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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2022 - 23

CERTIFICATE

This is to certify that the report entitled **ORIENTATION ESTIMATION OF OBJECT USING RF SIGNAL** submitted by us , to Department of Electrical Engineering in partial fulfillment of the B.Tech. degree in **Electrical Engineering** is a bonafide record of the seminar work carried out by them under our guidance and supervision. This report in any form has not been submitted to any other University or Institute for any purpose.

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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 bonafide work done by us under supervision of Dr. Ashwani Sharma .

This submission represents my ideas in my own words and where ideas or words of others have been included, We have adequately and accurately cited and referenced the original sources.

We also declare that we have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in my submission. We understand that any violation of the above will be a cause for disciplinary action by the institute or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma or similar title of any other University.

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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. The proposed method takes advantage of the fact that the reflected RF signals from an object exhibit characteristic changes in phase and amplitude as the object's orientation changes relative to the RF source.

The proposed method includes three main steps: RF signal acquisition, feature extraction, and orientation estimation. 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

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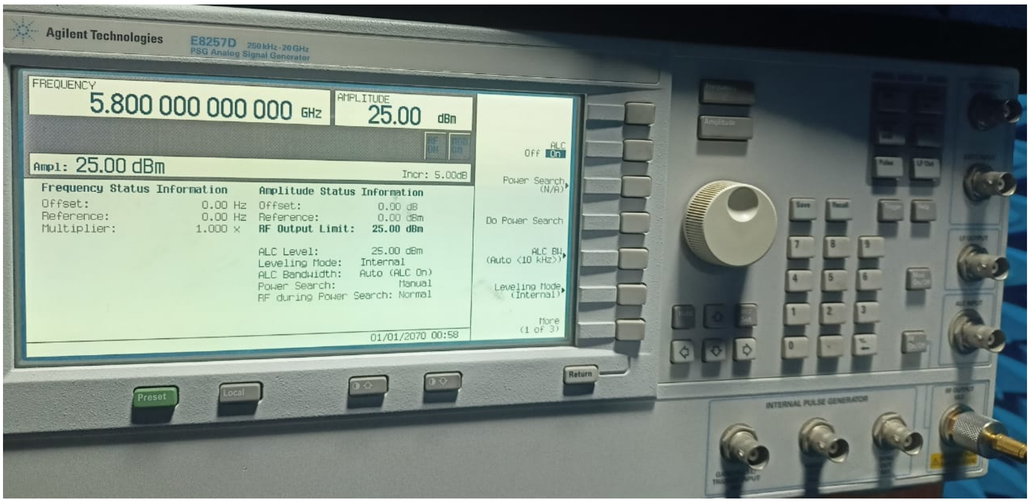

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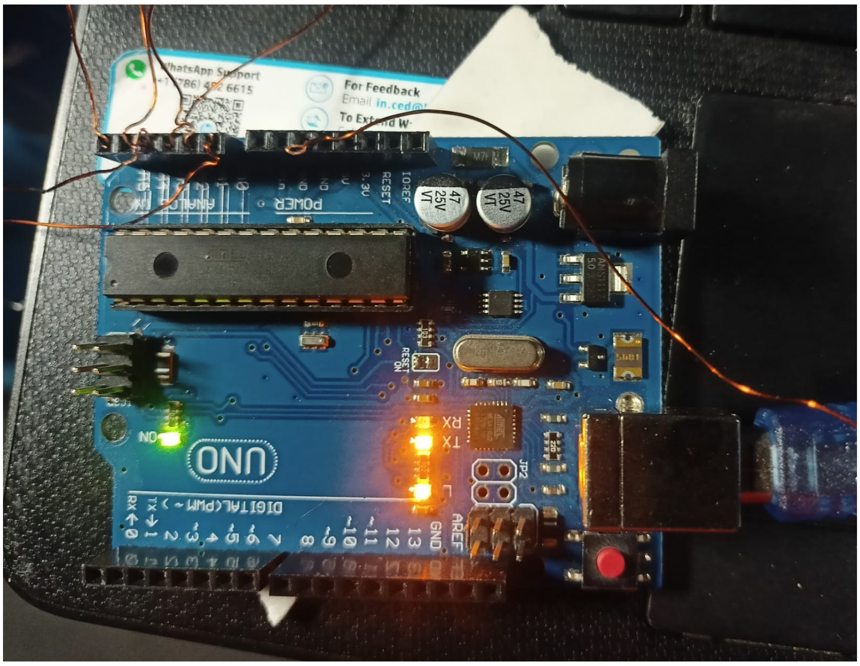

