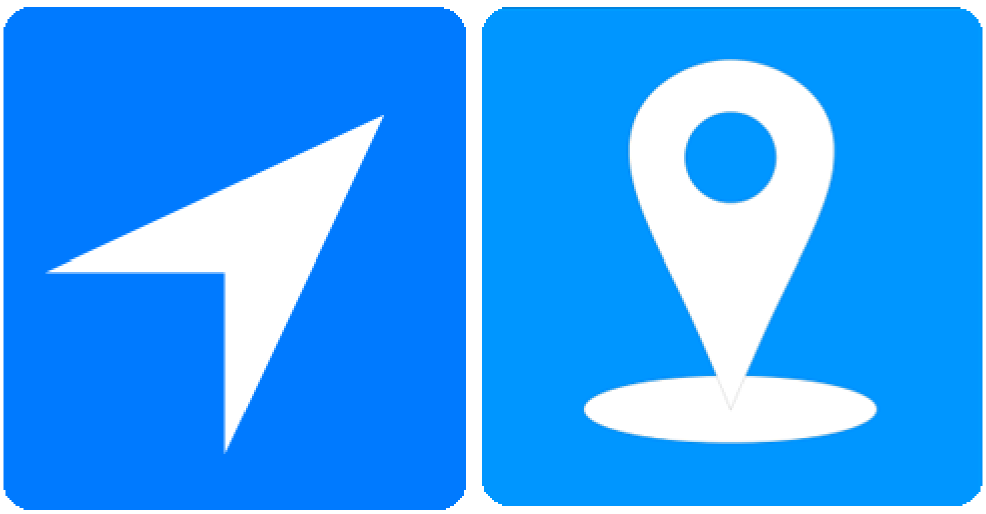
# Indoor Positioning System

II2302-SENSOR BASED SYSTEMS

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# Abstract

This project describes an indoor positioning system built using ultrasonic transducers. The system is based on estimating the distance by calculating the time it takes for the echoed signal (time-of-flight) reflected from an object to reach the transducer. It is designed to be able to locate the position of an object within a predetermined region.

The report discusses the initial project idea and the methodology used in building the system. The team was successfully able to implement and demonstrate a scalable prototype which is able to give an estimated position of an object inside a predetermined region.

This report also discusses the potential applications, limitations and further possibilities of developing such a system.

# Background

Indoor positioning systems have always been a challenge for engineers and designers. Due to the limitations of the Global Positioning System when it comes to indoor positioning there has to be other ways to apply the principle without depending on GPS.

Using beacons and sensors, of different kinds, is an ideal method used in indoor positioning systems. There are other approaches which consist of using ultrasound utilities, where an object can be localized indoor using ultrasound sensors and receivers or transceivers. By calculating time required for an echoing Ultrasound to reach back to the transceiver, distance can be measured.

Such indoor systems used to locate objects when the GPS can’t be used or a satellite signal is difficult to detect. Indoor positioning has a big market and the demand for it by the industry is increasingly high. The system can be applied into a prototype that is ready for marketing depending on the accuracy of the final system.

# Applications

Some of the most important applications are listed below:

- Security applications, where a sensor based system can be used for warning about any kind of intrusions as well as providing a precise location of the intruders.
- The concept of a “smart home” where saving energy is an added benefit. The system can locate humans in a room and switch off lights, fans, etc in the other parts of the room.
- Gaming and virtual reality, to track the gamer as he/she moves across the room.

# System description

The prototype is built around three ultrasonic transceivers (HC-SR04-based) and an Arduino® Mega 2560 board. The system calculates the location of the object inside a predetermined area based on the distance of the object from each of the three sensors.

The system was calibrated for a triangular area with sides of 1m each (equilateral). The sensors were placed at the vertices of the triangle. The Arduino® calculates the distances of the object from each of the three sensors and then determines the location of the object inside the triangle.

