INDOOR OBJECT TRACKING USING ULTRA WIDEBAND LOCALIZATION

A PROJECT REPORT

Submitted by

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(Under Section 3 of UGC Act, 1956)

BONAFIDE CERTIFICATE

Certified that this project report titled "**INDOOR OBJECT TRACKING USING ULTRA WIDEBAND LOCALIZATION**" is the bonafide work of " **KAVAN V PURANIK [RA1611004010145], MIHIR AMOL NIGAM [RA1611004010281], PRANAV SRINIVAS M [RA1611004010544], DINDI BALAJI [RA1611004010621]**", who carried out the project work under my supervision. Certified further, that to the best of my knowledge the work reported herein does not form any other project report or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

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ValueLabs

March 18, 2020

TO WHOMSOEVER IT MAY CONCERN

This is to certify that Mr. Mihir Amol Nigam has completed his Internship in our company from January 06, 2020 till March 18, 2020.

He has done his Internship in Software Development.

Project Title – Web App for Employee management.

Mihir is a quick learner and an enthusiastic team member. We wish him all the best in his future endeavors.

Yours faithfully,

for **ValueLabs Solutions LLP**

Anusha Mandavilli
SVP – Human Resources

MathWorks

INDIA

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THE PARTIES

Name and address of employer (the **Company**)	:	MathWorks India Private Limited 9th Floor, 'B Wing', Etamin Block Prestige Technology Park II, Marathahalli - Sarjapur Outer Ring Road, Bangalore – 560103
Name and address of employee (referred to in this contract as **you**)	:	Pranav Srinivas Murali No.523, Roja Street, VGP Layout, Uthandi, Chennai, Tamilnadu. Pin:600119

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Your employment with the Company will commence on 6th January, 2020 and that is the effective date of this contract. Your contract will end on 29th May, 2020 without the need for further notice. The reason for the fixed term nature of your employment is that you are working on an internship.

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You must devote your full time, attention and abilities to your job duties during working hours, and to act in the best interests of the Company at all times. You must not, without the Company's written consent, be in any way directly or indirectly engaged or concerned in any other business, or prepare to be engaged or concerned in any other

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ABSTRACT

This system proposes a method to track objects with a precision of 30cm in an indoor environment. Ultra-wideband (UWB) is a radio technology lying between the frequency spectrum of 3.1 to 10.6 GHz. UWB pulses carry low energy,short-range and occupy a high-bandwidth of more than 500MHz of the RF spectrum. UWB communication can measure range instantaneously as messages are transmitted. Hence it can be used for indoor positioning application too. Our system is constructed by using independent devices called ‘anchors’ and ‘tags’. Time of Arrival signal between anchors and tag is used to compute position using the concept of multi-lateration.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my guide, Dr.R. Kumar for his valuable guidance, consistent encouragement, personal caring, timely help and providing me with an excellent atmosphere for doing research. All through the work, in spite of his busy schedule, he has extended cheerful and cordial support to me for completing this research work.

Author

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ABBREVIATIONS

AVR	Alf-Egil Bogen Vegard Wollan Reduced Instruction Set Computer
GHz	Giga Hertz
GPS	Global Positioning System
GPIO	General Purpose Input/Output
I2C	Inter Integrated Circuit
IMU	Inertial Measurement Unit
IPS	Indoor Positioning System
ISP	In System Programmer
IRQ	Interrupt Request
LDO	Low Dropout
LED	Light Emitting Diode
Li-Po	Lithium Polymer
MHz	Mega Hertz
PCB	Printed Circuit Board
RADAR	Radio Detection and Ranging
RFID	Radio Frequency Identification
RSSI	Received Signal Strength Indication
RX	Receiver
SONAR	Sound Detection and Ranging
SPI	Serial Peripheral Interface
TDOA	Time Difference of Arrival
TOA	Time of Arrival
TTL	Transistor Transistor Logic

TX	Transmitter
UART	Universal Asynchronous Receiver/Transmitter
USB	Universal Serial Bus
UWB	Ultra Wideband
Wi-Fi	Wireless Fidelity

LIST OF SYMBOLS

d	Distance for the Origin, m
t	Time of Arrival, s
v	Velocity of Radio Wave, m/s
x_0	X Coordinate of Origin, m
y_0	Y Coordinate of Origin, m
x_1	X Coordinate of Master Anchor, m
y_1	Y Coordinate of Master Anchor, m
x_2	X Coordinate of Anchor1, m
y_2	Y Coordinate of Anchor1, m
x_3	X Coordinate of Anchor2, m
y_3	Y Coordinate of Anchor2, m
x_t	X Coordinate of Tag, m
y_t	Y Coordinate of Tag, m

CHAPTER 1

INTRODUCTION

The Global Positioning System (GPS) is the biggest technology used for localization. However, for precise indoor tracking the accuracy of 5m provided by GPS is insufficient and hence alternate technologies are required. Currently, several technologies for Indoor Positioning System (IPS) exist. They are useful in real time cases to locate people and things in hospitals, warehouses and sports. The field of robotics also requires precise tracking for feedback, and to make decisions regarding path planning and navigation. Measurements of acoustic, optical or radio signals are used to determine the position. However, each system varies in cost, accuracy and update frequency.

Broadly, any system can be classified as non-radio and radio technologies. Magnetic, inertial (using Inertial Measurement Unit (IMU)) and computer vision localization are non-radio technologies while Wireless Fidelity (Wi-Fi) and Bluetooth are two radio systems used for precise tracking. However, these radio technologies rely on the Received Signal Strength Indication (RSSI) which can easily be affected by the presence of obstacles and other radio devices.

Ultra Wideband (UWB) uses a short range, low energy and large bandwidth signal for communication. The frequency spectrum of UWB is 3.1 to 10.6 Giga Hertz (GHz). A dielectric chip antenna which is linearly polarized in the Azimuth plane is used. The pulse used for communication has a duration of less than 1ns. Hence the data rate of communication is very high. The bandwidth used for the communication is over 500 Mega Hertz (MHz) and the received signal can be determined correctly even when it is subject to noise and reflections over a particular frequency. The path loss and multi path fading is also very low. All these factors give UWB an advantage over the other technologies. Using UWB it is possible to track objects with a precision in the centimeter range. Hence we propose a system which can track objects in an indoor environment of maximum size 5x5m with an accuracy at least 30cm.

CHAPTER 2

LITERATURE SURVEY

2.1 Time Difference of Arrival based Localization System

Tiemann J (2016)[5] proposed and validated wireless clock synchronization based method for a multi-agent Time Difference of Arrival (TDOA) based positioning system. The accuracy of the system was analyzed by an experiment, using the robot's motion and a feedback optical measurement system. The accuracy of the results proved that the accuracies achievable by wireless clock synchronization based TDOA positioning is at par to other approaches based on two-way ranging.

2.2 Self Localization Systems

Anton Ledergerber (2015)[2] proved that transmission from UWB modules using one-way ranging, can help scaling the system. Multiple robots can be tracked with ease. Furthermore, the real time positioning of the can provide feedback and enable quick maneuver of the robot. The publication also described the pain points of the system's algorithm, discussed decisions regarding the design and the quality of the position so obtained and justified real world constraints. Data from a motion capture sensor and the positioning system built were compared to provide the difference.

2.3 Improved Range Measurement

The ultra-wideband range measurement model presented by Anton Ledergerber (2017)[1] to predict the noise and error which depended on the pose. It utilized a sparse pseudo input Gaussian method. The authors established that the method can improve the accuracy of localization. It is very reliable if the antenna is covered or blocked by an obstacle.

It was proved that the achieved improvement by such a measurement model strongly depends on the antenna position, the choice of covariance function, the number of pseudo-input points, the training data and the optimization routine used.

2.4 Applications of UWB Localization

Factory and commercial systems are required to track independent objects with a high accuracy. In order to achieve this, it is proved that the use of passive ultra-wideband (UWB) Radio Frequency Identification (RFID) was suggested. It proved to be better than the current RFID. Davide Dardari (2016)[3] provided a sample on emerging development regarding UWB-RFID addressing main advantages and problems in providing accurate positioning accuracy of autonomous energy devices.

