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Research Paper

Design, construction and testing of security based sonar radar system using MCU and controlling software for application in nuclear industries

AdamuAbdulkarim*1, M. S. Anas [1] and A. S. Adamu[1]
[1] *Physics Department Ahmadu Bello University, Zaria, NIGERIA*
Corresponding author AdamuAbdulkarim

ABSTRACT
The work of improving nuclear security is not done, though leaders are no longer meeting at the summit level. The threats of nuclear theft and terrorism remain very real states, nuclear operating organizations, institutions and initiatives supporting nuclear security must struggle for continuous improvement in nuclear security. In this research project Radar System controlled via Arduino is used to secure our nuclear industries. This RADAR system consists of an ultrasonic sensor, servo motor GSM module for sending massage to the control manager and buzzer for beeping (alert); these are the major components of the system. Basic working of the system is that it has to detect objects in its defined range. Ultrasonic sensor is attached to the servo motor it rotates about 180 degree and gives visual representation on the software called Processing-3.5.4 software (Processing development Environment) java language. The Processing gives graphical representation and it also gives angle or position of the object and distance of the object, also when an intruder is detect our buzzer will sound and our module for GSM will as well send message to the control manager. This system is controlled through Arduino. Arduino UNO board is sufficed to control ultrasonic sensor and also to interface the sensor and display device while researching. Main application of this RADAR system comes into different field of navigation, positioning, object identification, mapping, spying or tracking and different applications.
KEY WORDS*: Arduino Uno 328, Ultrasonic Sensor, Servomotor, GSM module, buzzer.*

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I. INTRODUCTION

Nuclear security is to prevent, detect, response to theft, sabotage, unauthorized access, illegal transfer or other harmful acts involving nuclear materials, other radioactive substances or their associated facilities (IAEA division of nuclear security, 2018). The threats of nuclear theft and terrorism remain very real States, nuclear operating organizations, institutions and initiatives supporting nuclear security must struggle for continuous improvement in nuclear security. Just as with safety, the goal must be a never-ending journey for excellence in nuclear security performance, but efforts focused on genuinely effective implementation of Nuclear Security Summit commitments and International Atomic Energy Agency (IAEA) recommendations that already exist could lead to dramatic improvements in nuclear security around the world (BUNN, *et al.*, 2016).Setting up a viable and feasible atomic security framework is essential for the assurance of individuals, society, and nature. Because about 30 new countries embarking on nuclear power programmes, more than 60 new nuclear power plants are being built, Millions of radioactive sources used in medicine, agriculture, industry, research…etc.(IAEA division of nuclear security, 2018).

For that, an idea of mine to use high tech sonar radar as security stuff in our nuclear industries arose, because RADAR is an object detection system which uses radio waves to determine the range, altitude, direction, or speed of objects. Radar systems arrive in an assortment of sizes and have distinctive execution particulars. Some radar systems are utilized for aviation authority at air terminals and others are utilized for long-range observation and early-cautioning systems, (Dutt BA,2017). Radar was furtively evolved by a few countries previously and during the World War II. The term RADAR itself, not the actual development, was invented in 1940 by United States Navy as an acronym for Radio Detection and ranging. The advanced employments of radar are exceptionally differing, including air traffic control, astronomy, air force, narvalapplications, applications in army, air defense systems and many more. High tech radar systems are associated with digital signal processing (Dutt BA,2016). So with that we can as well use it in nuclear industries for security.

II. THEORETICAL CONSIDERATIONS

2.1 Component description

2.2 Hardware and software components;

A concise depiction of the parts that is utilized in the execution of this project is canvassed in this chapter. It incorporates the hardware components (Arduino Uno board, ultrasonic sensor, GSM module, servo motor and others) and also the processing software as well as the compiler software for arduino as such forms the integral part of this project in actualizing the system design.

2.2.1 Micro Controller Unit (MCU)

Microcontroller unit (MCU) is also called Arduino. It is a single board microcontroller used to control the function of servo motor, module for GSM, buzzer and ultrasonic sensor. It sends the angular information to servo motor on which the motor rotates and sensor works as per that direction (Anju, *et al*., 2016).
"Uno" means one in Italian

Fig. 1: Arduino Uno Board.