The major challenge here is synchronizing all three transceivers together and ensuring that they don’t interfere with each other while ensuring that the system has a fast enough response. Cables were used to connect the sensors together as a one functional prototype (in a larger area, it would make more sense to attach wireless links to the sensors)

# Hardware

## System block diagram

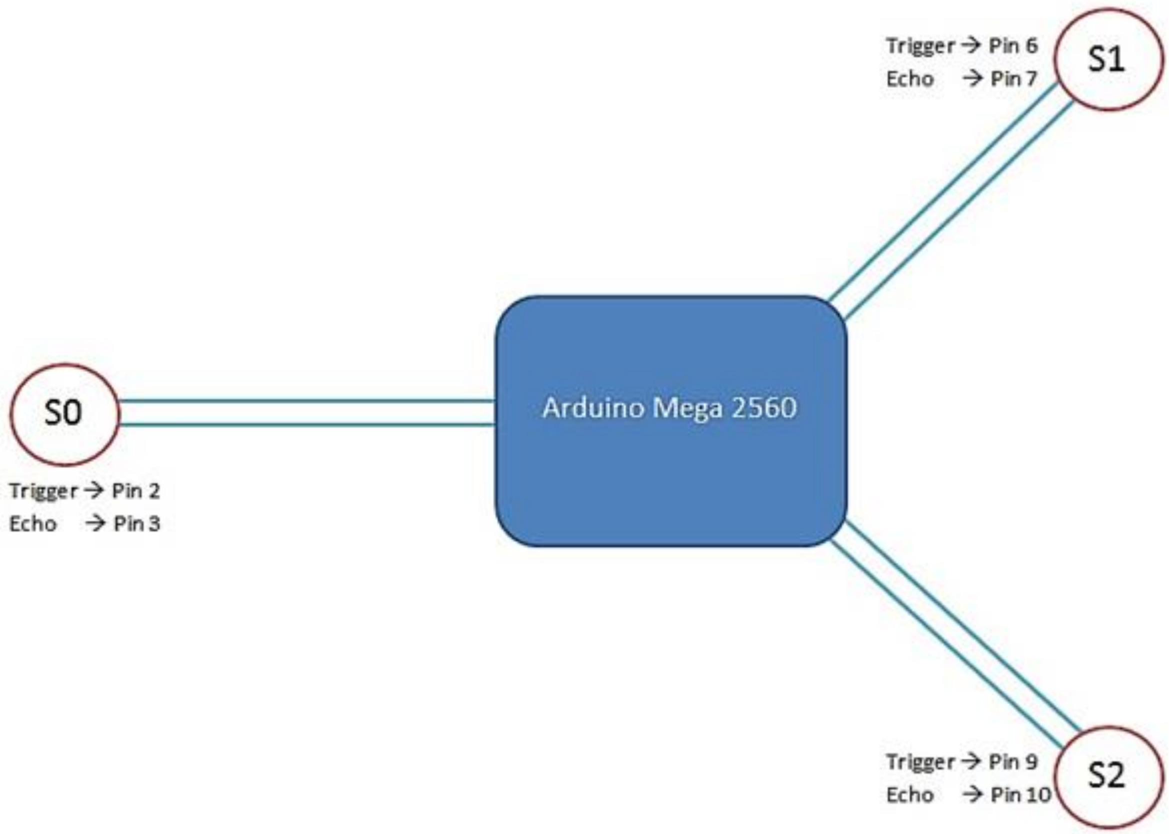



Fig: Block Diagram

HC-SR04-based ultrasonic transceivers were well-suited for this project:

- Easy to use with the Arduino®, it has 4 pins: The trigger, echo, VDD and GND.
- The HC-SR04 needs a short 10 us pulse to initiate the trigger sequence. It will then send out 8 cycles of 40 kHz pulses and raise the echo pin waiting for the signal to be reflected back after hitting an object. The duration for which the echo pin stays high is the time-of-flight of the echo signal. This is used to calculate the distance of the object from the sensor.
- It has a minimum measuring range of 2 cm and can go up to a maximum of 4 m

The formula used to calculate the distance of the object (provided in the datasheet) from the sensors is:

**(time-of-flight)/58** => Distance of the object from the sensor (centimeters)

As mentioned before, the sensors in the prototype were placed at the vertices of an equilateral triangle with 1 m sides. The typical field of view of the sensors is about 40$^{o}$ each (for a cylindrical object).

