DESIGN AND CONSTRUCTION OF ROTATING ULTRA-SONIC RANGING DEVICE FOR ENVIRONMENTAL SENSING

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The objectives of this project are designing and constructing a cost-effective system that able to sense the topography of the environment. Many systems for this purpose have been made, but do not cost-effectively. For example, MIT has made an environmental topography sensing system using laser sensor, which costs more than 5000 USD. Therefore, the alternative system which is more cost-effective is needed.

This system is capable to sense the topography of the environment within the radius of 360^{o} with four ultrasonic sensors that are mounted perpendicularly to each other and work simultaneously. The experiment concluded that the system can create maps of the environment within a radius of 360^{o}; the speed of the system in making the map depends on the size of the environment. This project is a beginning part of a bigger project of creating a map maker mobile robot.

I. INTRODUCTION

For the purpose of topography sensing, a system that can do this quickly, accurately, and also cost effective is needed. Therefore, rotating ultrasonic ranging device is designed, which uses four ultrasonic ranging sensors and a servo motor to rotate them within 90 degrees back and forth so the topography of the environment within 360 degree can be made.

II. Theory

2.1. Arduino Mega

Arduino is an open source electronics prototyping platform based on flexible, easy to use hardware and software. It is intended for artists, designers, hobbyists, and anyone interested in creating interactive objects or environments. Arduino Mega version is chosen because its features, which belong to microcontroller Atmega 1280, are needed such as four 16-bit timers which have better resolution than 8-bit timers. So, the signal that can be produced can be smoother. Two 16-bit timers are used for controlling the sensors and servos.

2.2. PING))) Parallax Sensor

Four PING))) Parallax sensors are used int his project. From the datasheet, they can measure the distance in 3 to 4 meter maximum.

The sensors working in this ways:

1. Trigger pulse is given to send the ultrasonic signal.
2. After a couple of time, while waiting for the echo pulse, the sensor gives an output HIGH in **Sig** pin. This rising edge of the pin is marked as a starting point of the measurement.
3. When the echo pulse received, the sensor will give an output LOW so that the distance of the object can be measured by calculating the time between the falling edge and the rising edge of the pin.

Figure 1 is the timing diagram of the sensor:

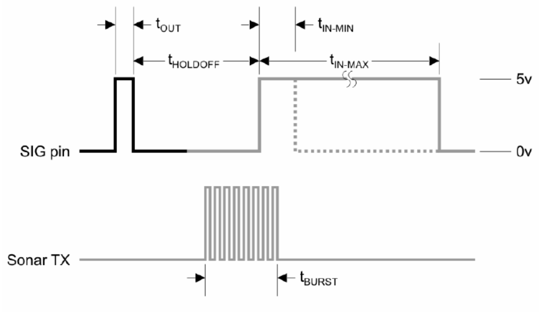

Figure 1. Sensor timing diagram

In Arduino Mega, a 16 MHz crystal is used. Therefore the execution time per tick is:

$$\frac{1}{16000000}\,second = 0.0625\,\mu s$$

If prescaler of CLKi/o / 64 is chosen, then the clock frequency is:

$$\frac{16}{64}\,MHz = 0.25\,MHz$$

So the execution time per tick is:

$$\frac{1}{0.25\,MHz} = 4\mu s$$

By calculating the number of ticks from the timer, the time between falling edge and rising edge of the pin can be known. Then, this value is multiplied with the value of speed of sound to get the distance **S**. The value of speed of sound in the air **Va** can be derived from the formula :

$$\boldsymbol{Va} = 331.45 + 0.61\,T_c \text{ m/s}$$

$$\boldsymbol{\Delta t} = \mathbf{n} \times 4\mu s$$

$$\boldsymbol{S} = \frac{\Delta \mathbf{t} \times \mathbf{Va}}{2}$$

Where:
Va = speed of sound in the air (m/s);
Tc = Temperature degree in celcius (^{o}C);
n = number of ticks between falling and rising edge signal;
Δt = time needed for pulse to return (s);
S = the distance (m).

2.3. Servo motor

Servo motor is used to rotate the system within 90 degree back and forth. To control the motor, PWM signal is given.

2.4. "Processing" software

"Processing" is an open source software and a programming language made by Casey Reas and Ben Fry from MIT Media Lab. The main purpose of this software is to provide visual programming based on C programming language.

This software is used to gather the data through a serial connection from Arduino board, then interpret the data into a radar screen in the PC.