2.2.2 Ultrasonic Sensor Hc-Sr04

The sensor contains the transmitter Tx (trig), which is used to transmits the signal that used to detect the targets, and the receiver Rx (echo), which receives the signal from the detected targets (Haitham,, *et al.*, 2015). The time required for sending and receiving the ultrasonic wave, several information related to the object or obstacle that causes the reflection of the wave can be measured such as the sensor distance from the object, size, etc.

Fig. 2: The Ultrasonic Sensor.

An ultrasonic sensor is a device that uses ultrasonic waves to measure an object's distance. Ultrasonic transducers which are the microphone and speaker tandems send and receive ultrahigh frequency sound waves to obtain an object's distance or proximity. The ultrahigh frequency sound waves are reflected from an object's surface creating a unique echo pattern.

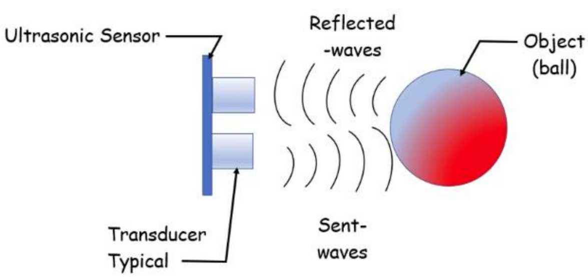

Fig.3 sent and reflected waves; ultrasonic sensor basic operation

2.2.3 Servo Motor

The servo motor system for position or distance measurements usually includes a special motor, a sensor for error signal requirements and a controller. CNC machines, robots and automation are a clearly applications of servomotors (kadam, *et al*., 2017). In this work, a servomotor (which provides ±90 degrees rotations) is used beside both the Arduino board and the ultrasonic sensor HC-SR04 for position determination.

Fig. 4: Servomotor.

2.2.4Interface

The interface between the PC and microcontroller is represented by a USB cable. The Arduino naturally draw power from either the USB connection or an external power supply.

Fig. 5: USB cable

2.2.5 Resistor

Resistors generally perform the function of current limiter; resistor comes in deferent sizes, related to the power they can safely dissipate. All electrical wires have resistance, depending on its material, diameter and length. Ohm's law state that current flow depends on circuit resistance:

$$I = \frac{V}{R} \quad (1)$$

Circuit resistance can be calculated from the current flow and the voltage:

$$R = \frac{V}{I} \quad (2)$$

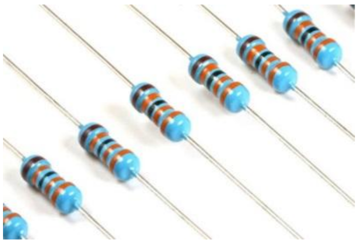

Fig. 6 Picture of resistor

2.2.6 Integrated Circuit (I.C) Regulator

Integrated circuits are the in-build of complete workable circuits on a single substrate (chip).
The particular ICs used in this circuit or project is the L7805 which is fixed positive regulator.

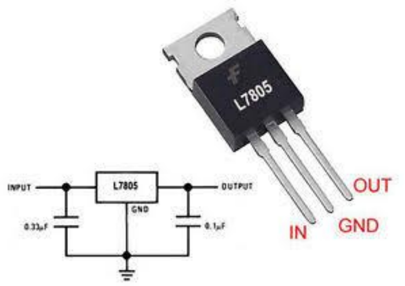

Fig. 7: Diagram and picture of regulator

Better regulations with good stability; reliability and overload protection are all available in the IC L7805 as used in the project.
WhereV_{ref} is the reference voltage.
The voltage across the power transistor (pass transistor) is varied in such a manner as to keep the output voltage constant. A V_{ref} voltage is compare with the output voltage (V_0) through the voltage divider $R_1 R_2$.
The difference between the two voltages is called an error voltage.

$$V_e = V_{ref} - [\frac{R1}{(R1+R2)}]V_0 \qquad 3$$

$V_e$is amplified by the op-amp and is to change the voltage drop across then pass transistor. This is feedback system that generates a variable. Voltage across the pass or power transistor in order to force the error voltage to zero.
When $V_e = 0$

$$V_0 = V_{ref}[1 + \frac{R_2}{(R_1)}] \qquad 4$$

The maximum power is the power dissipated in the internal pass or power transistor,

$$P = (V_{max} - V_0)\, I_{max} \qquad 5$$

Increase in current is increase in power; hence sink is required when I_L exceeds a certain value typical value is 0.75A.