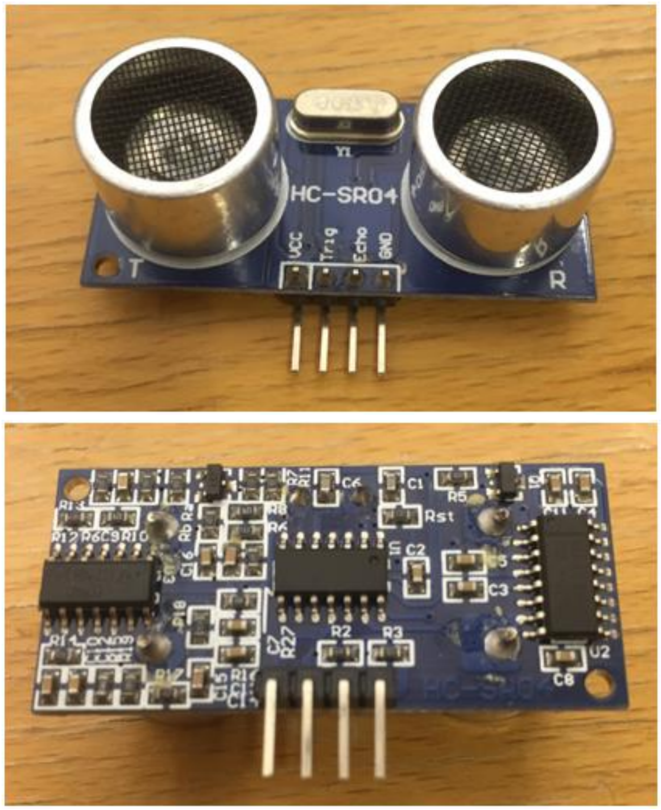



Fig: HCSR04 ultrasonic Transceiver

Some features about the Arduino® Mega 2560 used:

- 54 digital I/O pins => 15 can be used for PWM
- 16 analog inputs (10-bit resolution)
- 4 UARTS
- Runs on a 16MHz crystal
- 32x8 General purpose registers
- **<u>Two</u>** 8-bit timer/counter and **<u>four</u>** 16-bit timer/counter both with separate prescaler and compare/capture mode.

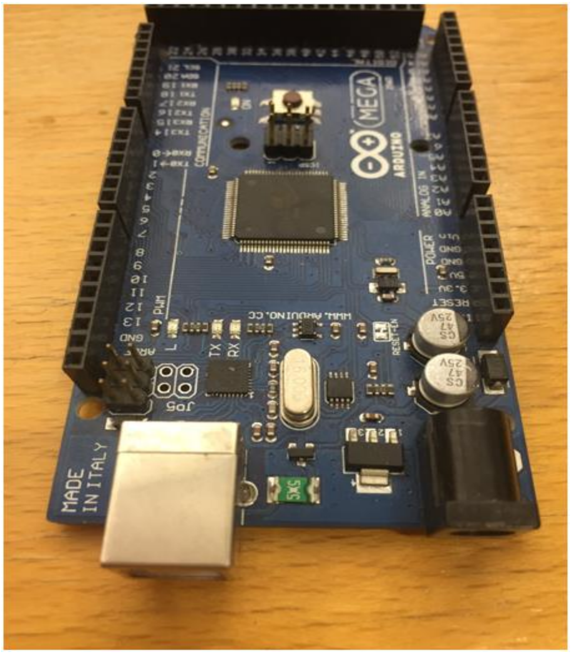


Fig: Arduino® Mega 2560

## Sensor Case

A small box was designed in order to keep the sensors stable on a surface for testing purposes, using Autodesk® Fusion 360 and 3D printed later on the MakerBot® 3D printer available at the lab. The box was printed in two pieces in PLA plastic.

Different design iterations were done to obtain a good outcome from the printing process but due to the short deadline the results can still be greatly improved.