III. Design and Implementation

3.1. Designing The System
Below is the block diagram of the system:

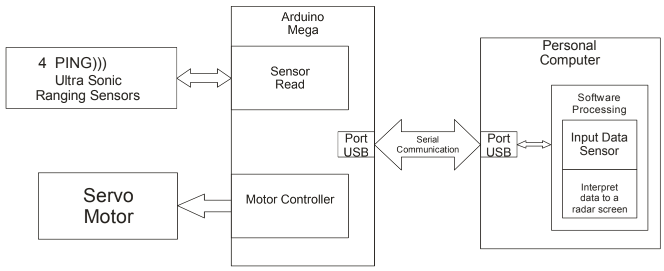

Figure 2. System Block Diagram

Arduino Mega is the main controller of the system. It controls the servo motor and reads the data from sensors. The data sent through the serial connection to the PC.

3.2. Hardware Design

Hardware design includes electrical system and the system platform.

Electrical design includes sensors and servo motor, the pin connection is listed below:

PING))) Sensor Pin: 46,47,48,49
Servo motor pin : 5 (PWM timer 3)

The platform is designed using Coreldraw and implemented using laser cutting acrylic workshop. The platform can be seen in the Figure 3 below:

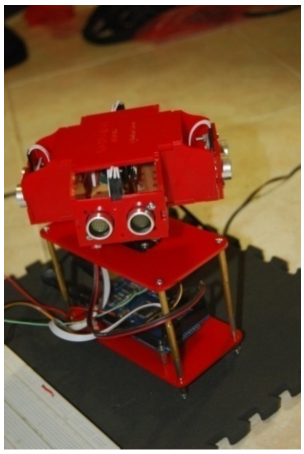

Figure 3. System platform

3.3. Software Design

The software design includes **Arduino** software and **Processing** software.

3.3.1. Arduino Software

Arduino has three main tasks : read the sensors value; control the servo; and send the data through serial connection. The format of the data is shown below:

"P" + servo position + "A" + sensor 1 value + "B" + sensor 2 value + "C" + sensor 3 value + "D" + sensor 4 value

Characters P, A, B, C, and D are given to simplify partition of the data in PC. Figure 4 is the diagram block of the Arduino software.

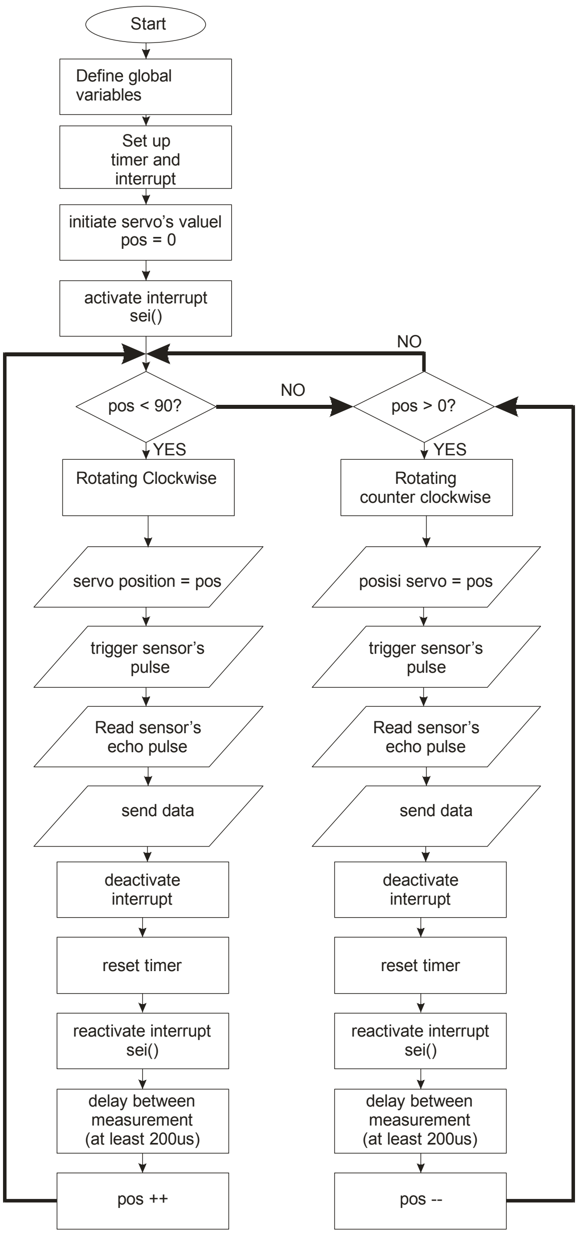

Figure 4. Arduino software flowchart

3.3.2. *Processing* Software

Processing has two main tasks: receive the data through serial port and interpret it into a radar screen. Firstly, a radar screen is plotted like shown in Figure 5.