2.2.7 Capacitor

Thecapacitor stores electrical energy in the form of electrostatic field. Capacitors are widely used to filter or remove AC signals from a variety of circuits. A capacitor's capacity to stored energy is called its capacitance, C, which is measure in farad. It can have any value from pF to mF. Capacitors in an AC circuit behave as "short circuit" to ac signals.
Electric current cannot flow through the insulator, so more electron pile up on one plate than the other. The result is a different in voltage level from one plate to the other. The current through the capacitor is equal to C multiplied by the rate change in voltage across the capacitor, that is:

$$I = C\frac{dv}{dt} \qquad 6$$

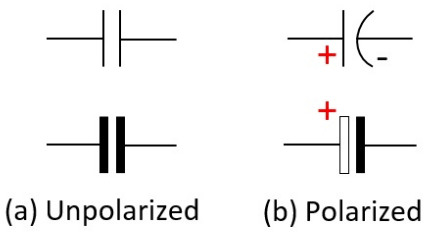

Fig. 7: symbol of a capacitor

2.2.8 Diode

A diode is made up of silicon. Silicon is neither an insulator nor a conductor. It is a semiconductor. This means that its properties are different from ordinary conductors such as copper. Small amount of substance are added to the silicon to give it a very special properties of a diode.

Fig. 8: Diode

2.2.9 Transformer

The transformer is one of the most common and useful application of inductance. It can step up or step down an alternative voltage (an input primary voltage) $V_1$to secondary voltage (output voltage) V_2. The relationship is given by

$$\frac{V_s}{V_p} = \frac{N_p}{N_s} = \text{n} \quad (7)$$

Where n is the ratio of the primary turns to the secondary turns.
The characteristic equation of an ideal transformer is given by;

$$V_s = nV_p \quad (8)$$

$$I_s = \frac{1}{n} I_p \quad (9)$$

Where;
V_1 = primary voltage, V_2 = secondary voltage, n = turns ratio, I_1 = primary current and
I_2= secondary current

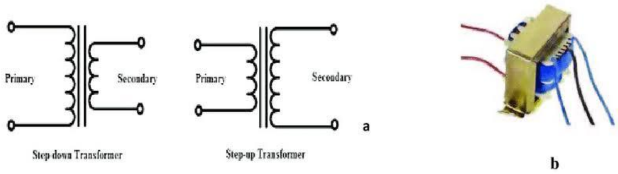

Fig. 9: transformer

2.2.10 GMS module

SIM800L GSM/GPRS module is a miniature GSM modem, which can be incorporated right into an amazing range of IOT projects. You can use this module to perform nearly anything a normal cell phone can; SMS text messages, Make or receive telephone calls, connecting to net via GPRS, TCP/IP, and greater! To top it off, the module supports quad-band GSM/GPRS community, which means it really works quite tons anywhere inside the world.

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Fig. 10: GSM Module

2.2.11 Buzzer

A buzzer is a small but efficient factor to feature sound to this project. It could be very small and compact 2-pin structure therefore may be comfortably used on breadboard and even on PCBs which makes this a widely used component in maximum electrical/electronic applications. This buzzer may be used by honestly powering it using a DC power supply starting from 4V to 9V.

Fig. 11: Buzzer

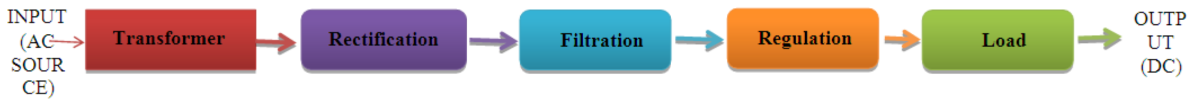
III. METHODOLOGY

3.1 Design procedure and analysis

In constructing this project, the project was subdivided into two units namely;