Richa Bharadwaj (2014)[4] presented a motion capture application using UWB technology. Overall accuracy of maximum 2cm was achieved using eight base stations. It was compared to the accuracy of light based motion capture system.

3.4 Objectives of the Study

To design and build a system for indoor object tracking with a precision of 30cm using Ultra Wide Band Communication technology is the main objective of our study. The system should have the characteristics such as Good Reliability, Low Latency, Immunity to Noise and Immunity to Reflections.

3.5 Formulation of Hypothesis

The hypothesis behind this project is that the characteristics of Ultra Wideband Communication such as less fading and penetration through objects can produce precise Time of Arrival. This information can be used for trilateration to produce the exact location in an local coordinate system.

3.6 Type of Project Work

The project work consists of building the hardware and software required for building the system. The hardware interfaces widely available electronic components with the UWB Module and the software is designed to perform trilateration. Hence, the project involves designing an embedded system focusing on hardware-software integration.

3.7 Sampling Design

Sampling Technique: The sampling technique used in our project is systematic sampling. The Time of Arrival is determined for each anchor in sequence. Distance from each anchor is calculated using the data and the distances are used for trilateration.
Sampling Unit: Samples are taken at each location of the object within the room.
Sampling Size: The sample size used in this study consists of 10 indoor locations.
Sampling Area: The area of sampling is the entire indoor environment, where data is collected symmetrically to understand the performance.

3.8 Method of Data Collection

Pilot Study: An Ultra Wideband signal is transmitted through the environment. The signals are reflected back by the anchors to the transmitter. The total time taken for this process is called the Time of Arrival.
Primary Data: The primary data is the Time of Arrival (TOA).

3.9 Limitation of the study

Since the range of each anchor is only 10 meters, a large number of modules will be required for larger areas. As the complexity of the algorithm increases, more powerful microcontrollers are required. The batteries of the modules get discharged quickly due to high power consumption of the UWB module.

Hence the study is limited to an indoor environment of size 5x5m.

CHAPTER 4

SYSTEM DESIGN

4.1 Theoretical Analysis

4.1.1 Determining distance between a wireless TX/RX pair

There are two methods to find the distance using a TX/RX pair:

1. **One Way Ranging** - In this technique, a known preset signal is transmitted over the medium by a Transmitter (TX). The Receiver (RX) reflects the signal back to the transmitter. Based on the total time for the signal to be received from the time of transmission, known as TOA the distance can be calculated using the formula:

   $$d(inm.) = \frac{v * t}{2} \tag{4.1}$$

   where, d = distance between transmitter and receiver in meters
   v = speed of radio wave in m/s
   t = total time taken by the signal to be received by transmitter

   The speed of propagation of the radio wave is known, thus the distance covered by the wave will be the time traversed by the wave multiplied by the speed. Since, the wave travels the same distance twice before reaching the transmitter, the time taken to reach the receiver will be half. This is the principle behind technologies like the Radio Detection and Ranging (RADAR) and Sound Detection and Ranging (SONAR).

2. **Two Way Ranging** – In two way ranging, the standard signal is transmitted only once. The transmitter and receiver are synchronized by a common clock. Hence, the time at transmission is known to the receiver and it determines the time at which the signal is received to calculate the distance using the formula:

   $$d(inm.) = v * (t_r - t_t) \tag{4.2}$$

   where, d = distance between transmitter and receiver in meters
   v = speed of radio wave in m/s
   t_t = time at start of transmission of the signal
   t_r = time at reception of transmitted signal

   As seen above, the time taken to estimate the distance is only half that of one way ranging. However, this method is complex because the clocks of both the transmitter and receiver have to be precisely synchronized to calculate the distance accurately.

4.1.2 Determining the position of object using wireless antennas

The concept of multilateration is used to determine the position of the object wirelessly. It is a technique which computes the position according to the Time of Arrival (TOA) of energy waves having a known propagation speed. In our case, radio waves are used for localization.

Assume that the object being tracked is located at x,y in the cartesian frame of reference. The distance formula for cartesian coordinates is given by:

$$d^2 = (x_1 - x_0)^2 + (y_1 - y_0)^2 \tag{4.3}$$

Suppose the coordinates (x_0, y_0) are unknown, we can guess them by finding out the distance with respect to a fixed reference given by (x_1, y_1) within the coordinate system. By substitution the known terms, Eq 4.2 can be simplified but we will still be left with unknown x_0 and y_0. Hence, we require more samples to determine the position. So, this is where the concept of multilateration comes into picture.

The simplest form of multilateration is the trilateration which estimates the position using the Time of Arrival (TOA) of three signals. Using the TOA information from different antenna placed at known positions, we can calculate the distances to each antenna individually using one of the ranging techniques described in the above section. We will now have three equations for determining the unknown coordinates which is mathematically solvable.

For an object located at (x_0, y_0) and three antenna at known coordinates (x_1, y_1), (x_2, y_2) and (x_3, y_3). The equations for trilateration will become:

$$d_1^2 = (x_1 - x_0)^2 + (y_1 - y_0)^2 \tag{4.4}$$

$$d_2^2 = (x_2 - x_0)^2 + (y_2 - y_0)^2 \tag{4.5}$$

$$d_3^2 = (x_3 - x_0)^2 + (y_3 - y_0)^2 \tag{4.6}$$

The equations 4.4, 4.5 and 4.6 can be solved to determine (x_0, y_0) as all the other terms are constants.

The example below is given to demonstrate mathematically the working of the system:

Let's place the object at (3,4).

The three antennas are placed at (0,0), (3,0) and (0,4) in meters respectively. The transceiver placed on the object determines the distances from respective antenna as 5, 3 and 4 meters. Upon substituting the eq 4.4, 4.5 and 4.6 become:

$$5^2 = (0 - x_0)^2 + (0 - y_0)^2 \tag{4.7}$$

$$3^2 = (3 - x_0)^2 + (0 - y_0)^2 \tag{4.8}$$

$$4^2 = (0 - x_0)^2 + (4 - y_0)^2 \tag{4.9}$$

Hence, by solving the above equations we get the coordinates as [3,4].

In our system each object to be tracked has the UWB transceiver which is contained in a device called the tag. Similarly, devices called the anchors are placed in different parts of the indoor environment. The anchors are placed in predetermined locations and act as beacons from which the distances are determined. The tag determines its distance from each anchor using two way ranging. Then position is then calculated by substitution in the trilateration formula.

4.2 SYSTEM ENVIRONMENT

The system environment can be summarized as shown below:

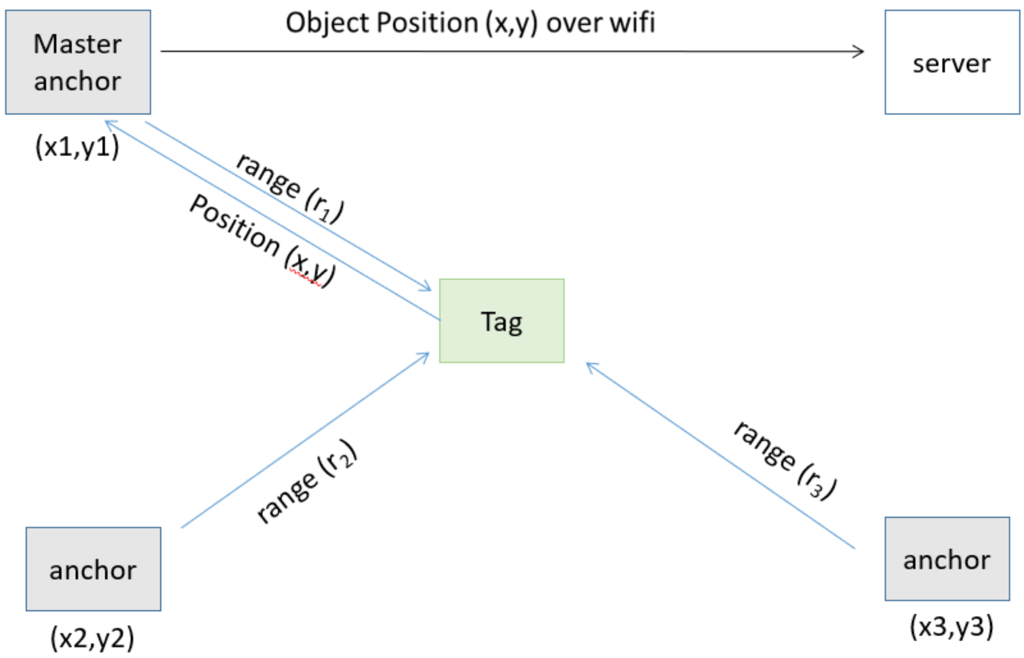


Figure 4.1: Block Diagram of the System

The anchors are stationary and the tag is attached to an object to be tracked within the environment. The practical setup is as shown below in fig 4.2.

