

Indoor Positioning System using Ultrasound

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Abstract— An Indoor Positioning system (IPS) is a system used to locate objects or people within an indoor environment using various technologies. Various technology options for the design of an IPS may be ultrasonic(US), infrared (IR), radio-frequency (RF) based systems which may be radio-frequency identification (RFID), received signal strength (RSS) of RF signals, Bluetooth, wireless local area network (WLAN), ultra-wideband (UWB), camera based vision analysis etc. This paper presents the design of an indoor installable beacon system with the user interface being a hand-held positioning device. The beacon system involves a serial network of ultrasound transceivers within a fixed area of consideration referred by grid matrix. Using TDoA of ultrasound signals and Multilateration algorithms, the position of the object within the grid system can be obtained. This location information can be viewed by the user in a graphical LCD display setup on the handheld device.

Keywords--Indoor Positioning system, TDoA, Ultrasonic module HC-SR04, Multilateration

I. INTRODUCTION

An Indoor positioning system (IPS) is analogous to the Global positioning system (GPS) except that GPS is used for positioning at a global scale while IPS is used for a smaller indoor area to obtain higher precision positioning. We have been relying on applications like Google Maps, Apple Maps, Here maps by Nokia, etc., on a daily basis. Accepting the fact that these interfaces have been very useful to us, we must consider its extension into indoor environments, so that this location convenience is extended into buildings to provide a point to point guidance system. GPS cannot be used indoors due to high signal attenuation from structures. Thus, there is a requirement to design a point to point guidance system rather than a place to place guidance system as offered by GPS. IPS has been under extensive research from the past decade. It is tried to achieve with different technologies or a congregation of multiple technologies. Yet, there is no established standard for IPS [1].

II. BASIC STRUCTURE OF AN IPS

The basic structure of an indoor positioning system involves a network of Access points (APs), which acts as a reference, and transmission and reception of some kind of signals from these APs. Different characteristics of these

signals with respect to the reference area are used to detect the position. Indoor positioning system can be divided into three phases in deriving location information, as shown in figure 1.

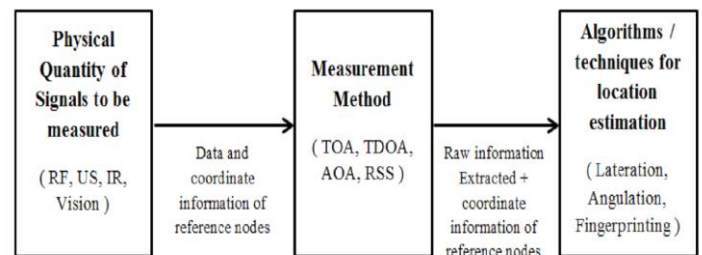


Fig1. Basic Structure of IPS

In the first phase in deriving location, sensing devices make use of any type of signals like US, RF, IR or Vision to measure the physical quantity for location. These signals travel between transmitters and receivers and also carry co-ordinate information of reference nodes determining the physical quantity of signals to be measured.

In the second phase, various methods are applied to calculate the physical quantity like measuring time of arrival (TOA), time different of arrival (TDOA), angle of arrival (AOA), received signal strength (RSS) etc. [2]. A brief explanation of some of these measurement methods, are as follows:

- **Time of Arrival (ToA):** This method of measurement is based on the fact that, the distance between sender and receiver of a signal can be determined using the measured signal propagation time and known signal velocity.
- **Time Distance of Arrival (TDoA) :** It is a measurement technique used in direction finding and navigation, in which the time of arrival of any signal, at physically separate receiving stations are calculated with properly synchronized time references. TDOA method calculates location from the differences of the arrival times measured on pairs of transmission paths between the target and fixed terminals.

- **Angle of Arrival (AoA):** This method of measurement depends on the direction of signal propagation and is typically achieved using an array of antennas or microphones. The angle between a signal and some reference forms the orientation of the measurement. The spatial separation of antennas or microphones leads to differences in arrival times, amplitudes, and phases, which are used to find the distances.
- **Received Signal Strength (RSS):** It is based on the fact that a signal decays with distance traversed. It is used by many devices which measure the signal strength with received signal strength indicator (RSSI) and uses this data to find the distances or location of a device based on the signal strength it has received from the transmitter. Basically it is expressed by Friis transmission equation and in practice, it is affected by factors such as attenuation multipath propagation effects, reflections, noise, etc.,

In the third phase, with the raw information of a physical quantity measured, various techniques and algorithms are used which transform raw data into usable position information. Techniques have been classified as triangulation, trilateration, multilateration and fingerprinting. To implement this algorithm for location estimation some processing unit is required.