1. Power supply unit
2. Arduino radar Sensor unit

3.1.1 Design of power supply unit



The reason behind using of external power source (A.C to D.C) to power almost all the component excluding the board is that the power generated by the computer is not sufficient to power all the components to work effectively. The power supply circuit comprises of the following components.

a. **Transformer**

1 and 2 = primary, 3 and 4 = secondary and connection between 3 and 4 is to gives 12V. The transformer chosen is to have the properties V_{in} = 220V, V_{out} = 12V and I_{ac} = 500mA = 0.5A. From ohms law we can easily find out the resistance load, R_L

$$R_L = \frac{V}{I}$$

$$R_L = \frac{12}{0.5}$$

$$R_L = 24\Omega$$

b. **Rectifier**

The changing of an AC supply to DC is termed rectification, or to say is the process of obtaining a unidirectional currents and voltages from AC and voltages it referred to as rectification. A main AC supply may be a wave and intrinsically alternate symmetrical above and below a mid-range value usually taken as zero volts with reference to the mains AC voltage.

$V_{rms} = 12\text{V}$

Given;

$$V_{max} = \sqrt{2}\text{X}\, V_{rms}$$

$$V_{max} = \sqrt{2}\text{X}\, 12$$

$$V_{max} = 16.97V$$

Given;

$$\text{Average value } = {}^{\pi}/_{3} = 0.636$$

Also;

$$V_{dc} = V_{max} \text{ x average value}$$

Therefore;

$$V_{dc} = 16.97 \text{ x } 0.636 = 10.79\text{V}$$

c. **Polarized capacitor**

Theoutput of the transformer has some AC ripples (is the fluctuating AC component present in rectified DC output) which need to be removed, the filter perform this operation. The polarized capacitor C has the capability to filter all the ripples voltages.

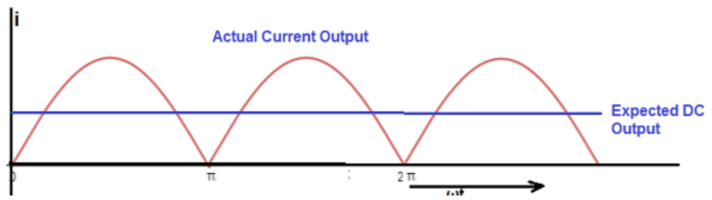


Fig.12: Rippled waveform

Hence, ripple factor(γ);

$$\gamma = \frac{1}{4(\sqrt{3}R_L F C_1)} \qquad 10$$

Where; $R_L = 24$
F = frequency = 50Hz
C_1 = capacitor

$$\gamma = 5\% = 0.05 = \frac{1}{4(\sqrt{3} \text{ x } 18 \text{ x } 50 \text{ x } C_1)}$$

$$C_1 = \frac{1}{4(\sqrt{3} \text{ x } 18 \text{ x } 50 \text{ x } 0.05)} = 3207.5\mu f \sim 3300\mu f$$

$$V_{cap} = 2V_{cmax} - \text{drop across the diode}$$

$$V_{cap} = 2 \text{ x } \sqrt{2} \text{x } 12 - 1.4 = 33.94 - 1.4 = 32.54 \text{ (prefer value 33V)}$$

d. **Regulator**

The circuit need a constant voltage supply for this reason a regulator is used to keep the supply constant at 5V. The regulator use is 7805 which capable of producing +5V regulated voltage at a minimum current of 1A.

$$V_{cc} = 5\text{V}$$
$$V_{rms} = 12\text{V}$$

From;

$$V_{max} = \sqrt{2} \text{ x } V_{rms}$$

Then,

$$V_{max} = \sqrt{2}\text{x } 12 = 16.97\text{V}$$

Also from;

$$V_{dc} = V_{max} \text{ x average value}$$
$$V_{dc} = 16.97 \text{ x } 0.636 = 10.79\text{V}$$