4.3 IMPLEMENTATION

4.3.1 Electronics Hardware

Our project consists of three different devices in total, called the tag, anchor and master anchor. Each device has an Ultra Wideband transceiver chip which is operated by a microcontroller. The master anchor contains an additional Wi-Fi transceiver to transmit the data wirelessly over the internet.

The first part of the design is choosing a suitable source of power for the device.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Statement of the Problem

Current indoor tracking technologies such as Bluetooth and Wi-Fi are based on signal strength measurement which is unreliable and inaccurate (ranging between 1 – 10 m).

The UWB technology is still under research and products sold at market as low cost UWB systems are poor in terms of accuracy.

3.2 Need for the Study

This study provides a method to build a low cost precise indoor tracking system with a minimum accuracy of 30cm. This is necessary because currently, high accuracy object tracking systems use visual markers for localization. The complexity and cost of such systems are high.

3.3 Scope of the Study

The system developed during this project can be used in any indoor environment regardless of other external conditions. The system developed at the end of this study works based on the trilateration algorithm which can be extended to multilateration by adding more components of the project called the tags. This can further improve the accuracy of the system.

With an inertial sensor fusion, the accuracy of the system can be improved to the millimeter scale.

As an outdoor application, the system can be fused with GPS to enhance the accuracy of GPS as well.

Figure 4.2: Experimental Setup

Power Supply

The DWM1000 operates at 3.3V DC and this requirement can be satisfied by a 3.7V Lithium Polymer (Li-Po) battery. However, the nominal voltage of the battery is only 3.7V and the actual voltage varies from 4.2V when fully charged to about safe discharge voltage of about 3.2V. This variation is not suitable for providing as input to the DWM1000 because it has a tolerance of 0.3V as given in the Nominal Operating Conditions section of the datasheet. Hence, a voltage regulator is required in the circuit to regulate the voltage to 3.3V.

There are many choices of voltage regulators providing an output of 3.3V. The regulator IC MIC5219 was chosen because of its Low Dropout (LDO) characteristic. This is a type of regulator which regulates the output even when the output voltage is very close to the input voltage. The IC has 5 pins as shown in fig 4.3.

Bypass capacitors of value 1uF are added across the input and output to reduce the ef-

Pin Number SOT23-5	Pin Name	Description
1	IN	Supply input.
2	GND	Ground: MSOP-8 pins 5 through 8 are internally connected.
5	OUT	Regulator output.
3	EN	Enable (input): CMOS-compatible control input. Logic-high = enable; logic-low or open = shutdown.
4 (FIXED)	BYP	Reference bypass: Connect an external 470 pF capacitor to GND to reduce output noise. May be left open.
4 (ADJ)	ADJ	Adjust (input): Feedback input. Connect to resistive voltage-divider network.
—	GND	Ground: Internally connected to the exposed pad. Connect externally to GND pin.

Figure 4.3: Pin Description of Voltage Regulator

fect of noise. The battery is connected across the input pin and ground.

A Schottky diode is connected between the positive terminal of the battery and the input pin to protect the circuit in case of reverse connection. The diode only conducts in forward bias which happens only when the positive terminal of the battery is connected to the anode.

Adding a slide switch will also enable turn the device ON or OFF according to the need. Also, an Light Emitting Diode (LED) can be good visual indicator for the user to know whether the device is ON or not.

Hence the power supply circuit is constructed as shown in fig 4.4.The output of 3.3V is used to power the rest of the circuit.

Next, A microcontroller is needed to control the operation of the DWM1000, the ATmega328P manufactured by Microchip Technology was chosen.

Microcontroller

The ATmega328P is an 8 bit microcontroller based on the Alf-Egil Bogen Vegard Wollan Reduced Instruction Set Computer (AVR) architecture. It is one of the most widely used microcontrollers because of its low cost and ease of interfacing. It has 32KB of programmable memory, 23 general purpose Input/Output lines, SPI serial port which are some of the features required for interfacing with the DWM1000 module. It also

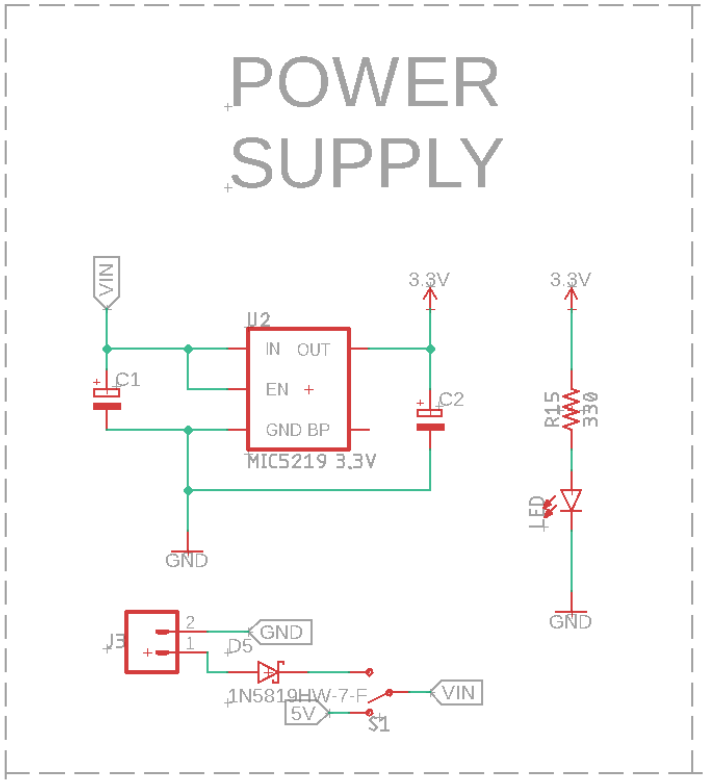


Figure 4.4: Power Supply Circuit

has an operating range of 1.8 to 5.5V and can hence be powered by the existing power supply.

However, the ATmega328P cannot be interfaced directly with the UWB module because there are few requirements to be fulfilled to be able to program the ATmega328P and use it as a microcontroller.

The ATmega328P has an unstable internal oscillator which is not reliable. Hence, an external oscillator should be added across the pins XTAL1 and XTAL2. A reset button is necessary for the user to restart the operation, a tactile switch is used for this purpose. An active LOW signal across the RESET pin of ATmega328P for 1 clock cycle resets the device. Hence the pin is pulled up when the switch is not pressed. Finally, a programming interface is required to program the microcontroller. An In System Programmer (ISP) connector is added for this purpose. The minimal circuit hence required to drive the UWB module is as shown in fig 4.5.

