CP301 Development Engineering Project

A Minor Project on

ORIENTATION ESTIMATION OF OBJECT USING RF SIGNAL

Submitted to the Indian Institute of Technology Ropar

in partial fulfillment of requirements for the award of degree

Bachelor of Technology

in

Electrical Engineering

by

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April 2023

DEPARTMENT OF ELECTRICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY

2022 - 23

CERTIFICATE

This is a certification that the report titled **ORIENTATION ESTIMATION OF OBJECT USING RF SIGNAL** submitted by them , to Department of Electrical Engineering in partial fulfilment of the B.Tech. degree in **Electrical Engineering** is an accurate record of the seminar work that was completed by them under my direction and supervision. No form of this study has ever been given to another university or institute for any reason.

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DECLARATION

We hereby declare that the minor project report **Orientation estimation of object using RF signal**, submitted for partial fulfillment of the requirements for the award of degree of Bachelor of Technology of the Indian institute of technology Ropar is a genuine piece of work that we produced under the guidance of Dr. Ashwani Sharma .

Where the thoughts or words of others have been used, we have properly and accurately cited and referenced the original sources. This submission expresses our opinions in our own words.

We further affirm that we have followed the rules of academic honesty and integrity and have not falsified or distorted any information, opinion, or fact in our work. We are aware that any infringement of the aforementioned rules will result in disciplinary action being taken by the university or the institute, as well as legal action being taken against the sources who were not properly referenced or from whose sufficient permission was not acquired. This report has never before used as the foundation for the award of a degree, diploma, or other comparable title by another university.

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26-04-2023

Abstract

This paper proposes a method for orientation estimation of objects using RF signals. The approach utilizes the phase and amplitude information of the RF signals reflected from the object to estimate its orientation. In the RF signal acquisition step, an RF sensor is used to collect the reflected RF signals from the object of interest. In the feature extraction step, relevant features such as phase and amplitude are extracted from the acquired RF signals.

Experimental results demonstrate the effectiveness of the proposed method in accurately estimating the orientation of objects using RF signals. The method shows promising potential in applications such as object recognition, object tracking, and human-robot interaction.

Acknowledgement

We would want to use this occasion to offer our profound gratitude and appreciation to everyone who assisted me in successfully completing this assignment. We would like to extend our sincere gratitude to , Head of Department, Electrical Engineering, Indian Institute of thecnology Ropar for providing us with all the facilities and assistance we required.

We want to sincerely thank, Department of Electrical Engineering, Indian Institute of thecnology, Ropar for their assistance and cooperation.

Additionally, we would like to express our profound appreciation to our project guide **Dr. Ashwani Sharma**, Assistant Professor, Electrical Engineering, Indian Institute of thecnology for their advice and mentorship throughout the course.