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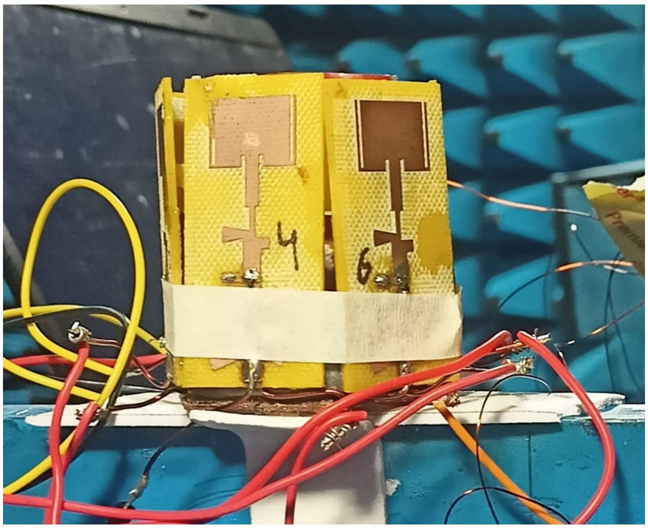

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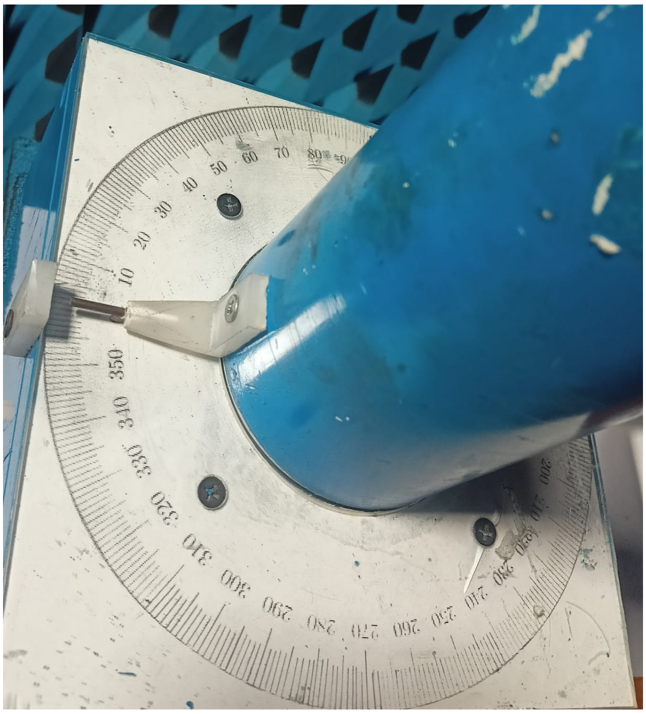