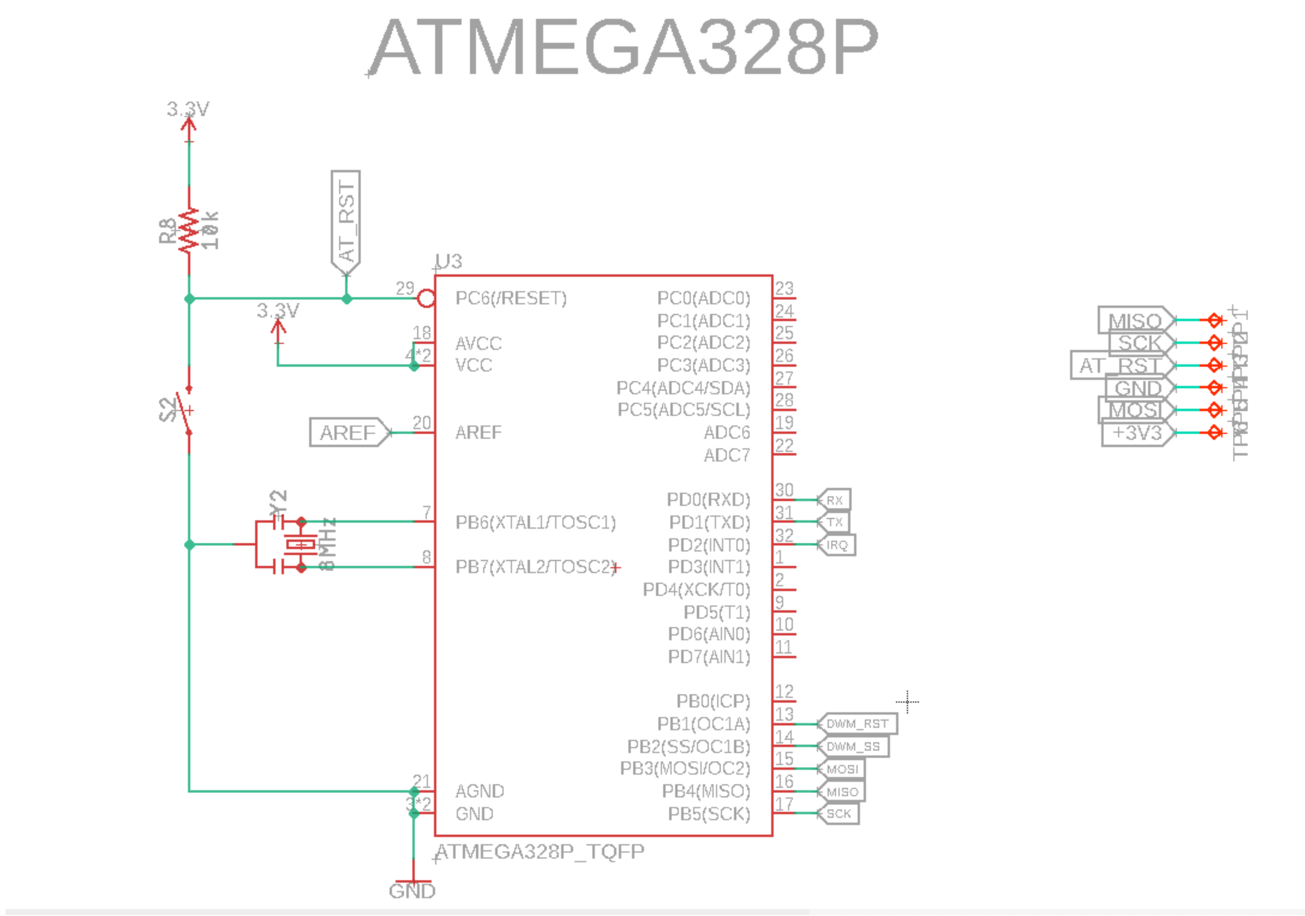


Figure 4.5: Microcontroller Circuit

Alternatively, an Universal Serial Bus (USB) connector can also be used to program the microcontroller, but the device requires a bootloader to be programmed using USB. The bootloader can only be burnt using the ISP. The signals from the USB connector are converted to Transistor Transistor Logic (TTL) using the part CH340G. The circuit is as shown below:

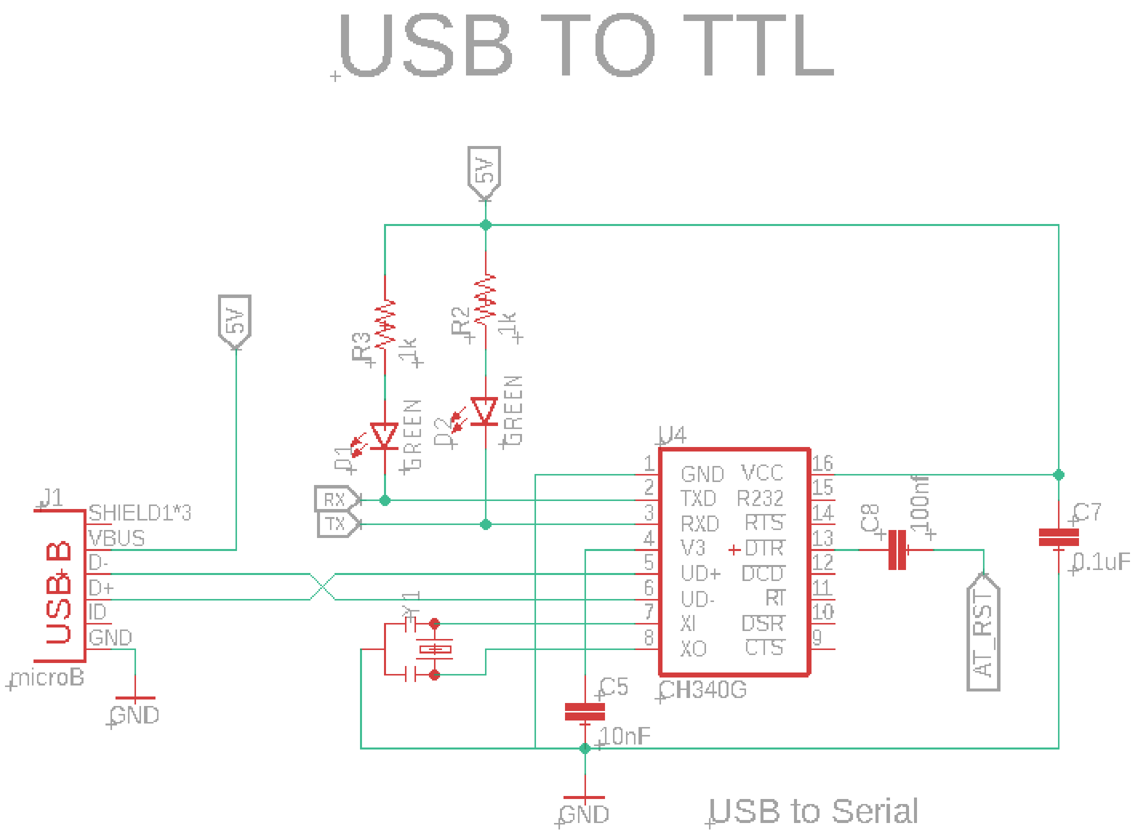


Figure 4.6: USB to TTL Converter Circuit

DWM1000

It is the UWB transceiver which is the core of this project. As explained above already, it is powered at 3.3V and controlled by the microcontroller using Serial Peripheral Interface (SPI) protocol. Additionally, there are two other output pins Interrupt Request (IRQ) and RESET of DWM1000 which is used to indicate the state of operation to the microcontroller. The IRQ is pulled LOW normally to prevent the recognition of incorrect signal by the microcontroller. The circuit is:

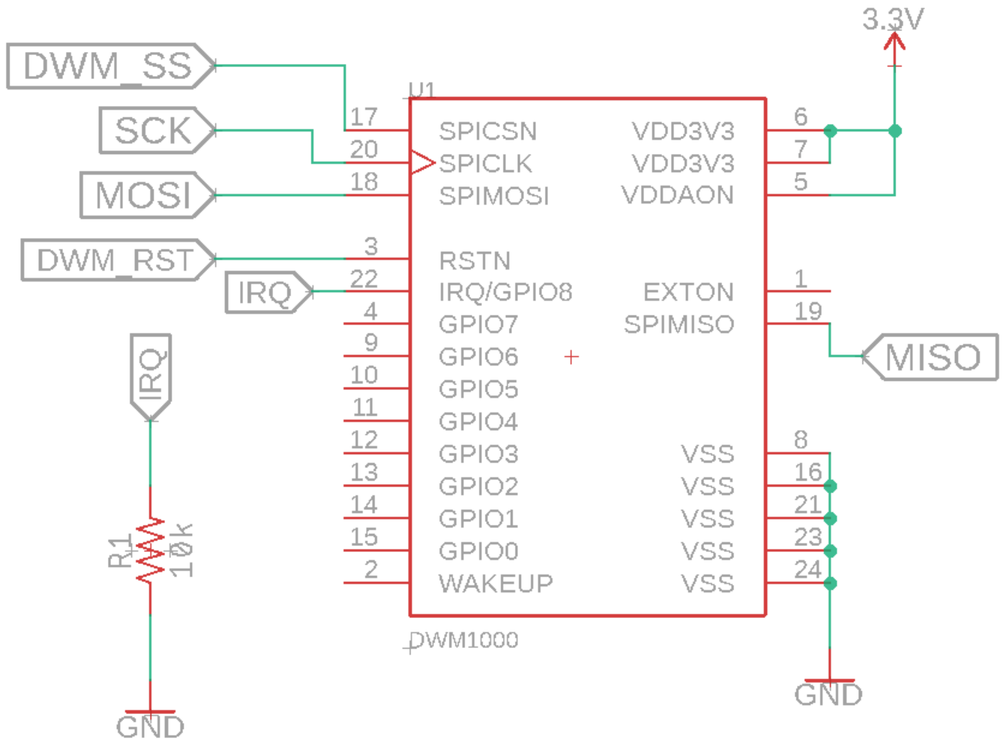


Figure 4.7: UWB Transceiver Circuit

The dependencies of all the parts are satisfied and the connections between ATmega328P and DWM1000 are made as shown in the table below:

ATMEGA328P	DWM1000
PB2 (14)	SPICSn (17)
PB3 (15)	SPIMOSI (18)
PB4 (16)	SPIMISO (19)
PB5 (17)	SPICLK (20)
PB1 (13)	RSTn (3)
PD2 (32)	IRQ (22)

Table 4.1: Interconnection of UWB Module and Microcontroller

ESP8266-12E

The master anchor contains an ESP8266-12E which is used to transfer the data through Wi-Fi. The ESP8266 also requires 3.3V, a reset circuit, Universal Asynchronous Receiver/Transmitter (UART) programming interface and certain specific pin configurations. General Purpose Input/Output (GPIO) 2 and GPIO 15 are pulled LOW. A switch is connected to GPIO 0 to switch between flash (normal operation) and external (programming) boot modes.

The circuit of ESP8266-12E is hence:

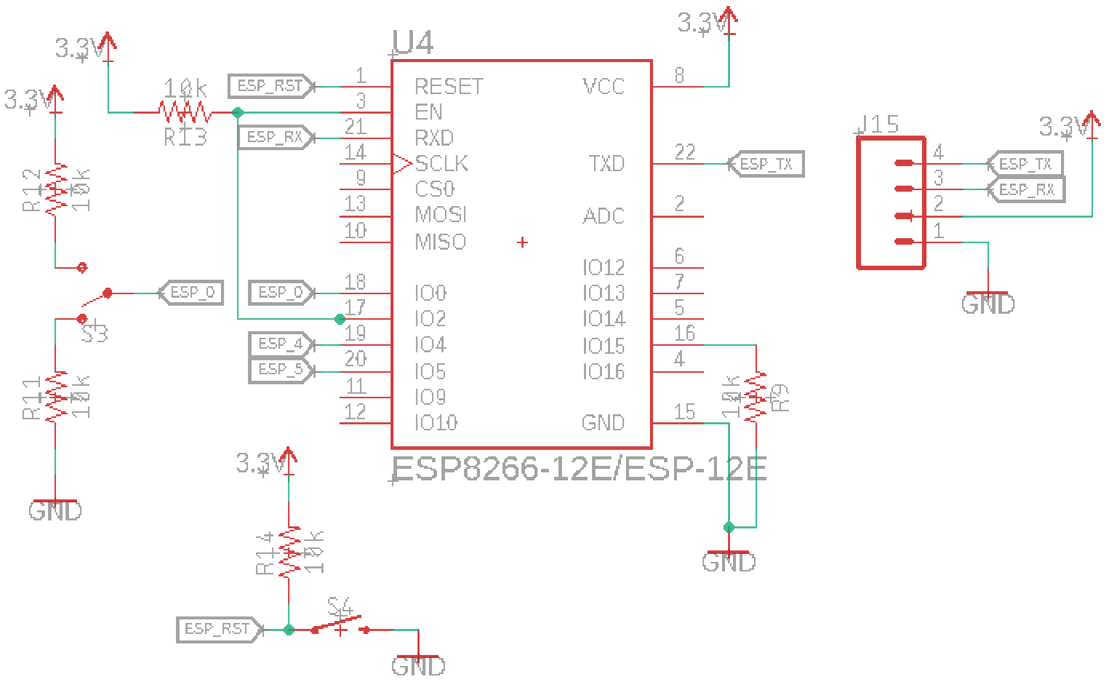


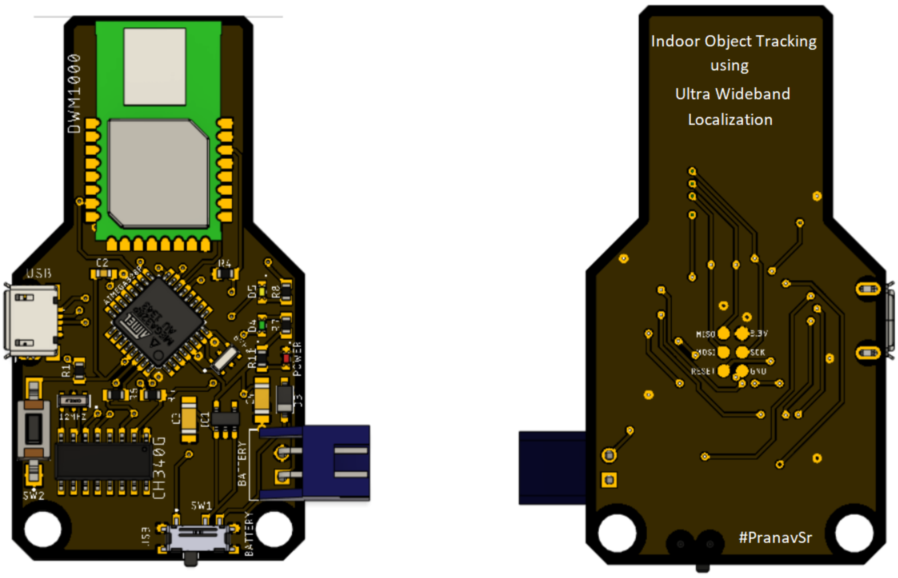
Figure 4.8: ESP8266-12E Circuit

The ESP8266-12E and ATmega328P use the Inter Integrated Circuit (I2C) protocol. So GPIO4 and GPIO5 are connected to PC5 and PC4 of ATmega328P.

PCB DESIGN

From the schematic, the parts are exported to make the Printed Circuit Board (PCB). Components are placed in the desired places and routed. The thickness of the current carrying traces are varied according to the amount of current. We have used trace widths of 12 mills for the signals from the microcontroller and 20 mills for the power bus carrying 3.3V and GND. The entire top layer is poured with copper connected to GND as it reduces thermal noise. The PCB's of the tag after design are as shown below:

PCB DESIGN



(a) Top View (b) Bottom View

Figure 4.9: PCB of the Tag

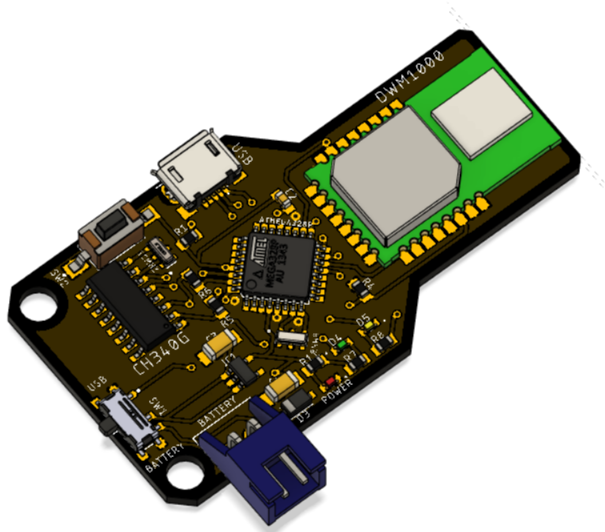


Figure 4.10: Isometric View of the Tag

Note: The device can be powered by both the battery and the USB. The switch is used to switch if both are available.