Contents

List of Figures

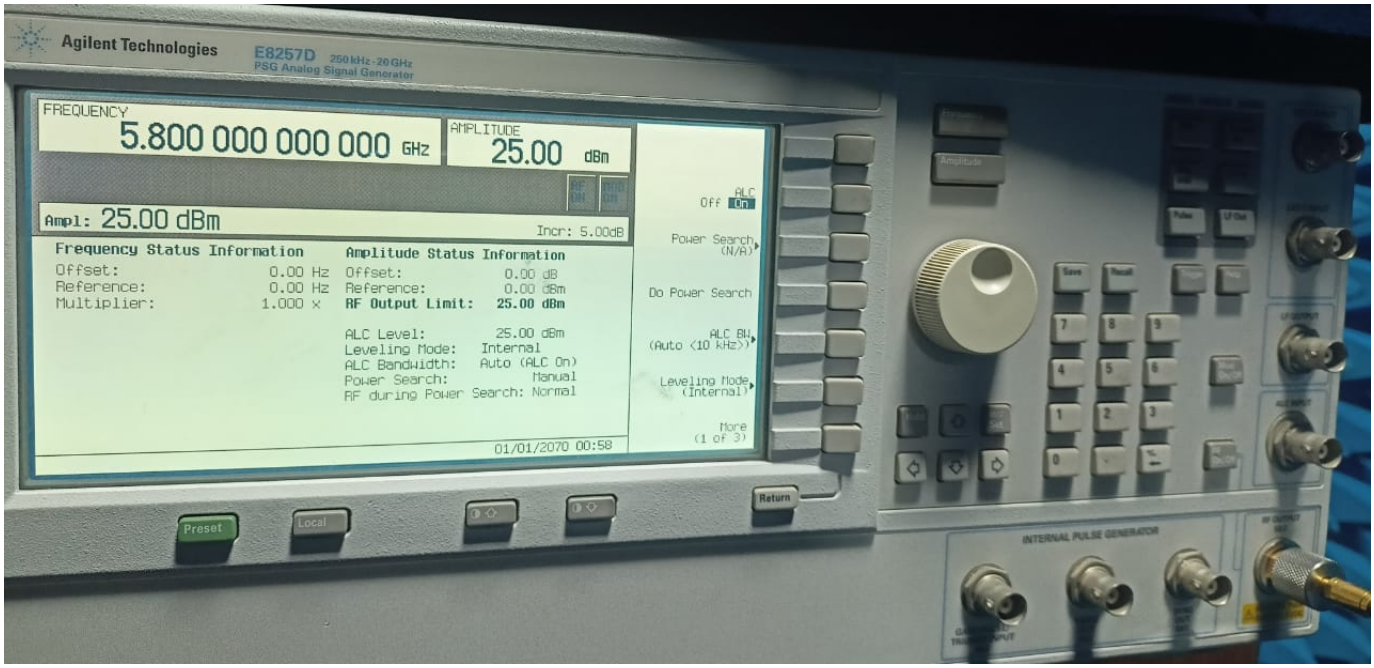


Figure 1: Signal Generator

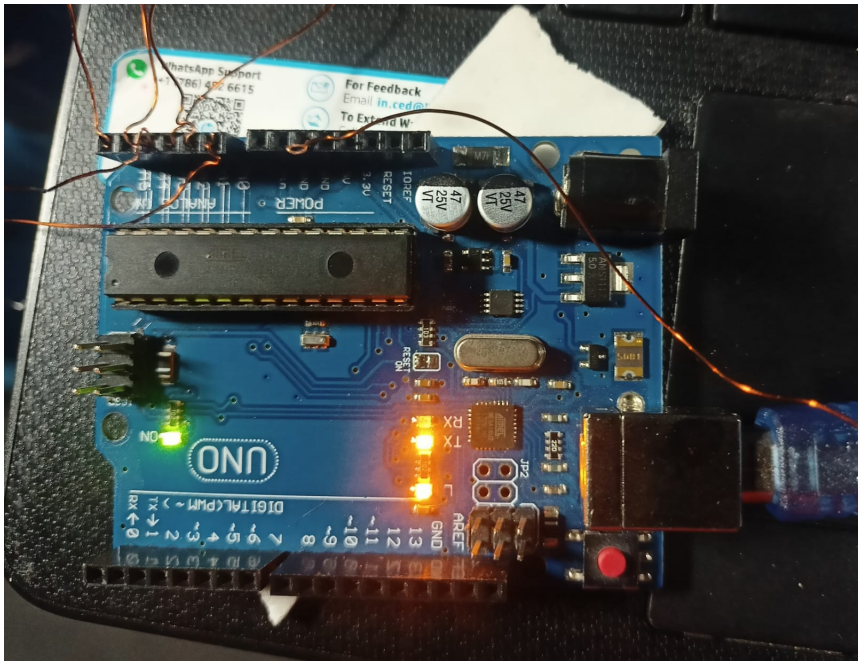


Figure 2: Arduino

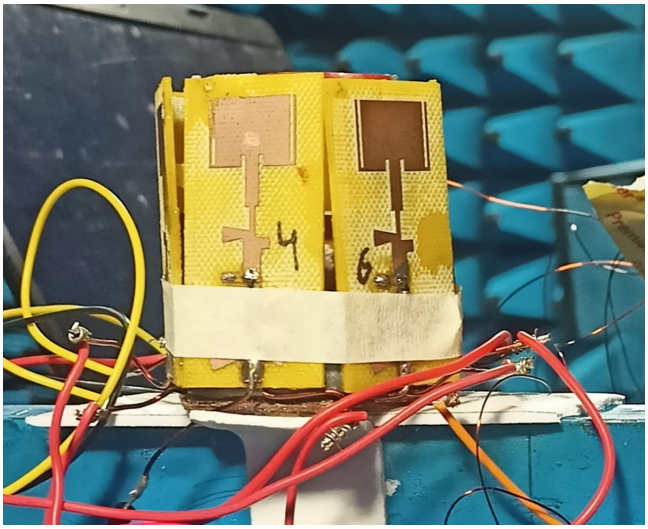


Figure 3: Six-Port Antenna

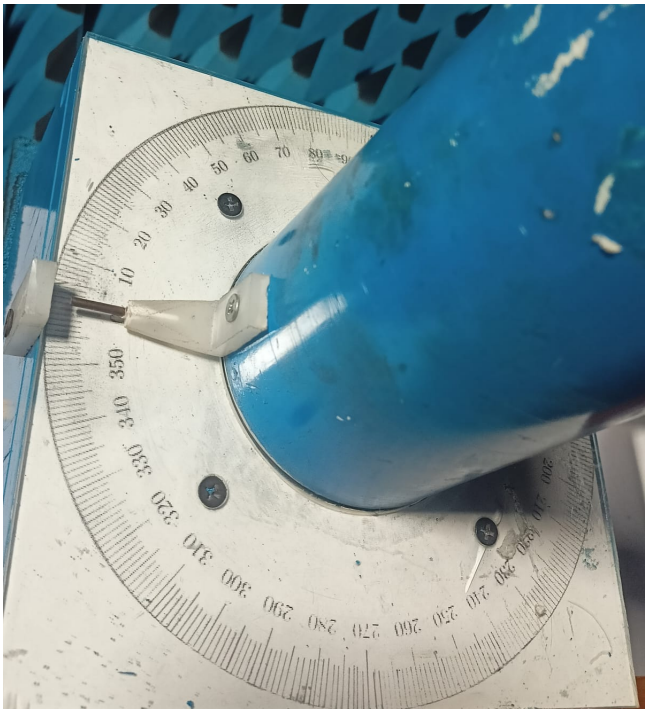


Figure 4: 360 degree rotor

Lab Setup

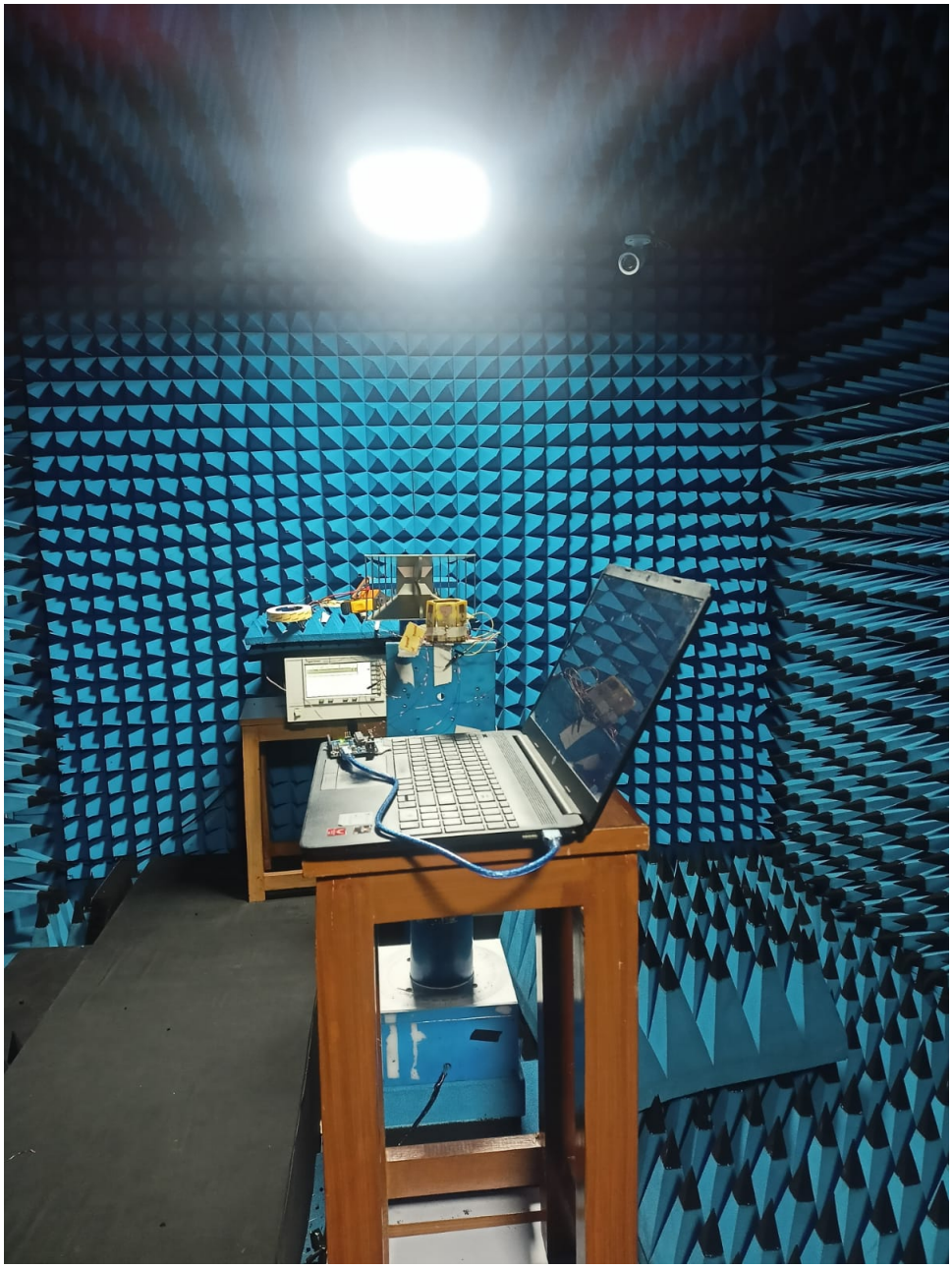


Figure 5: AMR Lab Setup

Introduction

Orientation estimation[5] of an object using RF signal is a kind of technique to determine the orientation or localization of any object in three dimensional space . When we transmit the wave using a transmission antenna, our wave interacts with the object and analyzes the estimation (position and displacement) of the object and then gives the correct position of the object . This technique gives the results based on feed data that is fed in a csv file using machine learning . We use the six patch antenna that receives the transmit signal and we convert it to DC voltages using Arduino.