Incorporating this basic information, the system of discussion in this paper uses

- Ultrasound signals as the physical quantity, which is generated through an ultrasound beacon system.
- TDoA (Time difference of arrival) as the measurement method.
- Multilateration (Multiple known points are used to locate an unknown point), as the algorithm for location estimation with the Arduino Uno as the functioning processor unit.

III. COMPONENTS INVOLVED

A. HC-SR04

Ultrasonic transceiver module HC - SR04 is used to emit and detect ultrasonic signals of 40KHz frequency for proximity and ranging applications [3]. It provides 2cm - 400cm non-contact measurement function range, with the ranging accuracy of 3mm. The module includes ultrasonic transmitters, receiver and control circuit.

In this system, HC-SR04 acts as the reference access point nodes, from which ultrasound signals are communicated, to detect object location.



Fig 2. HC-SR04 Ultrasonic transceiver module

B. Arduino Uno

The Arduino Uno is a microcontroller board based on the ATmega328 microcontroller. It has 14 digital input/output pins, with 6 used as PWM outputs, 6 analog pins, a 16 MHz crystal oscillator, a USB connection, an ICSP header, a power jack, and a reset button. It can be powered by simply connecting to a computer using USB cable, with an AC-to-DC adapter or battery.

In this system, the Arduino Uno acts as a computational and processing unit to employ multilateration algorithms to obtain object location.

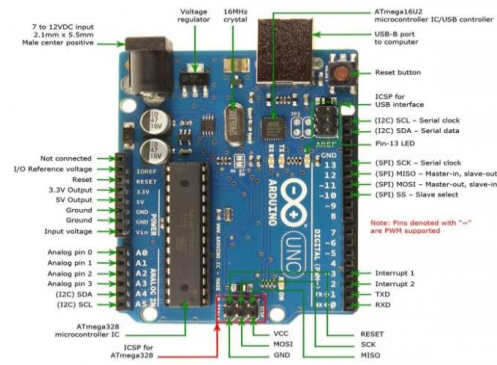


Fig 1. Arduino Uno

C. CC2500

The CC2500 is a low-cost 2.4 GHz transceiver designed for very low-power wireless applications. This module is used to transmit the data or information wirelessly from the beacon system to handheld device.



Fig 4. CC2500 RF Transceiver

D. SG-90

It is tiny and lightweight Servo motor with high output power. This servo can rotate approximately 180 degrees (90 in each direction), and works just like the standard kinds but smaller.

This motor is used for directional applications which will be discussed ahead.

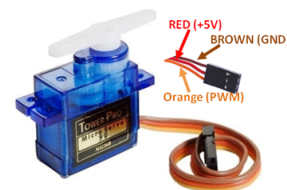


Fig 2: SG-90 Servo motor

E. Nextion Display

Nextion is a Human Machine Interface (HMI) display system that provides a control and visualization interface between the user and the process, machine, application or appliance. Nextion is mainly applied to IoT and consumer electronics field. It is the best solution to replace the traditional LCD and LED Nixie tube. The Nextion Editor software allows the users to create and design their own interfaces for Nextion display.

In this system, the Nextion display is used for the users to view the geometric location of objects within a grid system and this forms the major component of the handheld device.

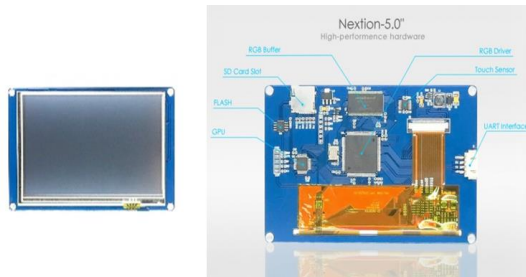


Fig 3. 5" LCD Nextion Display unit

F. Other

This system uses other supporting components such as a buzzer for proximity alarm application, barrel jack adapters to power the system, IC7805 voltage regulator (+5V) coupled with heat sinks, connecting wires and a plastic board as the chassis for supporting the components and defining the range of positioning.