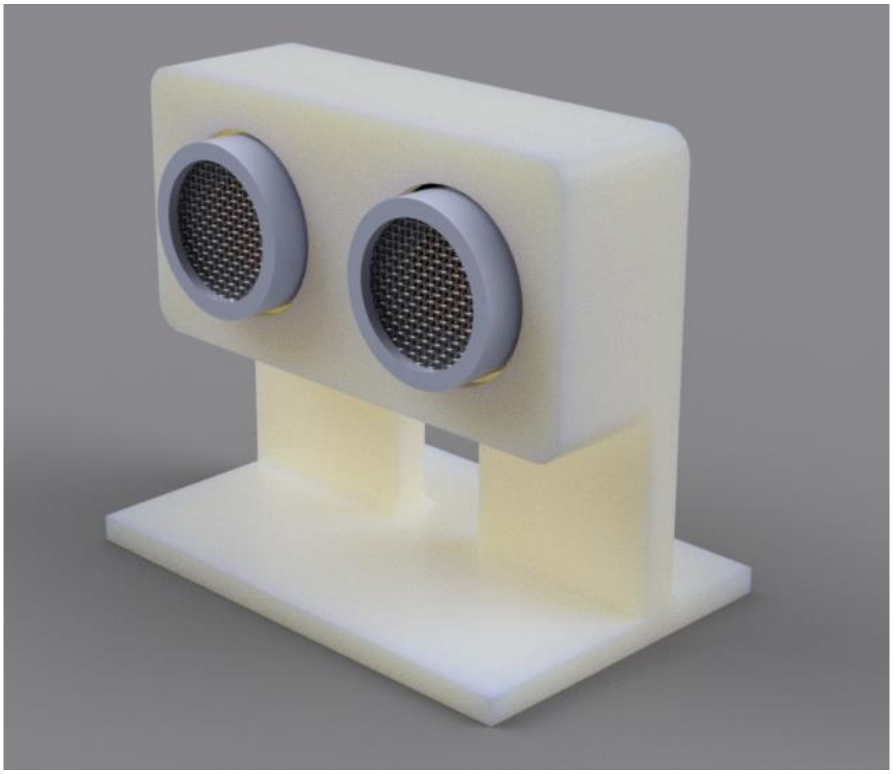


Fig: Rendered image of the sensor case

## Software

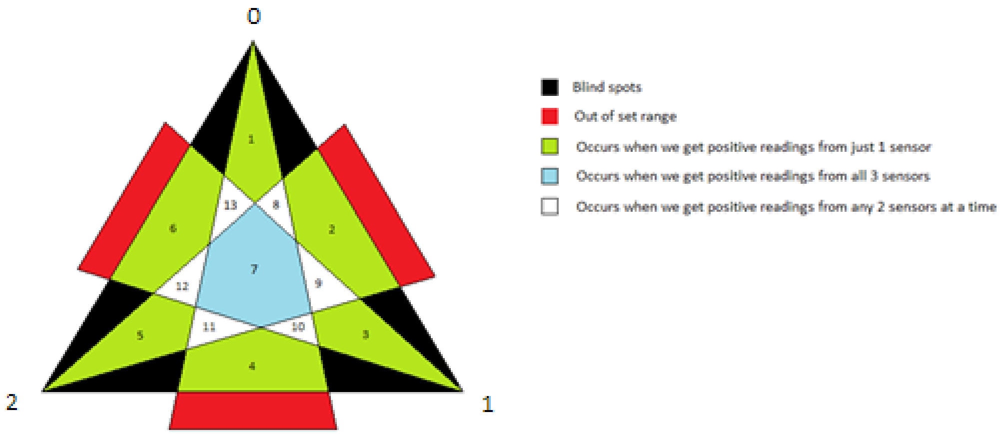



Fig: Field of View

Sensing range was limited to 87 cm since the sensors were placed at the vertices of the equilateral triangle of side 1m. The minimum and maximum thresholds for each region were derived by trial and error. The minimum threshold was used to define which sensor the object was closest to (regions 1, 3, 5), and the maximum threshold was used to find which sensor the object was far away from (regions 2, 4, 6).