Our team's main motivation to do this project is solving real life problems that detect the orientation or localization of any kind of object . mainly we prepare this project for blind people so that we are minimizing the problems . application of this project in many fields like robotics , industrial company and automotive vehicles etc.

Literature Review

RF-based object orientation refers to the use of RF signals, typically in the microwave frequency range, to determine the orientation or pose of objects. Several techniques have been proposed for object orientation estimation using RF signals. One common approach is to use multiple antennas or multiple transceivers to capture the multipath components of RF signals from different directions. By analyzing the phase and amplitude of the multipath components, object orientation can be estimated based on the changes in the signal characteristics when the object rotates or moves.Among the vaious ways to estimate an objects orientation based on RF signal features are techinques that utilize machine learning algorithms including support vector machines. This metgod have shown strong potential for indoor positioning applications or obstacle detection efforts.

Despite their successes however there remain some significant challenges when it comes to developing reliable estimates of an objects orientation through this type of technology.To achieve the best possible outcome in estimating an objects orientation through RF signals its crucial to develop comprehensive models detailing how these signals propagate and scatter.Another challenge is the need for sophisticated signal processing and machine learning algorithms to extract meaningful features from RF signals, as RF signals are often noisy and subject to interference. Real-time processing of RF signals can also be computationally expensive, requiring efficient algorithms and hardware implementations.

Theory

Orientation estimation of objects using RF signals, a six-port antenna, Arduino, and machine learning involves several key steps. In this process, RF signals are transmitted and received by a six-port antenna, which is connected to an Arduino microcontroller. The received RF signals are then processed and analyzed using machine learning algorithms to estimate the orientation of the object in question.

We are collecting the data in different environments using arduino and saving it to excel and based on data we will find out the angles at different positions of our object using the polynomial regression (machine learning) so we will give the accurate orientation of our object. The project may face challenges such as signal interference, noise but taking more data from the interface To overcome these challenges, the system should use advanced signal processing techniques, such as filtering and error correction. It is easily affordable everywhere like rural areas. So easily every blind person can take advantage of this technology by buying it and saving many lives .

RF Signals: RF (Radio Frequency) signals are a type of electromagnetic waves with frequencies ranging 3 kHz to 300 GHz. These signals are commonly used for communication, radar, and sensing applications. In the context of orientation estimation, RF signals are used to probe the object and gather information about its orientation based on the reflection, scattering, and absorption of the RF waves by the object's surface.

Six-port antenna: It is also known as the vector antenna, that is the special type of antenna in which we can measure the magnitude and phase of RF signal. It contains six antennas, in which we can used them for transmission and receiving the RF singnals in different directions. In this, It can able to capture the polarization and

phase information of the RF signal, it will be used for further process.

Arduino Microcontroller: Arduino is a microcontroller, that is a user interface for controlling the electronic devices. It is used in our project for the collecting of the readings and send it to the python script with help of COM3 port(Communication Port 3) of computer for further analysis.

Machine learning algorithms: It is used in our project to predict the orientation of the object(angles) and different voltage gains. In our project, we first try algorithms for example linear regression, logarithmic regression, polynomial regression, etc. we get a minimum error in polynomial regression. We trained our machine learning model on the polynomial regression algorithms.

Methodology

The "orientation estimation of object using RF signal" have mainly 7 steps that we are explain flowing blow:

1) RF Signal generator: Signal Generator generates an Rf signal that has 5.8 GHz Frequency and 25 dBm amplitude.The Rf signal transmitted by transmitter antenna to six port antenna(object).we send RF signal toward the object which we have to find orientation.

2) RF Transmission: The transmitted RF Signal reaches the receiver antenna and some part of the signal reflects back and a major part is absorbed by the six-port antenna.we also try to do perfect alignment and neglect environment obstacles.

3)Signal Processing: After that using an arduino microcontroller we collect the data, usually magnitude and phase information of the object from the output of the 6 port antenna.The data is stored in a dataset to analyze further.

4)Dataset Creation: The RF signal combined with object orientation to make a dataset.dataset have information about the input and object orientation .We can save this data to a csv file.

5)Machine learning Training: The stored data is used to train ML algorithms and ML Algorithm is to understand the patterns of data behavior from the stored data and create a modal that can predict the object orientation of an object with the help of RF signal.