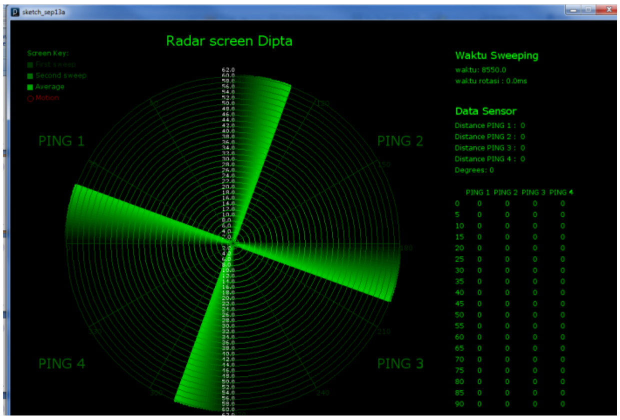

Figure 5. Plot radar

Secondly, the data is divided separately based on the character P, A, B, C, or D explained before into four sensors value and one servo position variable. Each sensor's value is interpreted into 4 areas.

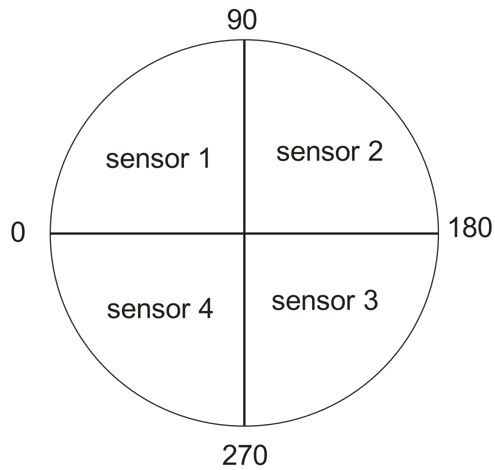

Figure 6. Sensor range area

When the servo motor rotates the system within 90 degree back and forth, the topography of the environment can be seen within radius 360 degree.

IV. Experiment and Analysis

The following experiments are performed:

1. Comparison the value of the sensors to the real distance in order to get the offset value of the sensors;

2. Experiment to measure the speed of the system to make an environmental topography image within 360 degree radius;
3. Comparison the result from the Radar screen in the PC to the real condition of the environment.

4.1. PING))) sensor Experiment

Measurement of the distance between the sensors and an obstacle is performed in this experiment to find out the offset value of the sensors in order to make the sensors work accurately.

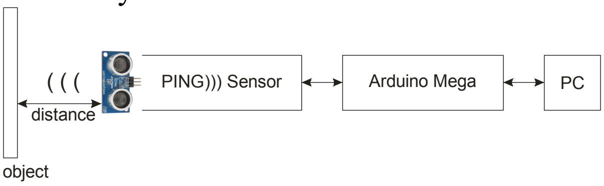

Figure 7. Block diagram experiment 1

From the experiment, the maximum distance that can be measured by the sensors is 377 cm.

The measurement took samples of the distance ranged from 20cm to the maximum distance that can be detected by the sensors with 20cm increment, so the last distance is 360 cm. Each distance is measured 1000 times. Hence, there are 18,000 times of measurement in total.

The result is compared to the real value of the distance, and then the result shows how many times the sensor can measure the distance correctly.

The results are shown in figures below with remarks:

Y axis shows the number of sensor readings;
X axis shows the difference between real value of the distance and the sensor's value which ranged from -2 cm, -1cm, 0, 1cm, 2cm and more than 2cm.

Sensor 1:

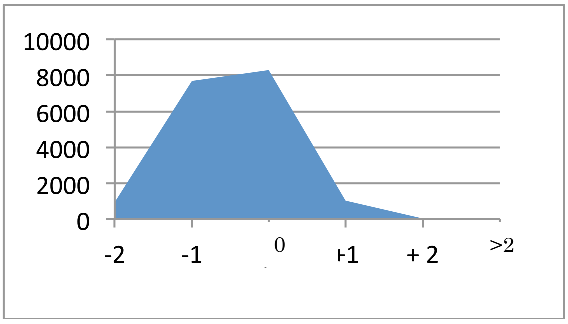

Figure 8. measurement result of sensor 1

From the figure, sensor 1 can measure 46,13% correctly, which is the highest possibilities of the measurement. No reconfiguration is needed for sensor 1 and the offset value is 0.