Hence the voltage drop is;

$$V_{dc'} = V_{rms} - V_{dc}$$
$$V_{dc'} = 12 - 10.79 = 1.21V$$

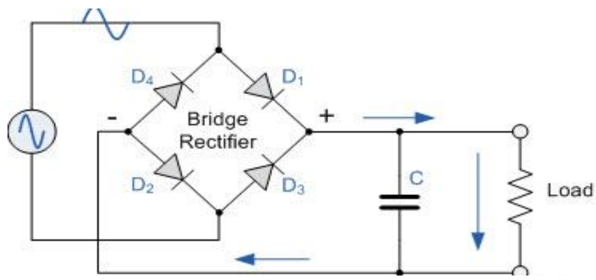


Fig. 13: Bridgerectification

3.1.2 Construction of the casing

The casing was purchased in the market as already made, though the dimension was calculated before it was purchased.
Where; H = 5.6cm = height, W = 15.5cm = width and L = 15.5cm = length
The cuboid was used to determine the surface area and volume

$$Surface\ area\ (A) = 2(LW + LH + HW) \qquad 11$$

$= 2[(15.5x15.5) + (15.5x5.6) + (5.6x15.5) = 2[240 + 96 + 90] = 852cm^2$6x15.5) = 2[240 + 96 + 90]= 852cm^2

$$\text{Total volume (V)} = \text{L x W x H} = 16 \text{ x } 15 \text{ x } 6 = 1440cm^3$$

Note, for ventilation of the components vent hole are included of approximately 0.5cm in diameter