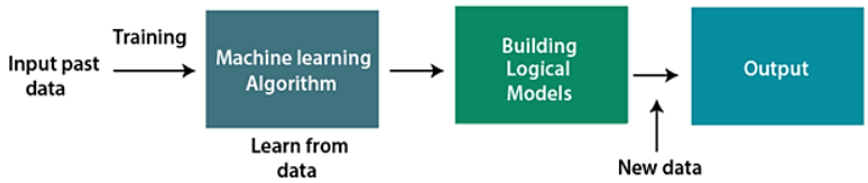
6)Model Validation: The modal validation is nothing but accuracy of modal is measured based on the precision,Recall, F1 score.It can also indicate modal performance and can be used for orientation of objects.

7) Orientation Estimation: After model validation it can be used for orientation of objects.The orientation of objects depends on environmental obstacles and the signal strength of RF signal,Wire connection.

The accuracy can be increased by perfect alignment of both antennas.

Machine Learning

In the real world, we are surrounded by people who can learn from their experiences as well as machines that follow our commands, like as robots or computers. Can a machine learn from past experiences or facts, like a person? So now comes the element of machine learning.



ref[3]

Figure 6: Block Diagram Of Machine Learning

Characteristics of Machine Learning

It can learn patterns from the given dataset. It can be more better further by previous data, so it is very useful in place where human beings can not do. We can say that Data mining or Data processing and Machine Learning are similar to each other.

Need Of Machine Learning ref[2]

Nowadays we can se that machine learning is becoming necessary. Machine learning is somehow important because it can handle jobs that are too challenging for a human to handle directly. Since people are limited in their ability to acquire vast volumes of data manually, we require computer systems, and machine learning fills this role. Machine learning algorithms can be trained by providing them with enormous volumes of data and letting them to independently analyse the data, create models, and predict the intended output. The cost function determines the machine learning algorithm's performance, which is influenced by the volume of data.

Looking at machine learning's applications will help you understand its worth. Self-driving cars, cyberfraud detection, facial recognition, and Facebook friend suggestion are just a few of the applications that use machine learning. Machine learning algorithms have been developed by a number of top companies, including Netflix and Amazon, to analyse user interest and provide product recommendations based on that information.

Classification of Machine learning ref[2,3]

At a wide level, machine learning is further divided into three types:

1. Supervised learning:

In supervised learning, we input sample labelled data to the system to train it, and it makes predictions about the output based on that. To evaluate the datasets and learn more about each one, the system designs a model using the given labelled data. We test the model by submitting sample data after training and processing to check if it accurately predicts the output or not. The linking of input and output data is the goal of supervised learning. Monitoring is necessary for supervised learning, just like when a student is learning something while being observed by an instructor.In spam filtering supervise learning is used.

Supervised learning can be divided further in two types of algorithms: • Classification • Regression

2. Unsupervised learning:

A machine learns using the unsupervised learning method, which involves no human intervention. A set of unlabeled, categorised, or sorted data is used to train the machine, and the algorithm must work independently on the data. Rearranging the input data into new features or a group of objects with related patterns is the goal of unsupervised learning.

Unsupervised learning does not have a predetermined result. The machine makes an effort to glean useful insights from the vast amount of data. There are two other categories of algorithms: • Clustering • Association

3. Reinforcement learning:

A learning agent is rewarded for doing the right thing and penalised for doing it wrong when using the feedback-based learning approach known as reinforcement learning. The agent automatically learns from these comments and enhances its performance. In this learning, the agent interacts with and explores the environment. The goal of an agent is to accumulate as many reward points as possible, so it performs better. The robotic dog uses reinforcement learning to show how it instantly picks up the movements of the owner's arms.

Our Problem-

The problem statement at hand involves the prediction of voltage gain at a specific angle for a given antenna data set using machine learning algorithms. This is a regression problem in supervised machine learning, where the objective is to predict a continuous output variable based on a set of input variables.

The dataset in question contains information on voltage gain at various angles for a given antenna. The aim is to use this dataset to predict the voltage gain at a particular angle using machine learning techniques.The difficulty is occurred for identify the good machine learning algorithm for our project in which we have to predict the angle at different voltage gains.

To solve this problem, we have try this problem on many algorithms. We got that polynomial regression was the well suitable for this purpose.

Now, we trained our project on the polynomial regression at the collected dataset. This process involves the predicting the angles at a particular voltage gain.we have to minimize the differences between predicted output and the input dataset.

Based on this we find accuracy of the prediction. In short, we are trying to predict the angle of the antenna at the different voltages gains. And based on this we find accuracy of the prediction. In short, we are trying to predict the angle of the antenna at the different voltages gains. And train the machine learning model on the appropriate ML algorithms. By testing with different algorithms, we conclude that polynomial regression was the well suited for this purpose.