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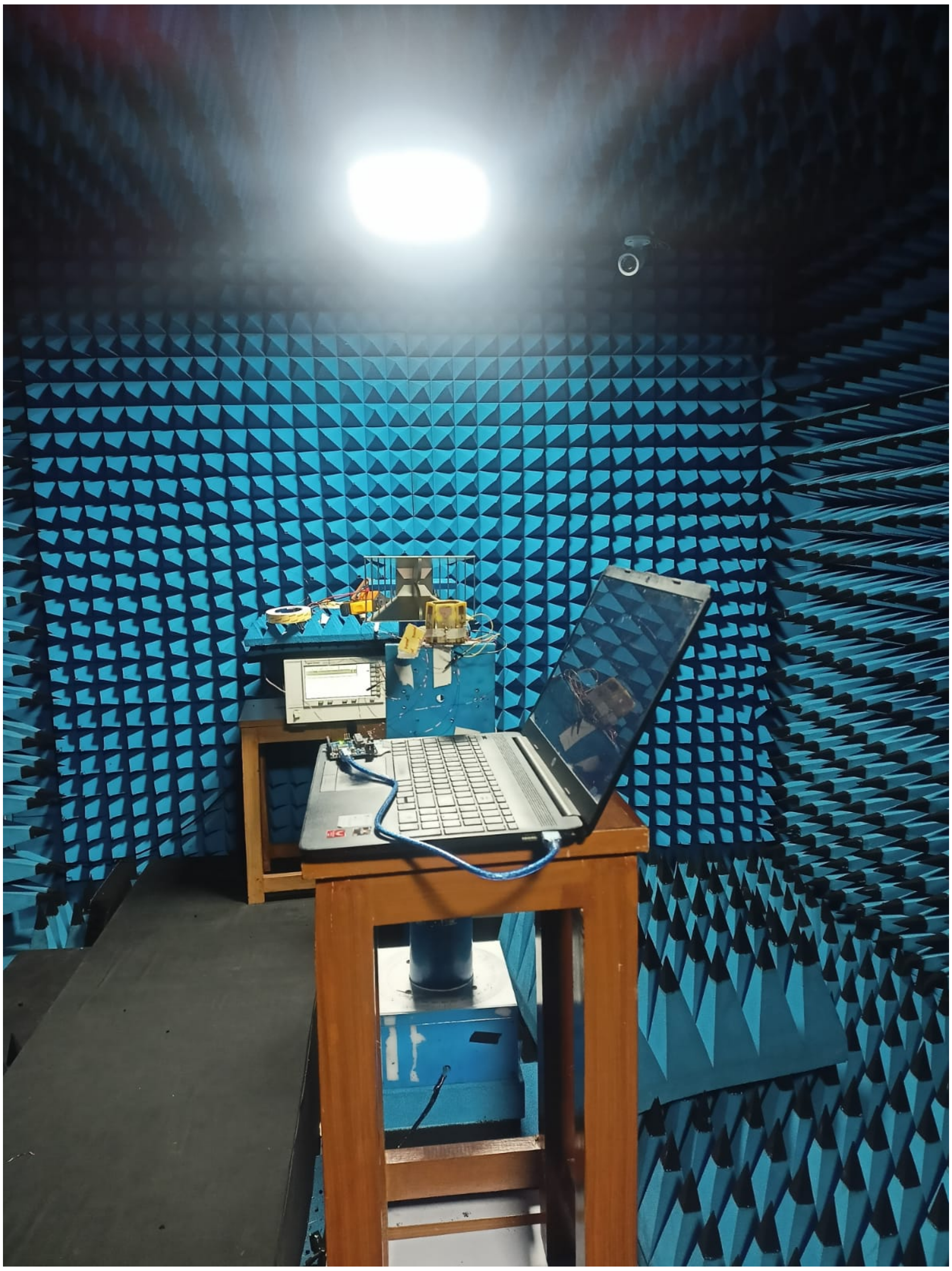

Introduction

Orientation estimation of objects using radio frequency (RF) signals is a technique that involves analyzing the characteristics of RF signals reflected or scattered by objects in order to determine their orientation in three-dimensional space. By analyzing the changes in the RF signals after interaction with an object, orientation estimation algorithms can deduce the object's orientation. These algorithms typically employ signal processing and statistical techniques to extract relevant features from the RF signals. These features are then processed to estimate the object's orientation parameters, which can be represented as angles or rotation matrices. We use six port antenna in which each port contains a rectenna that captures the RF signals and convert them to DC voltage.

The motivation behind orientation estimation of objects using RF signals lies in the potential for enabling a wide range of applications, including robotics, indoor navigation, object recognition,etc. by providing accurate and reliable information about the orientation of objects in the environment.

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. Other techniques include using machine learning algorithms, such as support vector machines, deep learning, and Kalman filters, to estimate object orientation from RF signal features. These techniques have shown promising results in various scenarios, such as indoor positioning, obstacle detection, and human gesture recognition.

Despite the promising results, there are several challenges in RF-based object orientation estimation. One major challenge is the complexity of RF signal propagation and scattering, which can be affected by various factors, such as environmental changes, interference, and noise. Accurate modeling of RF signal propagation and scattering is critical for reliable object orientation estimation. 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 electromagnetic waves with frequencies ranging from 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: A six-port antenna, also known as a vector antenna, is a special type of antenna that can measure both the magnitude and phase of the incident RF waves. It consists of six ports or connectors that are used to transmit and receive RF signals in different directions. The six-port antenna is capable of capturing the polarization and phase information of the RF waves, which can be utilized for orientation estimation of objects.

Arduino Microcontroller: Arduino is an open-source microcontroller platform that provides an easy-to-use interface for programming and controlling electronic devices. In the orientation estimation system, the Arduino microcontroller acts as the control center that interfaces with the six-port antenna to transmit and receive RF signals, and also processes and analyzes the received data.

Machine learning algorithms: Machine learning algorithms are used to analyze the received RF signals and estimate the orientation of the object. These algorithms are trained on a dataset that consists of labeled examples of RF signals and their corresponding object orientations. The machine learning algorithm which we use in this project is Polynomial Regression. This model can capture non-linear relationships between variables by fitting a non-linear regression line, which may not be possible with simple linear regression.

Methodology

The orientation estimation system using RF signals, six-port antenna, Arduino, and machine learning can be summarized in the following workflow:

1) RF Signal Transmission: The Arduino microcontroller generates RF signals and transmits them through the six-port antenna. The RF signals are directed towards the object whose orientation needs to be estimated.