4.3.2 Software Design

The software of the project was written in Arduino IDE.

To implement this project, the software should contain the following:

1. **Initialization of DWM1000** - The code shown below is used to initialize the UWB traceiver module(DWM1000). Library “SPI” is added to establish communication between DWM1000 and ATmega328P through the SPI protocol. The libraries “DW1000Ranging” and “DW1000Device” consist of useful functions to control the DWM1000.

   The next three lines of the program define the hardware pin connections between ATmega328P and DWM1000.

   The function void setup() executes once the microcontroller is powered. The function initCommunication is used to define the hardware connections of the DWM1000 to begin the communication. Then, attachNewRange is a function to scan other UWB devices within proximity and connect with them. Finally, startAsTag is used to define the device as a tag with the address passed in the first argument and its accuracy. The code for initialization is given in Appendix A.

2. **Algorithm of trilateration** - The code to perform trilateration was written by following the steps:

   Step 1: Define a 3x2 matrix anchor to store the coordinates of the anchors.

   Step 2: Define a 3x3 matrix to store all the constant terms on the right side of the equations 4.4, 4.5 and 4.6.

   Step 3: Invert the matrix from Step 2.

   Step 4: Determine the distance of tag from each anchor using Two Way Ranging and store it in a matrix Distance.

   Step 5: Square the coordinates from matrix anchor and do row wise subtraction from the matrix Distance.

   Step 6: Multiply the result of step 6 with that of Step 2 to get a 3x1 matrix.

   Step 7: The first two elements of the matrix in the above step provide the coordinates x and y respectively.

   Step 8: The steps 4 to 7 are repeated continuously to obtain the real time position of the tag.

4.4 EXPERIMENTAL PROGRAM

The experimental procedure is followed as shown in the flow chart below:

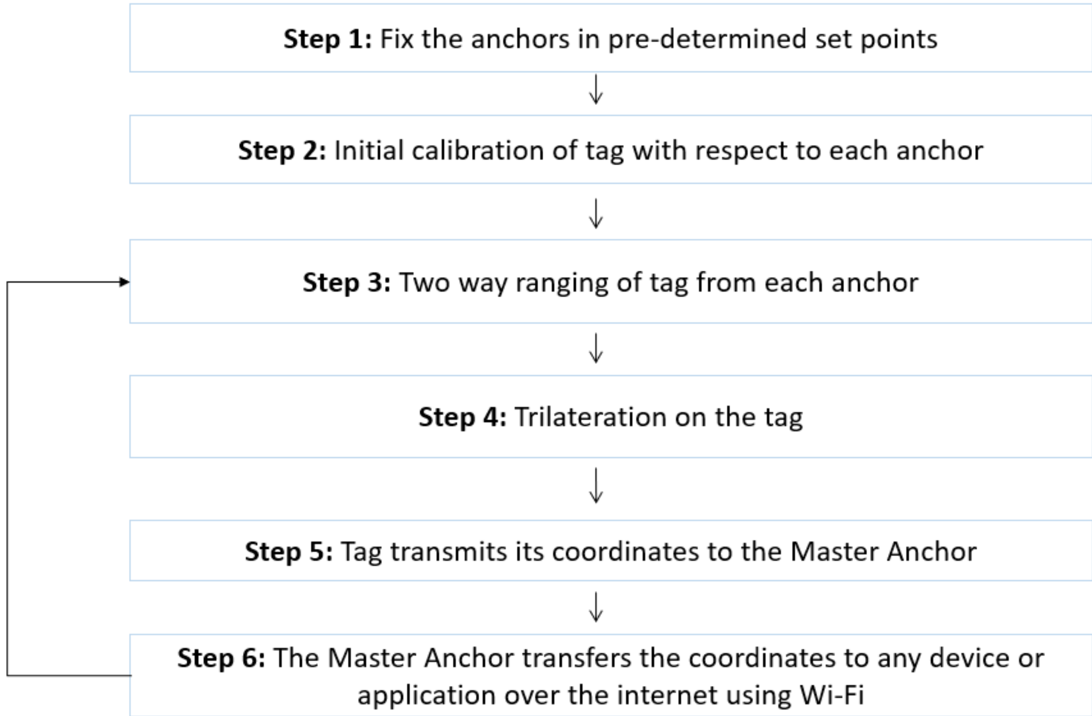


Figure 4.11: Flowchart of Object Tracking

Step wise explanation:

Step 1: As explained already in section 4.1, to determine the unknown position of the tag, the coordinates of the anchor has to be known. Hence, we place the anchors at coordinates according to our preference and provide this information to the program doing trilateration.

Step 2: According to the conditions and obstacles of the indoor environment, the ultra wideband signals might encounter some losses or interference. In order to overcome this effect, the tag can be calibrated against the values obtained from the time of flight.

In our project, the calibration is performed for two different distances from each anchor as shown in fig 4.12. The slope of the variation between the values obtained for the two distances are calculated. This correction factor is multiplied with all the readings obtained hereafter during operation.

Step 3: The tag first establishes connection with each anchor using the known device ID. It then performs two way ranging sequentially with each anchor and multiplies with the correction factor determined in the previous step.

Step 4: The tag then performs trilateration using the algorithm explained in the software design section.

(a) Distance 1

(b) Distance 2

Figure 4.12: Calibration of the Tag

Step 5: The tag updates its current position to the master anchor.

Step 6: The master anchor transfers these coordinates to an application using Wi-Fi to visualize the live data.
The buffer is then cleared and the procedure is repeated from step 3 to 6 continuously to perform real-time tracking.

4.5 INTERPRETATION

The tag was placed within the environment. The coordinates were measured to be (2.5,2.5) as shown in the picture below:

Figure 4.13: Tracking of the tag

The results obtained from the tracking system in the terminal are:

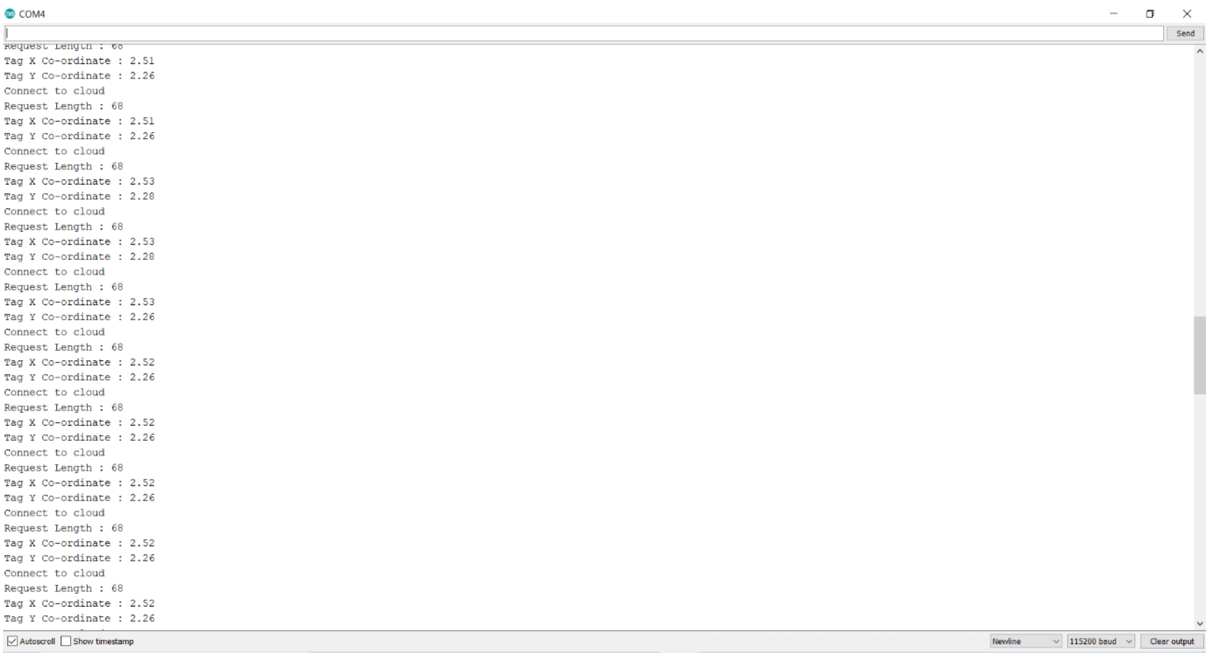


Figure 4.14: Tracking Results

Similarly, we moved the object around the environment and observed the change in the tracking data to correlate with the real-world position of the object.

