ESP32, DHT22, OLED and ultrasonic sensor HC_SR04. Vcc, data output and ground of DHT22 are connected 3.3V, D4 and gnd of ESP32. Vcc, ground, serial clock (SCL) and serial data (SDA) of OLED are connected to 3.3V, gnd, D22 and D21 of ESP32. Vcc, trigger, echo and gnd of HC_SR04 are wired to Vin, D5, D18 and gnd of ESP32. The circuit connection as shown in (figure 8). The schematic circuit diagram drawn by EasyEDA software and its PCB layout design are shown in (figure 9).

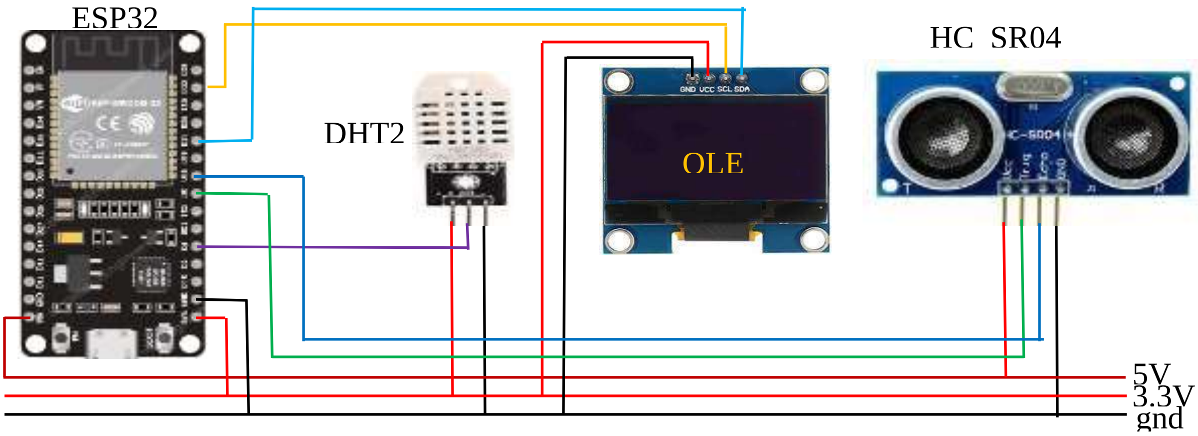

Figure 8. Circuit connection of Ultrasonic range meter

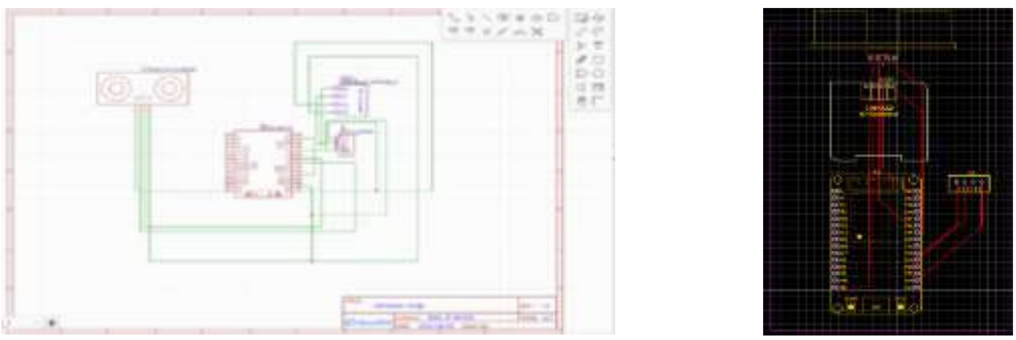

Figure 9. Schematic circuit and PCB layout using EasyEDA software

Software Explanation

Many programming environments such as Arduino IDE, espressif IDF, micropython, Javascript, Lua and etc. can be used with ESP32. In this research, Arduino IDE and C++ language are used. Firstly, the libraries of DHT and SH110X OLED are included. The variables used in code, configurations of pin and baud rate (data transfer rate between ESP32 and PC) are defined. DHT library and OLED library are initialized and then, the table heading for Excel spreadsheet is prepared. ESP32 obtains the values of temperature and humidity from DHT22 sensor. Based on these values, the velocity of sound is calculated with the equation of v ={331.4+(0.6×Tc)} + {0.0124 × relative humidity (%)}. After that, ESP32 sends the 10μs trigger pulse to HC_SR04 ultrasonic sensor to produce 8-pulse of 40kHz. Simultaneously, echo pin is HIGH. As soon as the reflected pulse reaches the echo pin, it goes LOW. This time of flight (ToF) or duration in microsecond is noted by using pulseIn( ) function. The distance is calculated by s = (duration × speed of sound) / 2. Here, the object distance in front of source is calculated with constant speed of sound of 340m/s and with the variable speed of sound which is function of temperature and humidity. Temperature, humidity, speed of sound, and two calculated distances are displayed on OLED. At the same time, the current date-time, temperature, humidity, speed of sound, two types of distance with % error are directly uploaded to Excel spreadsheet using PLX_DAQ software. Data can be refreshed with optional period. In this research, refreshing time is 2 seconds. [8,9,10]