IV. PROPOSED SYSTEM

A. Beacon System

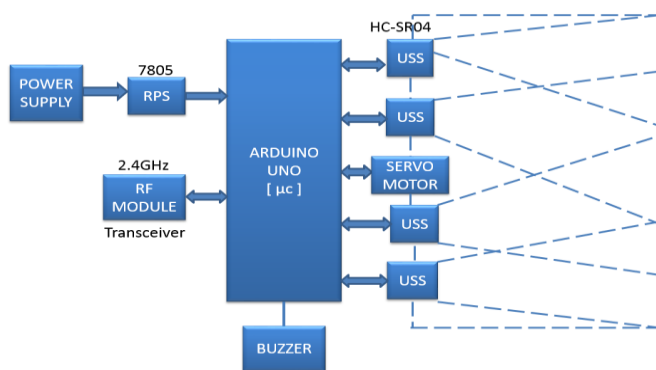


Fig 4: Beacon system block diagram

B. Handheld Device

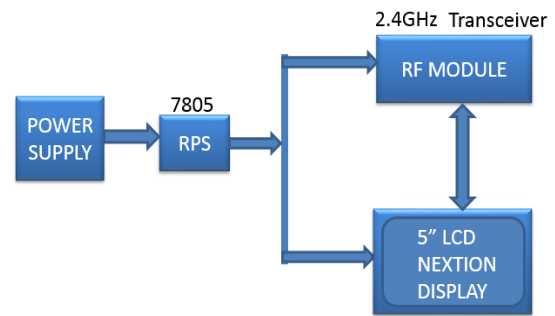


Fig 5. Handheld device block diagram

The above figures 7, 8, show the block diagram of indoor positioning system using ultrasonic modules. It is divided into two phases. First, is the beacon system and the other is handheld device.

The Beacon system, consists of power supply, regulated power supply, Arduino Uno, RF transceiver, ultrasonic modules, servo motor, and buzzer, while the Handheld system consists of regulated power supply, RF transceiver and Nextion display unit.

Firstly, we consider a pre-defined area for the positioning of the object, where we use a series of ultrasonic transceiver modules which are connected to the Arduino Uno. When we power up the beacon system, the ultrasonic modules emit sound waves and reads back reflections within the defined range. These measurements are sent to the Arduino where it is processed and location within the pre-defined area is obtained. A buzzer and a servo motor is also connected to the Arduino for serving applications. This Arduino is powered by an adapter through a 7805 voltage regulator.

A pair of RF Transceivers are used on both systems, for synchronization and wireless data transfer. Arduino transfers the position data to the handheld module through the RF transceivers where the data is displayed in as a location within a grid system [4] on the LCD Nextion display screen. This handheld system is also powered by an adapter through a 7805 voltage regulator.

V. PROGRAM FLOW

Before proceeding to the program flow, the main design goals of the system are defined as

- Location determination within the grid system.
- Proximity determination towards the beacons.
- Directing mechanism of servo motor.