Fig. 14: Hardware module of project

Complete Module of Project

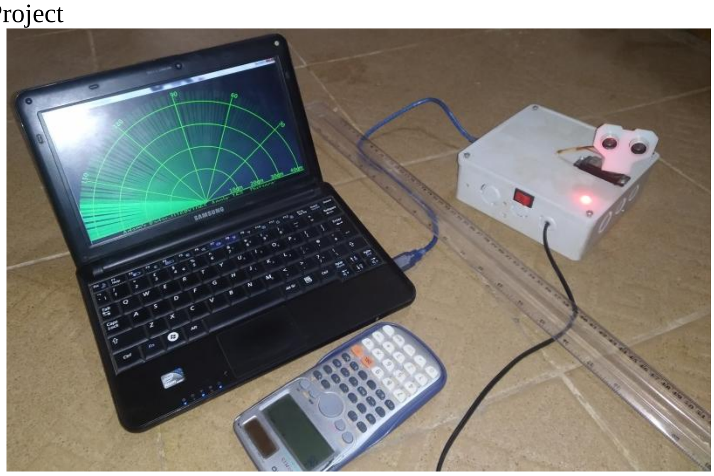


Fig. 15: Complete system

3.1.3Block Diagram of the Radar System

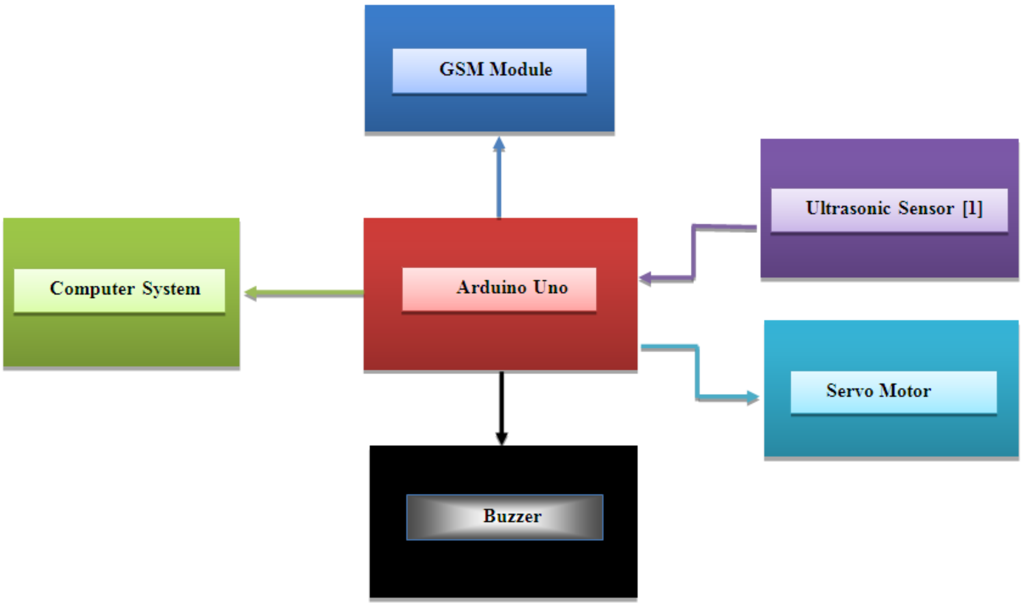


Fig. 16: Block diagram of the system

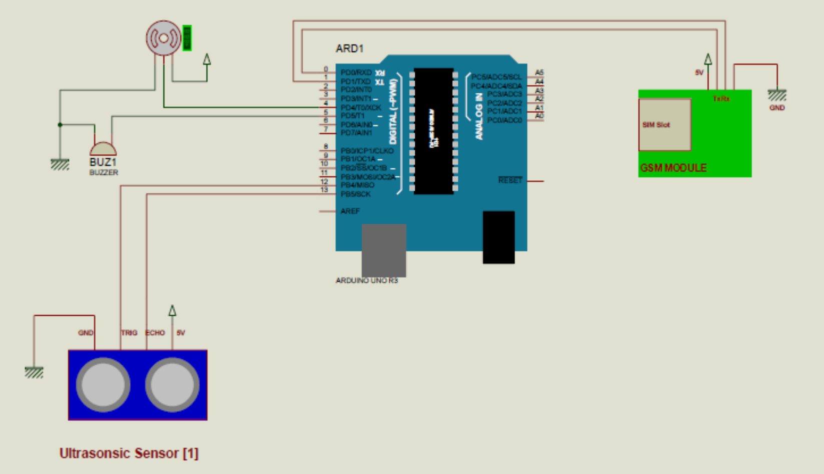


Fig. 17: Complete circuit diagram of the Arduino radar sensor unit

We have now successfully wired the discrete components to an Arduino, we are now ready to install (upload) all the codes to the Arduino.

3.2 Arduino software (processing software)

Processing (Figure below) is an Integrated Development Environment (IDE) designed for several purposes such as electronic arts and visualizing the fundamentals of programing. Arduino as an IDE builds in Java language, but uses a simplified syntax and graphics programming model.

Fig. 18: Processing software**Fig. 19:** arduino software (compiler).

IV. RESULT AND DISCUSSION

4.1 Result

The validation of the planned framework has been tried tentatively in the center for energy research and training (CERT) Ahmadu Bello University, Zaria. Three types of materials (human, wood and aluminum) are considered as an obstacle. The obtained results for each material are graphed and tabled to obviously focus on the difference between the real and measured distances to infer the error of the measurement.

4.1.1 Experimental Setup

The design comprises of ultrasonic sensor (HC-SR04) that coupled with the servomotor. The combination is controlled by Arduino board to identify the sensitivity of the sensor. In this project, the materials: human, wood and aluminium are chosen for the objects to validate the design operation.

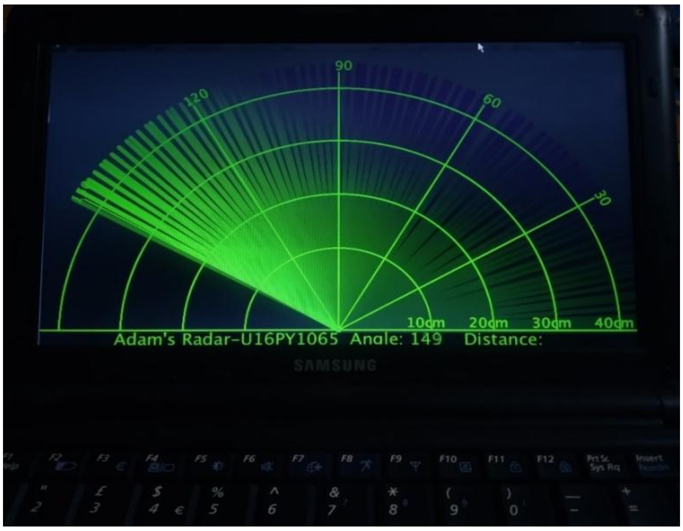


Fig. 20: Ranging Screen.

The estimations (measurement) are recorded over the space of (5-40) cm at various angles (from 0 to 180 degrees). The micro-controller (MCU) is interfaced with a PC to show the running screen of the radar (Figure 8).