Collection Of Dataset Using Arduino Microcontroller and Python

ref[1]

Figure 7: Arduino Microcontroller

Now we have to prepare dataset for the training of the machine learning model. For this, we use Arduino microcontroller. In the setup, we connect input analog pins of this connected to 6 port antenna positive tereminal and one ground connected to the common terminal. Now, we write code to collect data from the antenna in real time and convert into a string for the further processing. For saving this data, we use python code in which we connect Arduino with Python script with the help of COM3(Communication Port 3 in computer). In this we sending antenna readings in the format of the string to overcome the delay problem in the Arduino.

Then we decode this string into the 6 float values of different six antennas. Then we collect 20 sample at different angles and then take average. And finally save this in the csv file for the further analysis.

Arduino Code ref[4]

In Arduino code, we first collect readings with the help of input analog pins i.e. A0,A1,A2,A3,A4 and A5. Then we convert them into a string for further analysis.

If we send these readings directly, we will face the problem of delay in readings, due to this sequence of the readings will not same as we send from adruino.The detailed code is given below-

```
float inputValue=0;
float inputValue1=0;
float inputValue2=0;
float inputValue3=0;
float inputValue4=0;
float inputValue5=0;
int analogOutputPin = 11;

void setup()
{
     pinMode(11,OUTPUT);
     pinMode(A0,INPUT);
     pinMode(A1,INPUT);
     pinMode(A2,INPUT);
     pinMode(A3,INPUT);
     pinMode(A4,INPUT);
     pinMode(A5,INPUT);
     Serial.begin(9600);
}
void loop()
{
    inputValue = analogRead(A0);
    inputValue1 = analogRead(A1);
    inputValue2 = analogRead(A2);
    inputValue3 = analogRead(A3);
    inputValue4 = analogRead(A4);
    inputValue5 = analogRead(A5);
    float temp = inputValue*5/1023;
    float temp1 = inputValue1*5/1023;
    float temp2 = inputValue2*5/1023;
    float temp3 = inputValue3*5/1023;
    float temp4 = inputValue4*5/1023;
    float temp5 = inputValue5*5/1023;
    // convert all float to string to avoid delay problem in values
    String str = String(temp, 4);
    String str1 = String(temp1, 4);
    String str2 = String(temp2, 4);
    String str3 = String(temp3, 4);
    String str4 = String(temp4, 4);
    String str5 = String(temp5, 4);
    Serial.println(str+","+str1+","+str2+","+str3+","+str4+","+str5);
    delay(2000);
}
```

Figure 8: Code for Arduino input and output

Python Script

```
import serial
import time
import pandas as pd
import numpy as np
import re


list=['COM1','COM2','COM3','COM4','COM5','COM6','COM7','COM8',
'COM9','COM10','COM11','COM12','COM13','COM14','COM15','COM16','COM17','COM18',]

COM1='COM1'
COM2='COM2'
COM3='COM3'
COM4='COM4'
COM5='COM5'
COM6='COM6'
COM7='COM7'
COM8='COM8'
COM9='COM9'
COM10='COM10'
COM11='COM11'
COM12='COM12'
COM13='COM13'
COM14='COM14'
COM15='COM15'
COM16='COM16'
COM17='COM17'
COM18='COM18'
COM19='COM19'
time.sleep(1)
```

Figure 9: Python script used

```
time.sleep(1)
ser = serial.Serial()
ser.baudrate = 9600

i=1

while True:
    time.sleep(.2)
    print(i)
    ser.port = list[i]
    try:

        ser.open()
        if ser.isOpen()==True:
            print('Connected')
            #print('arduino is on COMPORT'.join(i))
            break
        break

    except:
        print('Waiting...')
        i=i+1
        if i==18:
            print('Kindly remove usb cable and try again')
            break


print('Loading...')
index_val = 0
```

Figure 10: Python Script used

Model Training Using Polynomial Regression

```
try:
    DF1  = pd.read_csv("data1.csv",header=None)
    if DF1.shape[0]==1:
        DF1 = DF1.iloc[0]
    else:
        DF1 = DF1.iloc[-1]
    index_val = DF1.iloc[0]
    print(index_val)
    index_val+=5
except:
    print("Empty CSV file")


arr1 = [0.0,0.0,0.0,0.0,0.0,0.0]
index=0
ans = 0.0
```

Figure 11: Creation Of Dataframe

```
while True:
    "a1,a2,a3"
    temp = re.findall(r"[-+]?\d*\.?\d+|[-+]?\d+", ser.readline().decode('utf-8'))
    if temp==[]:
        continue
    print(temp)
    for j in range(len(temp)):
        arr1[j]+=float(temp[j])
    index=index+1
    if index==21:
        break


for elem in range(len(arr1)):
    arr1[elem] /=20.0

arr1.insert(0, index_val)
DF = pd.DataFrame(arr1).transpose()
DF.to_csv('data1.csv', mode='a', index=False, header=False)
print(DF)
```

Figure 12: extracting data from arduino

The next step to train our machine learning model on the collected dataset with help of Arduino and python.Now, we have to train this model on Polynomial Regression ML algorithm. Python code for same is given above.