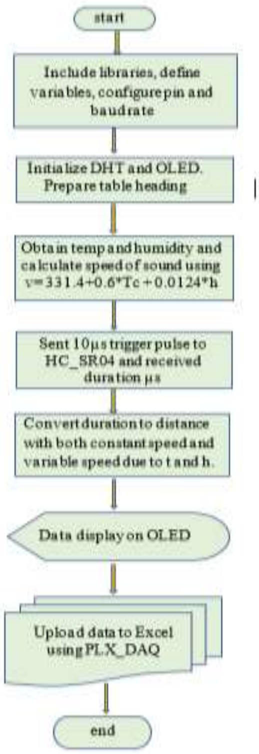

Figure 10. Flowchart of range meter

Results

The ultrasonic range meter is designed and constructed as shown in figure 11(a). Firstly, the object is placed at a distance of 1foot in front of meter in figure 11(b). The distance is measured by both UNI-T laser distance meter and the ultrasonic range meter as shown in figure 11(c). And then, the temperature, humidity, speed of sound, distances measured with constant speed, the distance measured with speed due to temperature and humidity and their respective errors with current date and time are uploaded to Excel spreadsheet via PLX_DAQ software. The uploaded Excel sheet is illustrated in (figure 12).

(a (b) (c

Figure 11. Ultrasonic range meter and distance measuring

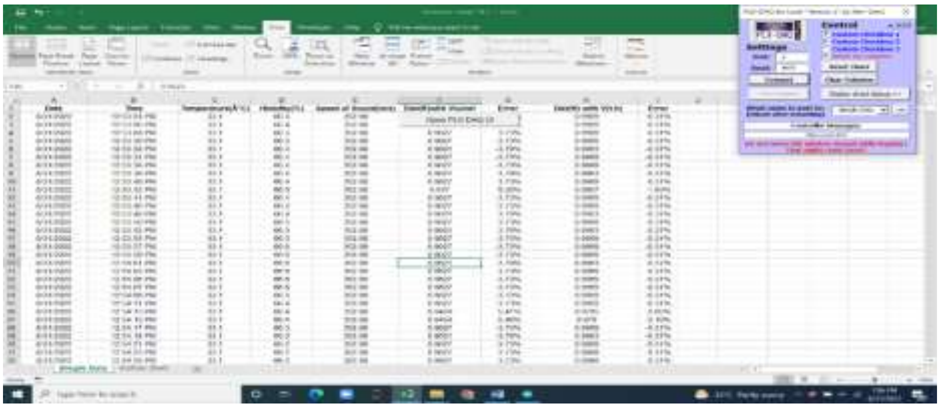

Figure 12. The data on Excel spreadsheet

The distance can be measured up to 10 feet. The (figure13) shows the various distances measured by both UNI-T laser distance meter and ultrasonic range meter. The comparison of distance measured with constant speed of sound and the distance with the speed of sound due to temperature and humidity as shown in (figure 14).

Figure 13. Comparison of distance measured by both meters

Figure 14. Comparison of distance measured with constant speed and varied speed of sound

Discussion

Firstly, the object is placed 1 foot in front of the HC_SR04 sensor using ruler. The distance is measured in two points of view. One is the distance measurement by using ultrasonic range meter while another is the distance measurement by using UNI-T laser distance meter which can measure up to 60m.In ultrasonic distance measurement, there are two methods used to measure distance. That is- the distance is measured with constant speed of sound and the distance is measured with varying speed of sound due to temperature and humidity. Using constant speed of sound of 340 m/s and measuring 1 ft distance, the minimum distance measured is 0.9454 ft and maximum distance 0.9627 ft with minimum percentage error is -3.79% and maximum percentage error is -5.46%. Using varying speed of sound and measuring 1 ft distance, the minimum distance measured is 0.979 ft and maximum distance 0.9969 ft with minimum percentage error is -0.31% and maximum percentage error is -2.10%. These measurements are carried out at the temperature 33.1°C and relative humidity 66% approximately. At these conditions, the approximated speed of sound is 352 m/s. The speed of sound is 340 m/s at the temperature of 20°C roughly. Therefore, distance measured with constant speed of sound has more percentage error. Higher temperature and humidity are, the more error is in measuring with constant velocity of 340 m/s. In this research, data refreshed time is 2 seconds that means data is measured each 2 seconds. It may be more précised by measurements taking 10 times and calculating the average values. As the HC_SR04 ultrasonic sensor transmits eight pulses at 40kHz, the receiver can distinguish its transmitted pulse from ambient noise. During the measurement carries out, the ambient sound intensity is minimum 24.6 dB, maximum 78dB and average 39.1dB as shown in (figure 15). As it is low intensity, it cannot affect the measurement.

Figure 15. Ambient sound

Conclusion

HC_SR04 ultrasonic sensor is reliable in terms of accuracy and overall usability but there are some limitations in using it. The distance between the sensor and obstacles can be measured 2cm to 400cm (about 13 ft) in factory issues. But, in this research, the distance can be measured within 10 feet. It is not suitable to measure the small object which is at distant location. HC_SR04 sensor is difficult to detect the object which has soft and irregular surface. There are some variations of distance measurement due to the variation of speed of sound. The surface of the object should be perpendicular to the line of sound propagated. If not, the sound is not reflected back to the receiver. Although, there are many limitations of HC_SR04 ultrasonic sensor, it is used in many innovations such as avoidable robot, water levelling, in- out counter, typical radar system. According to the researched results, HC_SR04 ultrasonic sensor is used by attaching the DHT sensor for more precise distance measurement.

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