The exhibition of the planned framework for a predetermined obstruction is estimated by finding the percentage error with equation 12.

$$\text{Error} = \frac{real\ distance\ - measured\ \ distance}{real\ distanc\ e} \text{x } 100\ \% \qquad 12$$

Where the parameters (real distance) and (measured distance) represent the distance in (cm) between the object and the system measured manually and by the system respectively.

Several reasons could lead to this error such as the change of temperature, wind speed and random noises; in fact, these reasons affect the ultrasound wave.

4.3.1 Human as an Obstacle

Table 1: Experimental Results (human).

Real distance (cm)	Measured distance (cm)	Error % (wood)
5	5	0.00%
10	10	0.00%
15	15	0.00%
20	20	0.00%
25	25	0.00%
30	30	0.00%
35	35	0.00%
40	41	2.5%

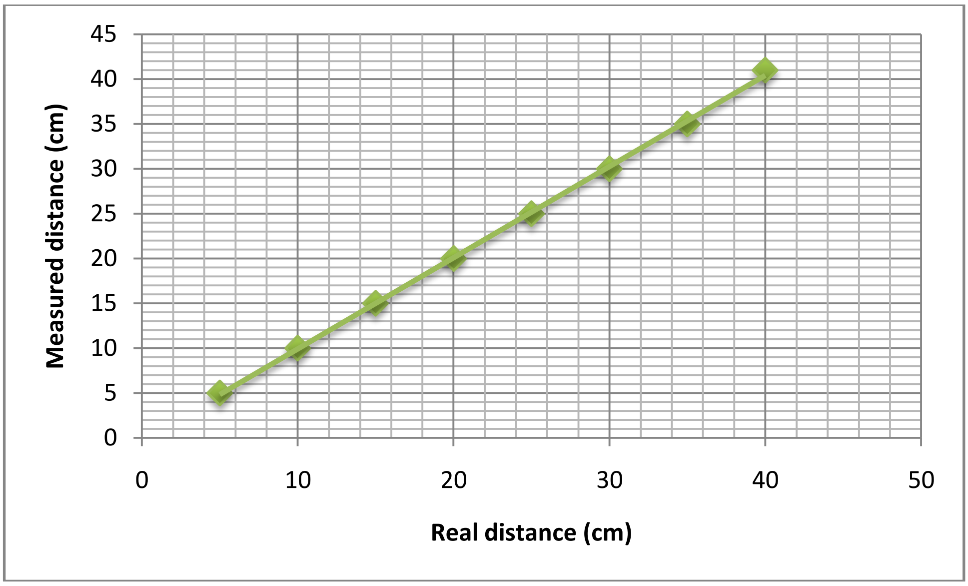


Fig. 21: Relation between Measurement and Actual Distance for human Obstacle

Wood as an obstacle

Table 2: Experimental Result (Wood)

Real distance (cm)	Measured distance (cm)	Error % (wood)
5	4	20%
10	10	0.0%
20	19	5%
25	27	8%
30	31	3.33%
35	36	2.86%
40	42	5%