4.6 INFERENCE

Hence by using Ultra Wideband communication technology, the effects of multi path fading, path loss and interference are reduced thereby producing a good tracking result. By performing repeated experiments, we obtained a dataset as shown below:

S.No	**Measured Position ($[x_1, y_1]$ in) m)** (a)	**Expected Position ($[x_0, y_0]$ in m)** (b)	**Measured Distance from Origin** (c)	**Expected Distance from Origin** (d)	**Percentage Error = (c-d)/d x 100** (e)	**Accuracy of the system for 1m z = 100-e**
1.	[0.22, -0.07]	[0.15,0.15]	0.2308	0.2109	9.43	90.56
2.	[1.09,0.02]	[1,0]	1.0901	1	9.01	90.99
3.	[2.14,0.03]	[2,0]	2.1402	2	7.01	92.99
4.	[3.27,0.21]	[3,0]	3.2767	3	9.22	90.78
5.	[0.02,1.13]	[0,1]	1.1301	1	13.01	86.99
6.	[0.03,2.31]	[0,2]	2.3101	2	15.005	84.995
7.	[0.02,3.37]	[0,3]	3.3700	3	12.33	87.67
8.	[1.10,1.09]	[1,1]	1.5485	1.414	9.51	90.49
9.	[2.06,1.99]	[2,2]	2.8642	2.8284	1.26	98.74
10.	[3.31,3.29]	[3,3]	4.6669	4.2426	10.00	90.00
					Average Accuracy =	$\frac{\sum_{n=1}^{10} z(n)}{10}$ = 90.42%

Table 4.2: Tracking Data of the Object

4.6.1 FORMULA

$$Measured\,, Distance\ from\ Origin = (x_1^2 + y_1^2)^{\frac{1}{2}} \tag{4.10}$$

$$Expected\ Distance\ from\ Origin = (x_0^2 + y_0^2)^{\frac{1}{2}} \tag{4.11}$$

$$Percentage\ Error = \frac{Measured\ Distance\breve{}Expected\ Distance}{Expected\ Distance} * 100 \tag{4.12}$$

$$Average\ Accuracy\ of\ the\ system\ for\ 1m = \frac{Sum\ of\ Accuracies}{Total\ no.\ of\ Samples} \tag{4.13}$$

4.6.2 CALCULATION

$$Average\ Accuracy\ (1m)\ = \frac{904.2}{10} \tag{4.14}$$

Therefore, Average Accuracy (1m) = 90.42%

Hence the average accuracy in terms of distance is 9.58cm.

CHAPTER 5

SOFTWARE DESCRIPTION

5.1 Arduino IDE

The code for the project is written and compiled on the Arduino IDE. It has functions written in C and C++. It is compatible with Windows, macOS and Linux based Operating systems. The compiler handles the job of converting the code into the required hex data which can be understood by the microcontroller. The extensive library support makes development and debugging of the code easier.

5.2 Autodesk Eagle

EAGLE is a PCB design software with computer-aided manufacturing features. EAGLE is developed and maintained by Autodesk. The process involved creating the schematic using the required components and their packages. Following this, the PCB is designed by placing the components as required and routing the air wires. The automatic design rule check done by the software can notify the maker of any design fault which can result in defective boards after manufacturing. The software also supports the generation of gerber files which can be sent to the manufacturer directly.

CHAPTER 6

CONCLUSION

The error and accuracy obtained however is dependent on the indoor environment and the amount of reflections occurring within the area.

Hence it is proved that by using UWB, a tracking system with accuracy of at least 30cm can be achieved which is much superior to the accuracy of 5m attained using GPS.

The results obtained are reasonably good and can be used in many areas such as factories, hospitals and research for precise object tracking.

CHAPTER 7

FUTURE ENHANCEMENT

The above system developed during this project can be used in any indoor environment regardless of other external conditions. The system can be expanded by adding more anchors and work on multilateration. This can further improve the accuracy of the system. This will support the tracking of more tags.

Further, noise reduction using Gaussian Process and Machine Learning can be implemented to enhance the accuracy.

Using an inertial sensor, the data from the IMU sensor and UWB is fused using a Kalman Filter. The accuracy of the system can be improved to the millimeter scale.

For outdoor application, the system can be fused with GPS to enhance the accuracy of GPS as well.

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1. Anton Ledergerber, R. D. (2017). “Ultra-wideband range measurement model with gaussian processes.” *IEEE Conference on Control Technology and Applications (CCTA)*.

2. Anton Ledergerber, Michael Hamer, R. D. (2015). “A robot self-localization system using one-way ultra-wideband communication.” *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*.

3. Davide Dardari, Nicolo Decarli, A. G. F. G. (2016). “The future of ultra-wideband localization in rfid.” *IEEE International Conference on RFID*.

4. Richa Bharadwaj, Srijittra Swaisaenyakorn, C. G. P. J. B. A. A. (2014). “Localization of wearable ultra-wideband antennas for motion capture applications.” *IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS*, 13, 507–510.

5. Tiemann J, Eckermann F, W. C. (2016). “Atlas - an open source tdoa-based ultra-wideband localization system.” *IEEE 2016 International Conference on Indoor Positioning and Indoor Navigation (IPIN)*.

APPENDIX A

PROGRAM OF INITIALIZE DWM1000

```
#include "SPI.h"
#include "DW1000Ranging.h"
#include "DW1000Device.h"

int DECA_RS = 3;
int PIN_IRQ = 2;
int PIN_SS = 10;

void setup() {
DW1000Ranging.initCommunication(DECA_RS, DECA_SLC, DECA_INT);
DW1000Ranging.attachNewRange(newRange);
Serial.begin(115200);
DW1000Ranging.startAsAnchor("3A:1A:1A:1A:1A:1A:1A:1A",
DW1000.MODE_LONGDATA_RANGE_ACCURACY);
}
```