2) RF Signal Reflection: The transmitted RF signals interact with the object's surface, where they are reflected, scattered, and absorbed. The reflected RF signals are received by the six-port antenna and converted into electrical signals.

3) Signal Processing: The received RF signals are processed by the Arduino microcontroller. The magnitude and phase information of the signals are extracted from the six-port antenna's output. The processed RF signals are then stored in a dataset for further analysis.

4) Dataset Creation: The processed RF signals are combined with the corresponding object orientations to create a labeled dataset. The dataset consists of RF signal features as input and object orientations as output labels.

5) Machine Learning Training: The labeled dataset is used to train machine learning algorithms. The machine learning algorithms learn patterns from the dataset and create a model that can predict the object orientation based on the RF signal features.

6) Model Validation: The trained machine learning model is validated using a separate dataset that was not used during training. The performance of the model is evaluated based on metrics such as accuracy, precision, recall, and F1 score. If the model's performance is satisfactory, it can be used for orientation estimation in real-time.

7) Orientation Estimation: Once the machine learning model is validated, it can be used to estimate the orientation of objects in real-time.

The accuracy and reliability of object orientation determination using RF signals can vary depending on the specific application, environmental conditions, and the quality of the RF signal. Robust algorithms, calibration, and signal processing techniques are often employed to improve the accuracy of orientation estimation using RF signals.

Machine Learning

In the actual world, we are surrounded by individuals who have the potential to learn from their experiences, as well as computers or robots that function on our orders. Can a machine, like a person, learn from prior experiences or data? So now comes Machine Learning's part.

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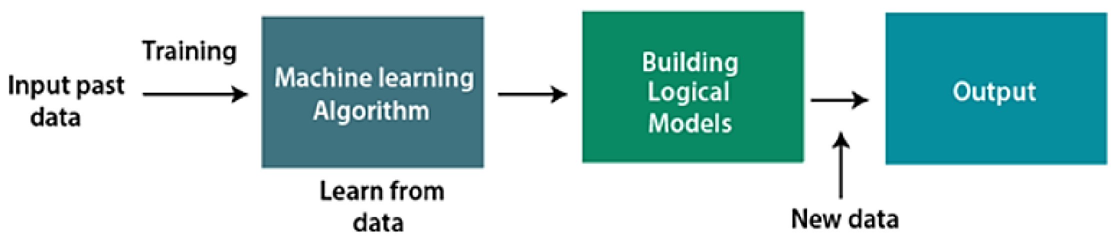


Features of Machine Learning

Machine learning uses data to detect various patterns in a given dataset. It can learn from past data and improve automatically. It is a data-driven technology. Machine learning is much similar to data mining as it also deals with the huge amount of the data.

Need Of Machine Learning

The need for machine learning is growing by the day. The necessity for machine learning stems from its ability to do tasks that are too complicated for a human to perform directly. As humans, we have some limits since we cannot access large amounts of data manually, therefore we need computer systems, and this is where machine learning comes in to help us. We can train machine learning algorithms by feeding them massive amounts of data and allowing them to autonomously examine the data, develop models, and anticipate the desired output. The performance of the machine learning algorithm is defined by the cost function and is dependent on the amount of data.

The value of machine learning may be simply grasped by looking at its applications. Machine learning is being employed in self-driving cars, cyber fraud detection, facial recognition, and Facebook friend recommendation, among other applications. Several leading firms, like Netflix and Amazon, have built machine learning algorithms that analyse user interest and propose products based on that data.

Classification of Machine learning

At a broad level, machine learning can be classified into three types:

1. Supervised learning:

Supervised learning is a form of machine learning approach in which we feed sample labelled data to the machine learning system in order to train it, and it predicts the output based on that. The system builds a model using labelled data to interpret the datasets and learn about each data. After training and processing, we test the model by supplying sample data to see if it predicts the precise output or not. The purpose of supervised learning is to connect input and output data. Supervised learning is dependent on monitoring, such like when a student learns something under the observation of a teacher. Spam filtering is one example of supervised learning.

Supervised learning can be grouped further in two categories of algorithms: • Classification • Regression

2. Unsupervised learning:

Unsupervised learning is a learning approach in which a machine learns without any supervision. The machine is trained given a collection of unlabeled, classified, or categorised data, and the algorithm must operate on the data without supervision. The purpose of unsupervised learning is to rearrange the incoming data into new features or a set of objects with similar patterns.