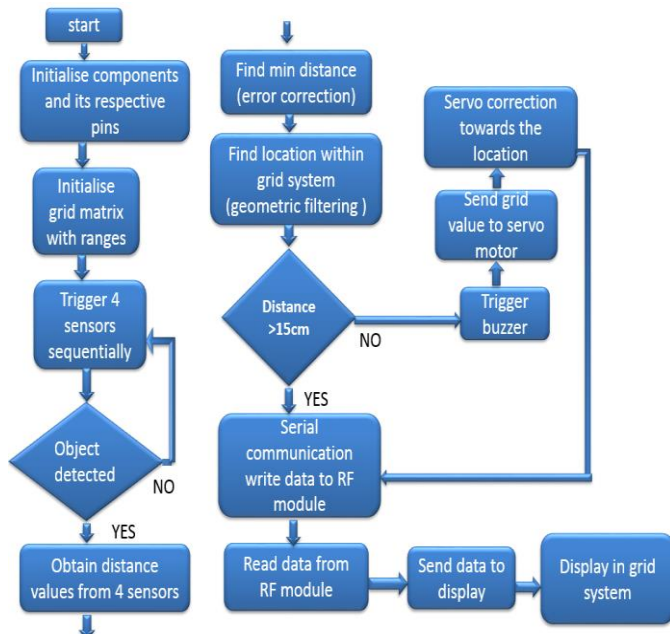


Fig 6: Programming Flowchart

A. Algorithm:

- Initialize all components with its respective pins.
- Initialize grid matrix, i.e. define the area considered. Here, it is a 2'x2' area divided into 12 rows and 10 columns of grids.
- Trigger the 4 ultrasonic transceivers one after the other with a short delay between each other's reception.
- If no reflection received for the set range, it indicates absence of any object and the control goes back to previous step.
- If reflection is received, the values of echo signal from all 4 modules are used to calculate 4 distances.
- Multilateration and minimum distance are used to compute the numerical values of distance of the object with respect to the reference modules.
- These numerical values are compared with the reference grid system and the grid location of the detected object is found using geometrical methods.
- If the derived grid location is within a predefined proximity range, i.e. here the range within 15cm from the sensor modules, then the buzzer is triggered.
- This grid information is sent to the servo motor as feedback, to correct its direction towards the grid located within the proximity range.
- If the derived grid location is not within the proximity range, or has completed the buzzer triggering and servo directing functions, the location data is written serially into RF transceiver at the beacon system.
- This data is transferred wirelessly to the RF transceiver on the Handheld device.

- On reception of data, RF module passes it to the LCD display where it is displayed within a grid system.
- These steps are continuously repeated to provide real-time locating feature.

VI. RESULTS AND OBSERVATIONS

On implementation of the hardware and software designs, we obtain the following results with respect to our design goals as mentioned in the previous section.

A. Location determination within the grid system

Our area of consideration is 2x2ft where we define a 12x10 grid system. On implementation, 3 grid accurate readings are achieved i.e. the original grid location along with a +1,-1 grid.

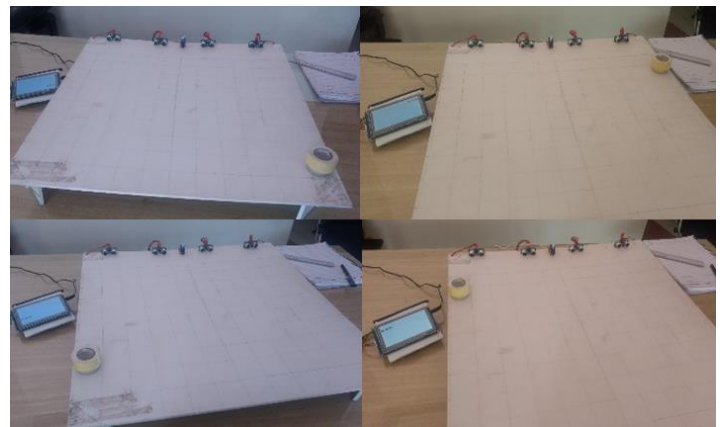


Fig 7. Object being detected and located when placed in four random positions.

B. Proximity determination towards beacons for security applications

If object is within 15cm from the reference node, buzzer is triggered.

C. Directing mechanism for various applications

If an object is detected within a specified range (15cm), the servo motor directs towards the location of the detected object.