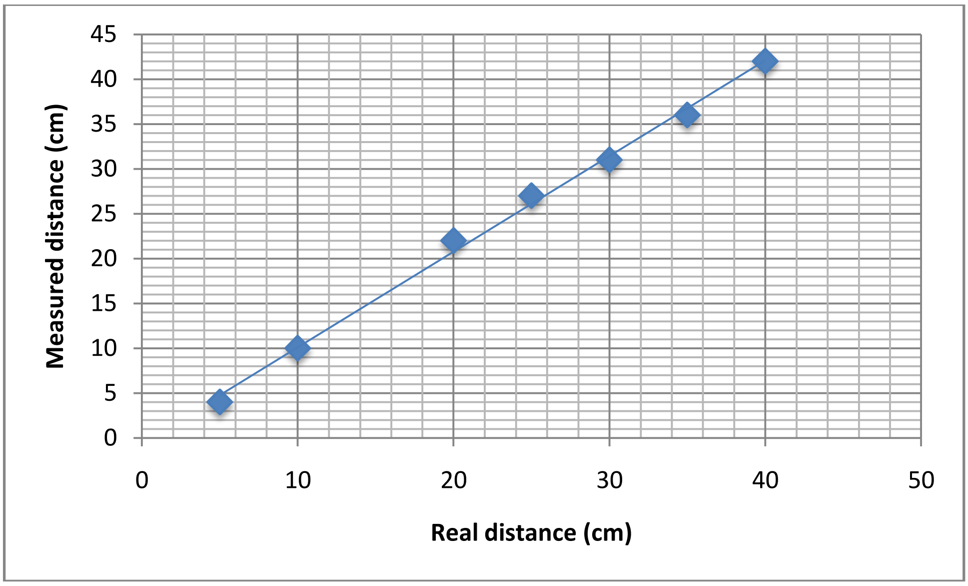


Fig. 22: Relation between Measurement and Actual Distance for Wood Obstacle.

4.3.4 ALUMINUM AS AN OBSTACLE

Table 3: Experimental Results (Aluminum Obstacle).

Real distance (cm)	Measured distance (cm)	Error % (wood)
5	3	40%
10	8	20%
15	16	6.7%
20	21	5%
25	26	4%
30	28	6.7%
35	34	2.8%
40	41	2.5%

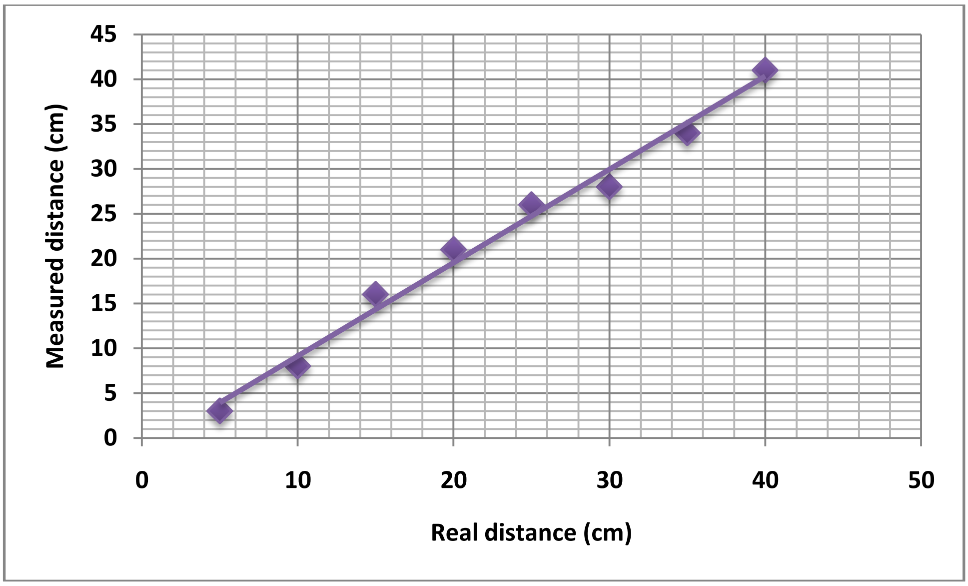


Fig. 23: Relation between Measurement and Actual Distance for Aluminum Obstacle

4.2 Discussions

Figure 21 and Table 1 summarize the results of distance/sensitivity measurements in case of human as an obstacle. It can be noticed that the maximum percentage error between the actual distance and measured distance is about 2.5% and most readings are less than 0.00%. Figure 22 and Table 2 summarize the results of distance measurements in case of wood as an obstacle. It can be noticed that the maximum percentage error between the actual distance and measured distance is about 20% and most readings are in the range 8-0%.In the case of aluminum obstacle; as clarified in Figure 23 and Table 3; the percentage error of most estimation is bigger than the estimations if there should arise an occurrence of wood as an obstacle.

According to the results of the percentage error for the measured distance using the proposed design. It can conclude that the design is working properly base on the objectives.

V. CONCLUSION

The Ultrasonic Sensor become related to the Arduino UNO board and the sign from the sensor in addition supplied to the display screen shaped at the computer to degree the presence of any obstacle in the front of the sensor in addition to determine the range and angle at which the obstacle is detected through the sensor. For this display screen, we use processing3 software programme by way of Ben Fry and Casey Rease.

Also, in addition to it, a GSM module connected through the shift register and a buzzer also tells about the range of the obstacle.

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