Each sensor module is polled one by one sequentially and the distance of the object from each sensor is calculated. Based on that the system infers the location of the object in one of the regions. There is 300ms delay before the Arduino® polls the next sensor to prevent false readings caused by secondary echoes. Thus it takes 600ms (plus time needed to make the decision about the object's location) for one iteration of the program to be executed.

## Main Flow Chart:

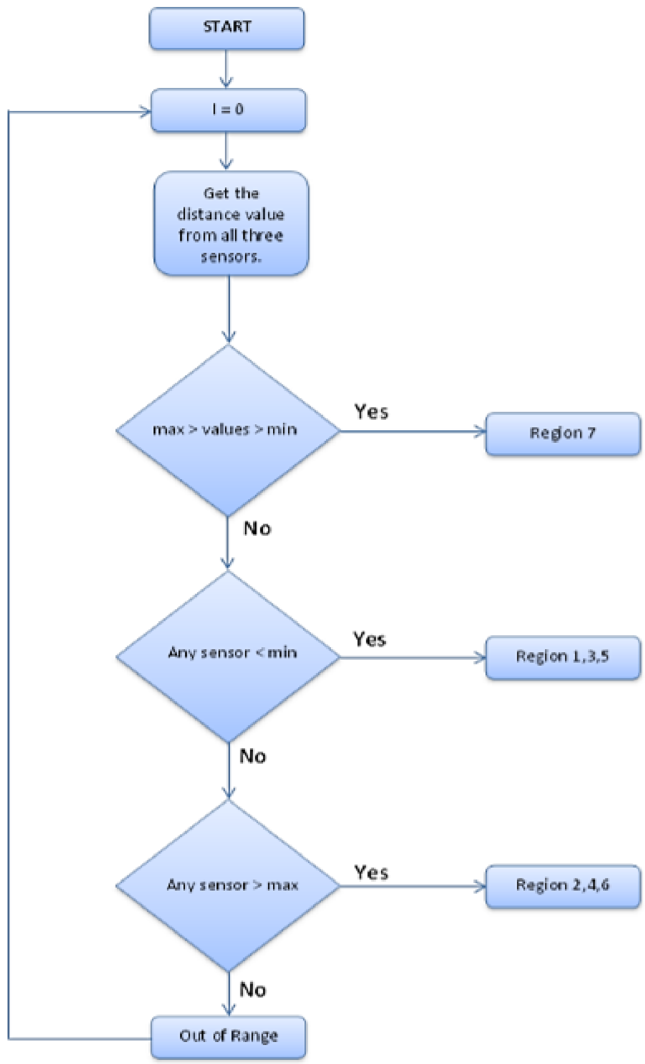



Fig: Flow chart of the program

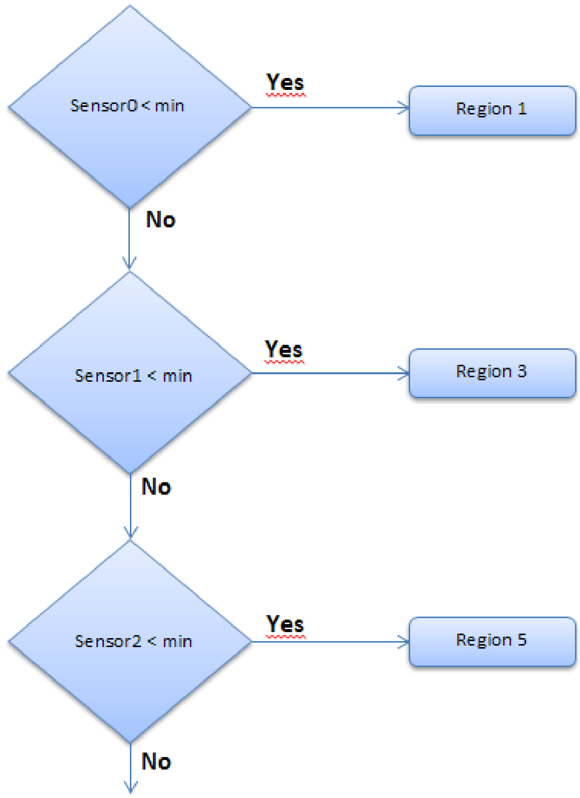



Fig. Part of the loop for region 1, 3, 5 (i.e. object is close to one of the sensors)