APPENDIX B

PROGRAM OF THE TAG

```
#include <SPI.h>
#include <DW1000Ranging.h>
#include <DW1000Device.h>
#include <MatrixMath.h>
#include <math.h>

#define ANCHOR_1_ADDRESS 0x1A1A
#define ANCHOR_2_ADDRESS 0x1A2A
#define ANCHOR_3_ADDRESS 0x1A3A

#define ANCHOR _1_X 0.00f
#define ANCHOR _1_Y 0.00f

#define ANCHOR _2_X 5.0f
#define ANCHOR _2_Y 0.0f

#define ANCHOR _3_X 0.00f
#define ANCHOR _3_Y 5.00f

#define ANCHOR _1_FIRSTDIST 2.368
#define ANCHOR _1_SECONDDIST 5.372
float anchor_1_slope
= 3.0f/(ANCHOR_1_SECONDDIST-ANCHOR_1_FIRSTDIST);
float anchor_1_offset
= 5.0f-(1.0f/anchor_1_slope*ANCHOR_1_SECONDDIST);

#define ANCHOR _2_FIRSTDIST 2.368
```

```
#define ANCHOR _2_SECONDDIST 5.372
float anchor_2_slope
= 3.0f/(ANCHOR_2_SECONDDIST-ANCHOR_2_FIRSTDIST);
float anchor_2_offset
= 5.0f-(1.0f/anchor_2_slope*ANCHOR_2_SECONDDIST);

#define ANCHOR _3_FIRSTDIST 2.368
#define ANCHOR _3_SECONDDIST 5.372
float anchor_3_slope
= 3.0f/(ANCHOR_3_SECONDDIST - ANCHOR_3_FIRSTDIST);
float anchor_3_offset
= 5.0f-(1.0f/anchor_3_slope * ANCHOR_3_SECONDDIST);

int DECA_RS = 3;
int DECA_INT = 4;
int DECA_SLC = 6;
volatile unsigned long delaySent = 0;
volatile boolean sentAck = false;
volatile float range = 0;
volatile int address = 0;

float anchors[3][2] = {{ANCHOR_1_X, ANCHOR_1_Y},
{ANCHOR_2_X, ANCHOR_2_Y},
{ANCHOR_3_X, ANCHOR_3_Y}};

float A[3][3];

void setup() {
Serial.begin(115200);
delay(1000);
pinMode(6,OUTPUT);
```

```
//init the configuration
DW1000Ranging.initCommunication(DECA_RS, DECA_SLC, DECA_INT);
DW1000Ranging.attachNewRange(newRange);
DW1000Ranging.startAsTag("7D:00:22:EA:82:60:3B:9C",
DW1000.MODE_LONGDATA_RANGE_ACCURACY);
unsigned long start, step_start, finished;

start = micros();

for(int i = 0; i < 3; i++) {
A[i][0] = -2.0f*anchors[i][0];
A[i][1] = -2.0f*anchors[i][1];
A[i][2] = 1.0f;
}

Matrix.Invert((float*)A, 3);

step_start = micros();

Serial.println(step_start - start);
}
void loop() {
DW1000Ranging.loop();
}

void newRange() {

address = DW1000Ranging.getDistantDevice()->getShortAddress();

range = DW1000Ranging.getDistantDevice()->getRange();

// ITERATIVE STEPS BELOW
```

```
float M[3];
for(int i = 0; i < 3; i++) {
M[i] = float((dist[i])*(dist[i])
- (anchors[i][0])*(anchors[i][0])-(anchors[i][1])*(anchors[i][1]));
}
float N[3];
Matrix.Multiply((float*)A, (float*)y, 3, 3, 1, (float*)x);

float location[2] = {N[0], N[1]};

Serial.print(" Location: [");
Serial.print(location[0]);
Serial.print("m, ");
Serial.print(location[1]);
Serial.print("m] \n");

DW1000Ranging.setLoc(location[0], location[1]);
}
```

APPENDIX C

PROGRAM OF THE MASTER ANCHOR

```
#include <SPI.h>
#include <Wire.h>
#include "DW1000Ranging.h"
#include "DW1000Device.h"

int DECA_RS = 3;
int DECA_INT = 4;
int DECA_SLC = 6;

String z;
char Z[10];

void setup() {
Wire.begin(8);  /* join i2c bus with address 8 */
Wire.onRequest(requestEvent); /* register request event */
Serial.begin(115200);
delay(1000);
delay(2000);
DW1000Ranging.initCommunication(DECA_RS, DECA_SLC, DECA_INT);DW1000R
DW1000Ranging.startAsAnchor("1A:1A:1A:1A:1A:1A:1A:1A", DW1000.MODE_L
}

int loopCtr = -1;
String request = "";

void loop() {
byte* addr = DW1000Ranging.getCurrentAddress();
```

```
if (loopCtr == 0) {
Serial.println("Connect to cloud");
}

if (loopCtr == 10000) {
request = "POST /location?x=" + String(DW1000Ranging.getTagX())
+ "&y=" + String(DW1000Ranging.getTagY()) +
" HTTP/1.1\r\nHost: " + DOMAIN + "\r\n\r\n\r\n\r\n";
Serial.print("Request Length : ");
Serial.print(String(request.length()));
Serial.println();
Serial.print("Tag X Co-ordinate : ");
Serial.print(String(DW1000Ranging.getTagX()));
Serial.println();
Serial.print("Tag Y Co-ordinate : ");
Serial.print(String(DW1000Ranging.getTagY()));
Serial.println();
z = String(DW1000Ranging.getTagX())
+ "," + String(DW1000Ranging.getTagY());
z.toCharArray(Z,10);
}

if (loopCtr == 20000) {
loopCtr = -1;
}

loopCtr++;

DW1000Ranging.loop();
}
```

```
void newRange() {
// Empty.
}

void requestEvent() {
Wire.write(Z);  /*send string on request */
}
```

Report as on April 29 - Pranav

ORIGINALITY REPORT

7%	3%	4%	4%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Anton Ledergerber, Raffaello D'Andrea. "Ultra-wideband range measurement model with Gaussian processes", 2017 IEEE Conference on Control Technology and Applications (CCTA), 2017 Publication	1%
2	Submitted to University College London Student Paper	<1%
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6	Davide Dardari, Nicolo Decarli, Anna Guerra, Francesco Guidi. "The future of ultra-wideband localization in RFID", 2016 IEEE International Conference on RFID (RFID), 2016 Publication	<1%

ABET Design Project Summary

Project Title	Objective of the Project	Realistic constraints imposed	Standards to be referred/followed	Multidisciplinary tasks involved
Indoor Object Tracking using Ultra Wideband Localization	To build a precise indoor tracking system with an accuracy of at least 30cm.	• The range of each anchor is only 10 meters, hence more modules are required to cover a larger area. • The batteries of the modules get discharged quickly due to high power consumption of the UWB module. • The anchors and tags have to be on the same plane and can be tracked only with an area of size 5x5m.	• IEEE 802.11 – Standard for Wi-Fi • IEEE 802.15.4a – Standard for UWB	1. Printed Circuit Board Design 2. Embedded System Programming using C 3. Mechanical Design of Casing

Project Plan

S. No.	Tasks in the project work	Duration (in days)	Start (date)	Finish (date)	Responsibility
1	Schematic Design	14	23-12-19	06-01-20	Pranav and Kavan
2	PCB Design	7	06-01-20	13-01-20	Pranav and Kavan
3	Fabrication	7	13-01-20	20-01-20	Pranav and Balaji
4	Literature Survey	30	23-12-19	22-01-20	Kavan and Balaji
5	Program for Two Way Ranging	12	30-12-19	10-01-20	Pranav and Mihir
5	Program for Trilateration	15	11-01-20	25-01-20	Pranav and Mihir
6	Program for Tag	7	26-01-20	02-02-20	Pranav and Mihir
7	Program for Anchor	7	03-02-20	09-02-20	Pranav and Mihir

8	Program for Master Anchor	7	10-02-20	16-02-20	Pranav
9	Web Interface	7	17-02-20	23-02-20	Pranav and Mihir
10	Code Integration	7	23-02-20	29-02-20	Pranav and Mihir
11	Testing and Verification	4	01-03-20	04-03-20	Mihir and Balaji
12	Documentation	40	23-01-20	02-03-20	Kavan and Balaji

Requirement and Proposed Budget

Item / Parts	**Supplier/ Manufacturer**	**Model No./ Description**	**Quantity**	**Unit Price**	**Total (Rs.)**
Printed Circuit Boards	PCBWay	-	4	$ 0.5	142
UWB Module	iodParts	DWM1000	4	1,842	7,368
Microcontroller	iodParts	ATMEGA328-AU	4	85	340
Wi-Fi Module	SUNROM	ESP8266 12E	1	199	199
Voltage Regulator		MIC5219-3.3YM5	4	10	40
Resistor – 10K	SUNROM	10K 0603 1% SMD	40	2	80
Resistor – 330R	SUNROM	330R 0603 1% SMD	4	2	8
Capacitor – 1uF	SUNROM	1uF SMDA Tantalum	8	12	96
Capacitor – 0.1uF	SUNROM	0.1uF 0603 SMD	4	2	8
LED	SUNROM	0603	4	2	8
Schottky Diode	SUNROM	1N5819 SMD	4	15	60
JST Connector	SUNROM	2 Pin Male JST	4	3	12
Battery	ELECTRONICS Comp	3.7V 750mAH Li-Po	4	375	1500
				TOTAL	**9861**