Sensor 2:

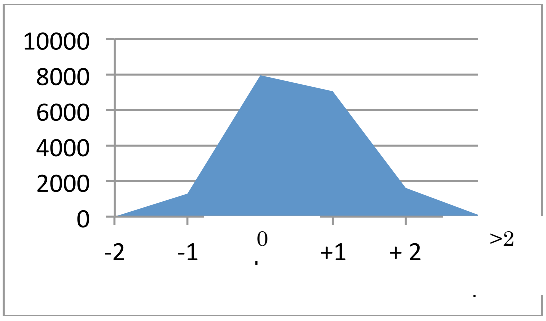

Figure 9. measurement result of sensor 2

From the figure, sensor 2 can measure the distance 44,23% correctly, which is also the highest possibilities in the measurements. Therefore, no reconfiguration for sensor 2 is needed and the offset value is 0.

Sensor 3:

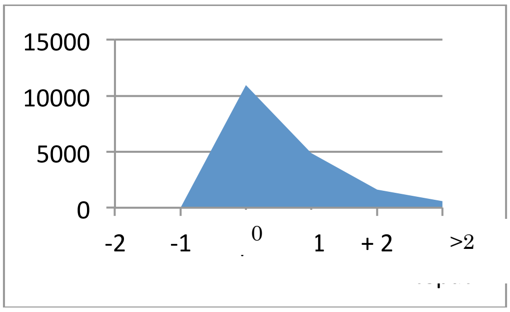

Figure 10. measurement result of sensor 3

From the figure, Sensor 3 can measure 60,69% correctly. Therefore, sensor 3 can be concluded as the best sensor and no reconfiguration is needed with offset value 0.

Sensor 4:

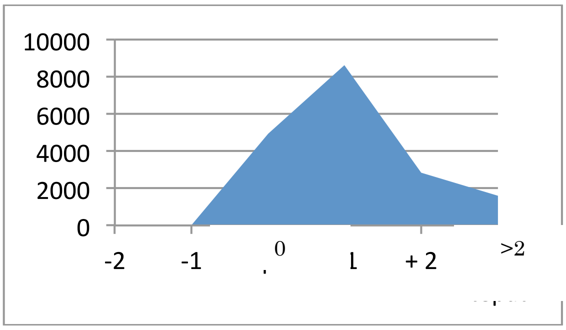

Figure 11. measurement result of sensor 4

From the figure, sensor 4 only measure 27.38% correctly, and 47,97% of the measurements valued “+1”. Therefore, reconfiguration is needed for sensor 4 by giving an offset value -1 (minus one).

4.2. System Speed Testing

The system is tested to sense environmental topography in four types of square room. Each type has different size:

- Room 1 sized 30cm x 30cm.
- Room 2 sized 60cm x 60cm
- Room 3 sized 90cm x 90cm
- Room 4 sized 180cm x 180cm.

The system is tested 3 times in each type of room. Therefore, the result is shown below:

Table 1. Time vs room type

Test	Time (ms)			
	Room 1 (30x30) cm^2	Room 2 (60x60) cm^2	Room 3 (90x90) cm^2	Room 4 (180x180) cm^2
1	3232	3410	3584	4384
2	3216	3406	3622	4335
3	3250	3409	3686	4386
Average	3232.6	3408.33	3630.67	4368.33

In the conclusion, wider the room, more time is needed to sense the environmental topography. This happens because ultrasonic sensors need time waiting the echo pulse from the obstacles to measure the distance. Longer the distance, more time is needed by the echo pulse to return to the sensor. Therefore, the speed of the system depends on size of the area to be scanned.

4.3. Comparison Between The Radar Screen from *Processing* and the Real Situation.

Result from room 1 scanning:

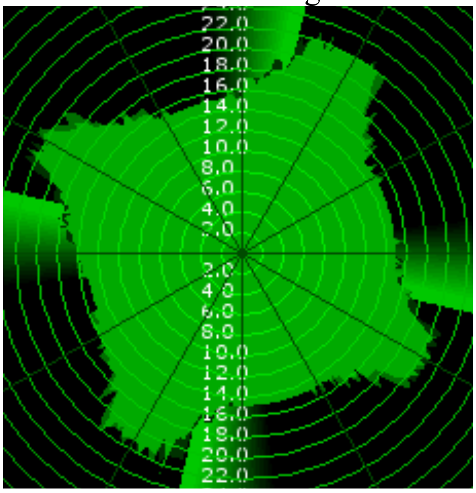

Figure 12. Image result from room 1

Result from room 2 scanning:

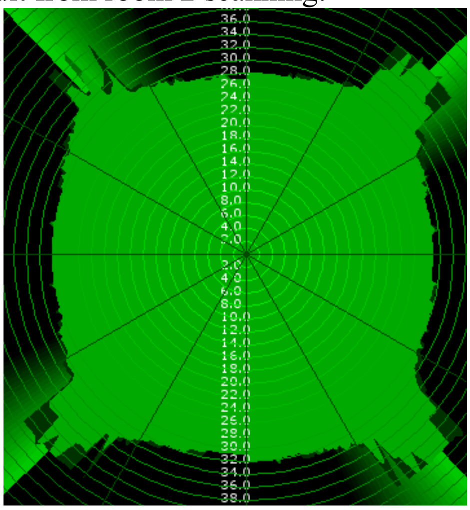

Figure 13. Image result from room 2

Result from room 3 scanning:

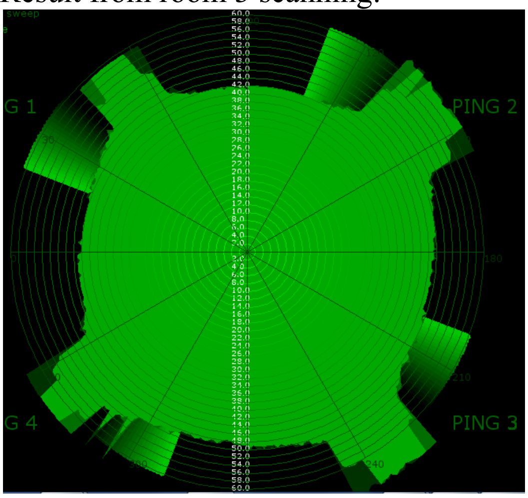

Figure 14. Image result from room 3

Result from room 4 scanning:

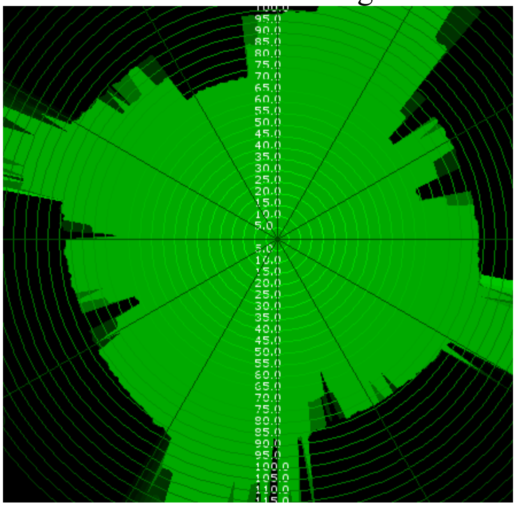

Figure 15. Image result from room 4

Although the room is square, the image in the radar screen is not perfectly square.

From the **Figure** 12, Noise does exist at each side of the room. It makes the sides of the room in the radar are not smooth. Error happens at the corner of the room because of the multi-tap at the each corner. Multi-tap means the signal is reflected more than once so that the distance measured is seems longer than the one in actual condition.

Image result from room 2 looks like from the room 3. The room in real situation is perfectly square, but the images show that the rooms seem semi-round.

At the image result from room 4, **Figure 15,** there are blind spots. The blind spots make the image seems not to be fully scanned. From this figure a conclusion can be made: wider or larger the room, more error occurs within the system.

V. Conclusion and Advice

The conclusions of this project are:

- This rotating ultrasonic ranging system is successfully designed and built, the system is capable in sensing topography of the environment within 360 degree radius.
- Maximum distance that can be measured by the sensors is 377 cm.
- Wider or larger the area to be scanned, the system takes more time to scan. Therefore, the system speed depends on the area to be scanned. Wider the area, slower the system.
- The average time needed to scan the whole room 1 is 3232,67ms, for room 2 is 3408,33ms, for room 3 is 3630,67ms and for room 4 is 4368,33ms;
- Error occurs while scanning corners of the rooms.

There are advices for the next step research:

- This system shall be built and integrated in the mobile robot, and mapping algorithm is needed to make a map maker robot;
- Wireless module can be implemented for the serial connection to make it more flexible to mobile, for example using Bluetooth or Zigbee;

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