Algorithm code

```python
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
from sklearn.model_selection import train_test_split
from sklearn.preprocessing import PolynomialFeatures
from sklearn.linear_model import LinearRegression
from sklearn.metrics import r2_score
import os

base_url = os.getcwd()
df=pd.read_csv(base_url+'/training data/6_port_data.csv')

def train_modal():
    # Dataframes
    X=(df.iloc[:,1:])
    y=df['Angle']
    y = pd.DataFrame(y, columns = ['Angle'])
    print(X,y)
    X_train, X_test, y_train, y_test = train_test_split(X,y, test_size=0.20, random_state=0)
    # Transform the input data into a polynomial feature space
    poly = PolynomialFeatures(degree=9)
    X_train_poly = poly.fit_transform(X_train)
    X_test_poly = poly.transform(X_test)
    # Initialize Linear Regression model
    reg = LinearRegression()
    # Fit the model to the training data
    reg.fit(X_train_poly, y_train)
    y_pred = reg.predict(X_test_poly)
    # Calculate R-squared score to evaluate the model
    r2 = r2_score(y_test, y_pred)
    print("R-squared score:", r2)
    print(y_test)
    print(y_pred)
    return reg,poly,y,X,X_test,y_pred,y_test
```

Figure 13: Polynomial regression script

```python
import matplotlib.pyplot as plt


def plot_Graph(y,X,X_test,y_pred,y_test,title):
    fig, (ax1, ax2) = plt.subplots(1, 2)
    fig.suptitle(title)
    ax1.plot(y,X)
    ax2.plot(y_test,X_test,c='blue',linestyle='dotted')
    ax2.plot(y_pred,X_test,c='red',linestyle='dashed')
    plt.show(block=False)
```

Figure 14: for plotting graph

Testing

The final stage of project is to test this machine learning model, to finding that how well it can work. In the other words we give live data to machine learning model, predict the value on this data and find the error for the testing, we write code for the collection of live readings from the antenna with the help of the Arduino microcontroller and the python script. In python script we take readings at the some interval delay. We collect first 20 samples and then find average of them and then give it to the machine learning trained model. It will give predicted angle. Then we show this angle in the terminal.

```
ser = serial.Serial()
ser.baudrate = 9600
# ---:Try to connect with arduino microcontroller:---
is_connected = True
# is_connected = connect_arduino(ser)

if is_connected:
    # ---:Training of model before live testing with antenna:---
    reg,poly,y,X,X_test,y_pred,y_test =  train_modal()
    # plot_Graph(y,X,X_test,y_pred,y_test,'Antenna Data training using Polynomial Regression')
    index=0
    ans_20=[0.0,0.0,0.0,0.0,0.0,0.0]
    while True:
        # res = read_values(ser)
        # print(res)
        res = [0.44989,0.20209,0.156405,0.01347,0.041055,0.4682]
        for i in range(len(res)):
            res[i] = float(res[i])
            ans_20[i]+=res[i]
        index+=1
        if index==20:
            index=0
            for elem in range(len(ans_20)):
                ans_20[elem]/=20.0
            input_arr = [ans_20]
            input_ = np.asarray(input_arr)
            X = poly.fit_transform(input_)
            print("Angle at => "+get_time()+"=>")
            print(round(predict_angle(X,reg)[0][0], 3))
            for elem in range(6):
                ans_20[elem]=0.0
        time.sleep(0.08)
else:
    print("Unable to connect with arduino. Try again...")
```

Figure 15: Script for testing

link for code

https://github.com/dishu987/DEP-Project

Results

Graph1 (Input data of 6 ports voltage gain vs angle)

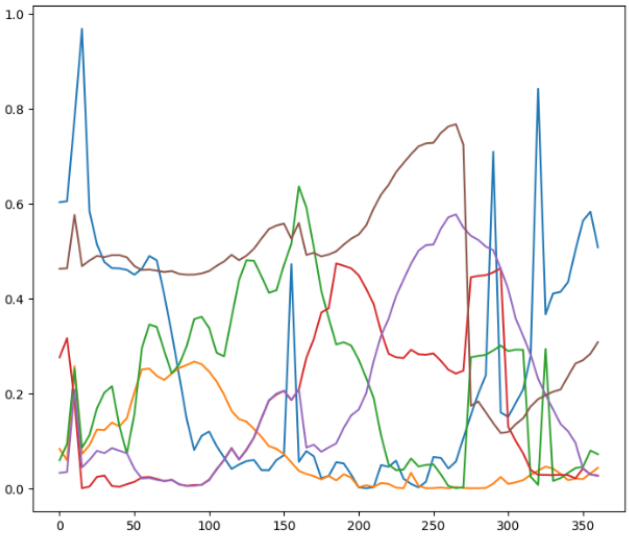


Figure 16: Six Port Inputs

Graph2 (Trained Output Angle(Red) vs Actual Angle(Blue))

The graph represents the relationship between the trained output of a machine learning algorithm and the actual output of an antenna. It shows how well the trained model can predict the actual output of the antenna at different angles. The graph is an important tool for evaluating the performance of the machine learning algorithm and can be used to identify areas where the model is accurate and areas where it needs improvement. The graph can also be used to make decisions about antenna design and optimization based on the predicted output.