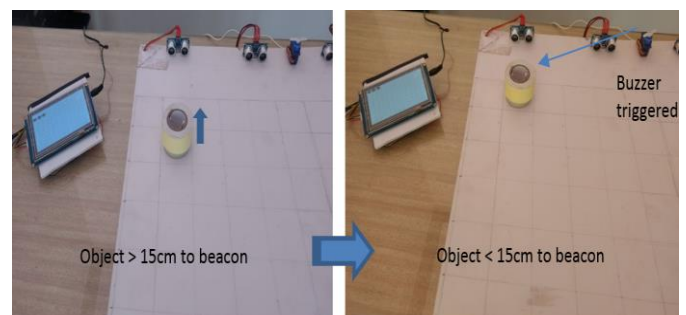


Fig 8: Proximity mechanism activates buzzer and corrects servo arm direction

VII. TESTING AND VERIFICATION

A. Operations Testing

A10	B10	C10	D10	E10	F10	G10	H10	I10	J10	K10	L10
A9	B9	C9	D9	E9	F9	G9	H9	I9	J9	K9	L9
A8	B8	C8	D8	E8	F8	G8	H8	I8	J8	K8	L8
A7	B7	C7	D7	E7	F7	G7	H7	I7	J7	K7	L7
A6	B6	C6	D6	E6	F6	G6	H6	I6	J6	K6	L6
A5	B5	C5	D5	E5	F5	G5	H5	I5	J5	K5	L5
A4	B4	C4	D4	E4	F4	G4	H4	I4	J4	K4	L4
A3	B3	C3	D3	E3	F3	G3	H3	I3	J3	K3	L3
A2	B2	C2	D2	E2	F2	G2	H2	I2	J2	K2	L2
A1	B1	C1	D1	E1	F1	G1	H1	I1	J1	K1	L1



Fig 9: Grid matrix divisions of considered area

B. Considerations: (As seen in figure 12)

- An area of 2feetx2feet, approx. 60cm in length and breadth, is divided into a grid matrix of 12 rows labelled **A** to **L** and 10 columns labeled **1** to **10**, with each grid having dimensions 5cmx5cm.
- HC-SR04 modules are located 10cm in front of grids B1, E1, H1 and K1.
- Servo motor located exactly in the middle of the starting row, i.e. F1 and G1.
- Proximity breach range set to 15cm from beacons, i.e. within first grid row from beacon position.
- Object dimensions considered for testing has dimensions 4.5cmx4.5cm with 5cm height.

TABLE I. TEST FOR LOCATION DETERMINATION WITHIN GRID SYSTEM

Trial Number	Grid number on area considered	Grid number on display	Time taken to display (in seconds)
1	No object	No display	-
2	A10	ABC-10	3
3	L10	JKL-10	4
4	D6	CDE-6	4
5	D5&E5	DEF-5	5
6	H7&I7	HIJ-7	4
7	C1&D1	No display	-
8	F5&G5	DEFGHI-5	7
9	B1	ABC-1	4
10	I1	GHI-1	5

C. Results: (As seen from table 1)

- Trail number 1 indicates no detection of objected and no display, showing that there is no object within the predefined range.
- Trial numbers 2,3,4 indicate normal operation of setup with a 3 grid precision and with display times as show.
- Trial numbers 5,6 shows objected being placed between 2 grids and is displayed normally with the 3 grid accuracy
- Trial number 7 shows the cases where object is very close between 2 sensors such that the emitted beam angle of 30deg from hcsr04 doesn't cover the range of object. Thus, in this trail the object is not detected.
- Trial number 8 shows a rare case where the object in placed exactly in the center of the setup such that it is equidistant from 2 sensors. Since, the positioning algorithm is based on minimum distance, the grids of both sensor values are displayed, giving a 6 grid accuracy.
- Trial numbers 9,10 shows the proximity breach cases where the object is displayed along with which the buzzer is triggered and servo motor is corrected to direct towards the object position.

D. Handheld device testing Considerations:

The purpose of designing a separate handheld device for displaying the location is to provide a monitoring interface to the user and allow remote viewing, i.e. the user can view the results of positioning and detection, at a distance from the actual beacon system setup.

For this purpose, we use a pair of CC2500 RF transceiver modules to communicate the location data wirelessly between the beacon system and the handheld device. According to the datasheet, CC2500 has a 20m indoor range and a 40m LOS range. This is tested and verified in this section along with observed results.

All measurements are made indoors i.e. within walls and structures, as this is the ideal indoor environment.

TABLE II. TEST FOR HANDHELD DEVICE OPERATION

Trial number	Distance between Beacon system and handheld device (in feet)	Time taken to display result (in seconds)
1	2	2
2	8	4
3	10	8
4	14	10
5	20	18
6	30	24
7	40	32
8	50	44
9	55	46
10	60	49

E. Results:(As seen from table 2)

- As distance increases, the time taken to refresh and display increases.
- As the building structure thickens due to beams or roofs, the delay is increased.
- Noise is encountered due to other devices operating at the same frequency (2.4GHz), such as Wi-Fi routers, Smart television etc.,
- Best and fastest results are obtained when the handheld device is in line of sight with the beacon system, irrespective of the distance between them.