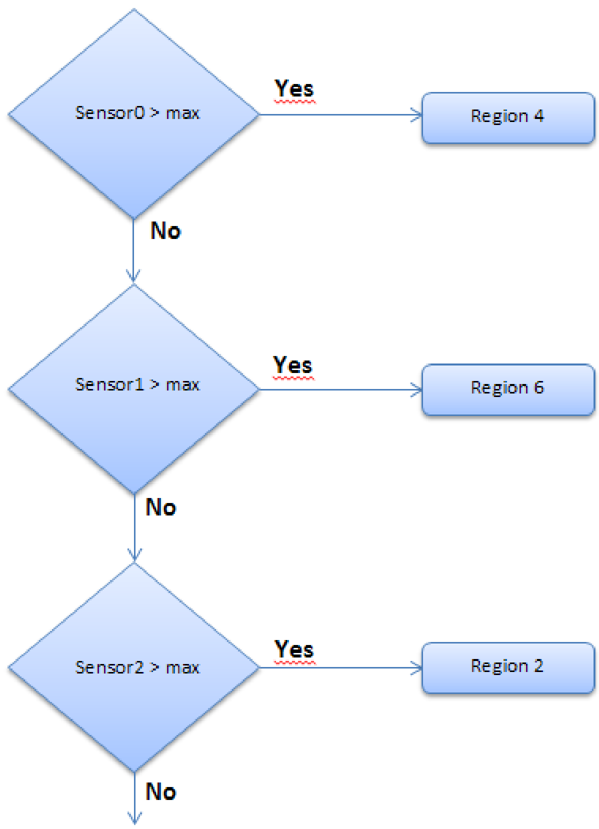



Fig: Part of the loop for regions 2, 4, 6 (i.e. at the far ends of the triangular area)

The 87cm limit which was set while calibrating the system is used to decide if the object is outside of the predetermined triangular area.