Here, based on observations, we can state that we are using the difference of conjugative antenna readings to train our ML model. As a result, even if we adjust the antenna's height, our model will continue to function because all antenna readings

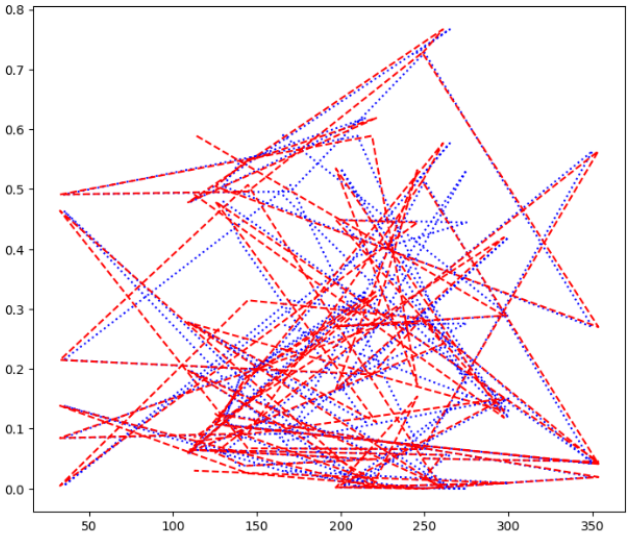


Figure 17: Output(red-predicted,blue-input data)

will change simultaneously.

If we change frequency then there is no effect on results because rectenna gives a DC output value that is independent of frequency.

Error

Due to interference we are observing difference in practical angle to actual angle of around 15-20 degree.

Applications

The orientation of objects using RF (Radio Frequency) signals has a wide range of applications across various fields such as-

Robotics : RF signals can be used in robotics to provide the correct position of any object . if we are making a big things like a car than car have many components to build properly so our RF signal provide targeted point of all things so easily robot make the car using all components without wasting the time .

Automotive vehicles :RF signal can be used for autonomous vehicles applications .likewise tracking and detecting the path . We are also used to improving driving (advanced driver assistance system) in vehicles and we avoid all kinds of accidents caused by careless driving and also use parking assistance to feed the data and accordingly train it

Navigation aids : RF signals can be used for blind peoples in many ways to find the orientation and position of any objects so that accordingly the blind peoples move their surroundings to avoid any kind of obstacle . first our signal is transmit on object and than receive that detect signal movement than given audio signal as using micro controller to blind peoples and indicate to the target position or location .

Industrial Automation : RF signals can be widely used to find the position of the same things . Its use to manufacture large things using object detection by the help of picking and pushing all those things can also be used to assemble the same manner of all things and accurately place and object oriented in belts.

Limitations

There are several limitations to using radio frequency (RF) signals for object orientation, including:

a) Proper Alignment of Object and Transmitter antenna: RF signals have tendency to be transmitted in front of the transmitter antenna in a straight line because we received maximum power on that port which is 0 degree angle of the transmitter antenna or we can say that just in front of the antenna.If there is any alignment miss match that our result will effect because we received less power. So Transmitter antenna must be in front of the receiver antenna with proper alignment.

b) Environmental Interference: RF signal is affected by obstacles such as noise,any movement,signal jumping that are present in the environment. These types of interference can affect accuracy of object orientation in the environment.

c) Hardware: We have limitation of Hardware that are receiving RF signals because Factor of antenna design, position of receiving (6 port) antenna, Interference can impact accuracy of our system.

Conclusion

We are collecting the data of voltage gain at specified angles using an arduino microcontroller. The received data from the arduino is saved into a CSV file. To train out ML Algorithms we use save data which is saved in csv file and Ml modal will predict the voltage gain at any angle within the range of collected data.

We have tried many ML Algorithms such as linear regression,Logarithmic ,SVM etc but Polynomial regression is very efficient and accurate for our orientation of objects using RF signal problem.After that we tested out modal by giving Live input data and it predict angle corresponding that voltage.

We are using ML algorithms in solving problems and also show the importance of Machine learning because ML has accuracy and ensures that data collection has zero error.We can say that ML has provided us good knowledge and upgraded user interest in research areas.

Problem statement “orientation estimation of objects using RF signals” solution can be used in many areas that can be solved by our model which we discussed in the application part.we can also further Implement algorithm model and try to make a device that can help humans to live an easier life.

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THANKS