F. Constraints

1) Precision of 3 grids for reducing error rate:

If precision is set to single precision on the grid, then due to frequent variations in the sound signals we may obtain erroneous results. To avoid this and to get a more accurate reading we consider a three grid precision. Also, if the position of the object is between two grids as shown in figure 13, then single grid display will not be suitable.

Hence to reduce the error rate of the results and to have a more accurate reading we consider 3 grid precision having +1,-1 grid with the actual location.

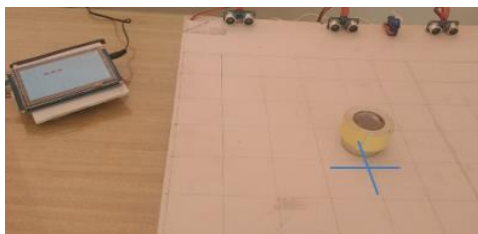


Fig 10: Condition of object present between two grids

2) Detection failure at a close distance between 2 sensors due to 30° beam angle restriction:

The HCSR04 sensor that is used has a 30° beam angle, so if any object is placed in between two sensors at a close distance as shown in figure 14, then the beam cannot reflect back and hence the object will not be detected in such a case.

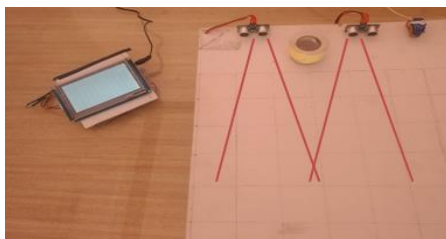


Fig 11: Condition of object being undetected

3) If same distance from 2 sensors, both values appear:

As explained earlier, the system is designed in such a way that it considers the minimum distance to the sensors that is reference location, so if we consider a case where the object is exactly equidistant from two sensors then both values are

considered to show two grid location output, i.e. 6 point on the LCD screen, this is a rare case.



Fig 12: Condition of object placed equidistant from sensors

VIII. APPLICATIONS

- *Geometric Positioning with Graphical location display:* A handheld device that shows the position in real time can assist a person to track and locate a particular asset. In simple geometric terms, if we know the predefined coordinates of the destination and recognize our coordinates, a navigational path can be established between them.
- *Used in Security systems* to detect even the slightest movement in a specific area, hence used for Entry protection, valuable asset protection, proximity alarm, etc.,
- *Object detection and counting:* By integrating this system to a counter such that it increments every time an object is detected, a counting system can be designed. This can be applicable in numerous industrial applications to reduce time consumption and human effort.
- *Directional surveillance:* The Servo motor when integrated with a camera provides image or video if obstacle detected, Gun or missile provides unmanned weapon system. Directional router provides max signal strength towards the direction of population.
- *Robot orientation and guidance system:* Autonomous systems such as robots can be guided to follow a certain path or deviate from obstacles, using ultrasound modules and ranging.

IX. CONCLUSION

An indoor positioning and navigation system can make any organization more efficient, productive, and effective. Almost in every industry, one can find applications for indoor positioning system, since it makes the basis for indoor positioning, people (personal) tracking, asset tracking, etc., Due to its importance and increasing popularity from the last decade, there is a need to research and experiment on this field. The system discussed in this paper gives a simple, low cost and efficient possibility of achieving indoor positioning. It has limitless applications like real time tracking, visitor guidance, commercial applications, workplace safety and security, asset security, surveillance etc.

X. FUTURE WORK

This project represents a simple demonstration of a vastly growing positioning technology known as the Indoor positioning system. It is designed to obtain location information and provide security applications. This system is able to recognize the closest object to the ultrasonic nodes and provide its position using minimum distance values from the reference. An improvement that can be made in the existing system, is to be able to position multiple targets within the reference area. This system does not differentiate targets. So, an upgraded system must be able to recognize the type of object present based on the obtained ultrasonic reflections. If we replace the ultrasonic modules any other technologies which are having advanced, complex, long range and expensive nodes, we can achieve a wider range of effective applications.

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