# Results

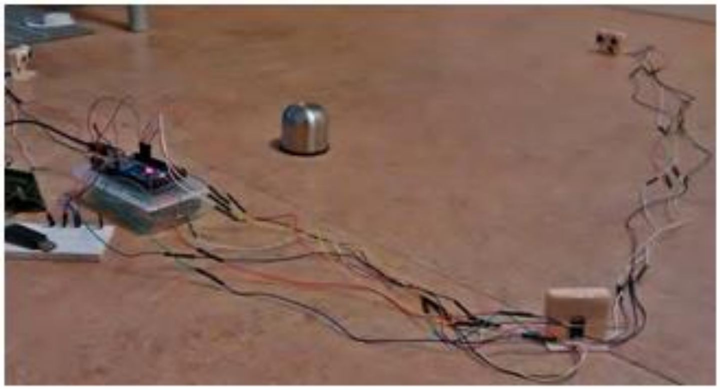


Fig: Implementation of the system

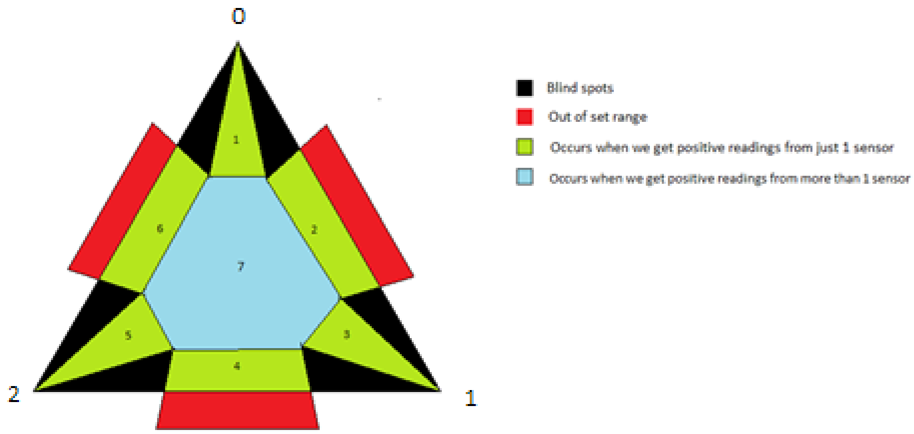
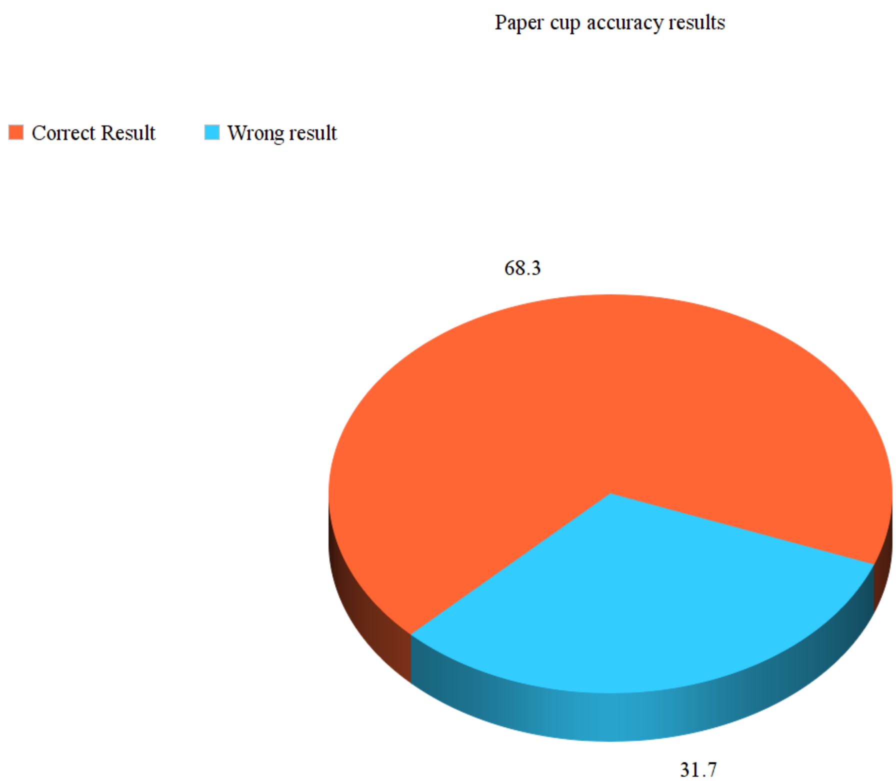



Fig: Achieved result

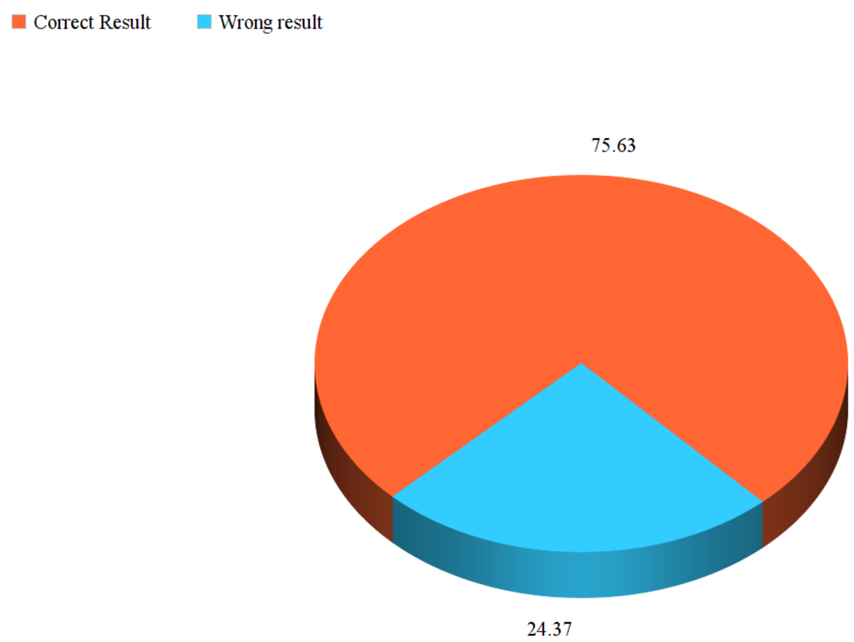
In the final prototype the resolution of the system was limited to 1 cm (HC-SR04 has 3mm resolution) for computational efficiency. The smaller sub-central regions were combined into one big central region (region #7). This was done because of the difficulty in characterizing these sub-regions due to their small area in the triangle.

**Objects under test:**

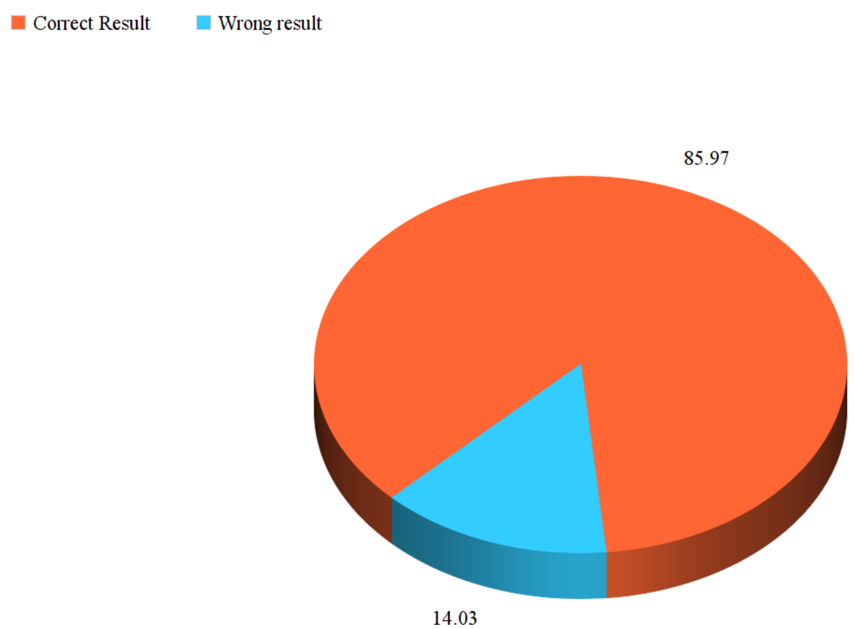
- a paper cup
- a plastic cube
- a human hand



Plastic cube accuracy results




Hand accuracy results



# Conclusion

**<u>Bill of materials:</u>**

- HC-SR04-based ultrasonic sensors x3: 180 SEK
- Arduino Mega 2560 x1: 499 SEK
- 3D printed casing for the sensors x3: NA
- Cables: NA

Power consumption was not a major concern as the system is not meant to be portable/mobile (in fact if it really mattered, an Arduino would never have been chosen as the "brains" of the system in the first place).

That said, the following limitations were observed:

- Effective field of vision varies depending on the object we tried to detect. Cylindrical objects reflect the best, and hence also tend to cause more false readings as they have the tendency to reflect signals from one sensor towards the other sensors. This is an inherent limitation of the transducers itself.
- Only one person/object can be guaranteed to be detect accurately inside the triangular area.
- Regions 2, 4, 6 (i.e. the far regions) had poor accuracy in general.
- Even with cylindrical objects, there are blind spots in the system. This maybe countered by using the sensors in pairs. So instead of $40^o$, we get $80^o$ field of vision effectively.

While such a design is a cheap alternative to camera-based systems, due to the fact that one person/object can be guaranteed to be detect accurately inside the triangular area, they might be best-suited for security purposes in places where human presence is absolutely prohibited; or for VR-based gaming.
It would be best to consider camera-based systems for home/office automation. In fact, even for security or VR-based gaming, a camera-based system would be a more robust and accurate alternative to its ultrasound-based counterpart any day (albeit at a higher cost).