There is no predefined outcome in unsupervised learning. The machine attempts to extract helpful insights from the massive volume of data. It is further divided into two types of algorithms: • Clustering • Association

3. Reinforcement learning:

Reinforcement learning is a feedback-based learning strategy in which a learning agent is rewarded for correct actions and penalized for incorrect actions. With these feedbacks, the agent automatically learns and improves its performance. The agent interacts with and investigates the environment in reinforcement learning. An agent's purpose is to earn the most reward points possible, so it enhances its performance. Reinforcement learning is demonstrated by the robotic dog, which automatically learns the movement of his 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 challenge lies in identifying an appropriate machine-learning algorithm that can accurately predict the voltage gain based on the available input variables.

To address this challenge, our group worked with various machine learning algorithms and tested their performance on the dataset. The goal was to identify an algorithm that could provide the most accurate predictions of voltage gain at a particular angle. After thorough experimentation and evaluation, the group found that polynomial regression yielded the best results for this problem.

We trained the polynomial regression algorithm on the dataset to predict voltage gain at corresponding angles. The training process involved providing the algorithm with input data and corresponding output data, and the algorithm adjusted its parameters to minimize the difference between predicted and actual outputs. The resulting model was then tested on a validation set to evaluate its accuracy and generalization capability.

In conclusion, the problem statement involved predicting voltage gain at a specific angle for a given antenna data set using machine learning algorithms. The group experimented with various algorithms and identified polynomial regression as the most effective technique for this problem. The resulting model was trained on the dataset and evaluated on a validation set, achieving accurate predictions of voltage gain at corresponding angles.

Collection Of Dataset Using Arduino Microcontroller and Python

We concern the collection of a dataset using an Arduino microcontroller connected to an antenna setup, and the use of a Python script to save the collected data in a CSV file. The objective of this data collection is to obtain information on the voltage gain at a particular angle for the antenna, to use this data for further analysis or prediction.

To collect the data, an Arduino microcontroller is used to interface with the antenna setup and obtain voltage gain measurements at specific angles. The microcontroller collects data for 20 different voltage gain readings, each taken at a particular angle, with a delay interval between each reading. This voltage gain data is transmitted via the COM3 port of a computer, where a Python script is used to receive and process the data.

In the Python script, the received data is saved in a CSV file, which can be used for further analysis or prediction. The CSV file contains the voltage gain readings collected by the Arduino microcontroller, as well as the corresponding angle for each reading.

The data collection process involves multiple steps, including setting up the Arduino microcontroller and the antenna setup, establishing communication between the microcontroller and the computer, and developing a Python script to receive and process the collected data. These steps require technical expertise and careful attention to detail to ensure that the collected data is accurate and reliable.

Arduino Code

```
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);
}
```

Python Script

```python
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)
```

```python
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
```

```python
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
```

```python
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)
```

Model Training Using Polynomial Regression

The next step to train the collected data using the machine learning algorithm polynomial regression. This step involves inputting the collected data into the polynomial regression algorithm, which will learn the relationship between the input variables (voltage gain readings at specific angles) and the output variable (voltage gain at a particular angle). The aim is to use this trained model to make accurate predictions of voltage gain at any angle within the range of the collected data. This step is crucial in utilizing the collected data to its full potential and can have implications in antenna design and optimization.

Algorithm Code

```
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
```

Plot Graph

```
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)
```

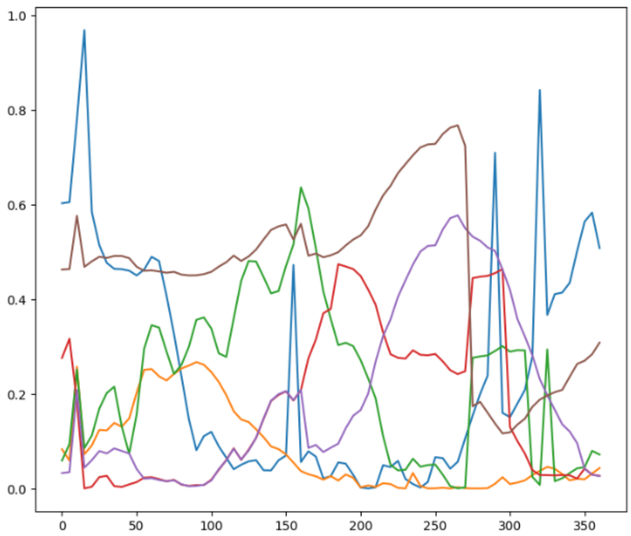
Testing

The final stage of the project involves testing the machine learning model by feeding it live input data and observing its performance in predicting the voltage gain at a particular angle. This stage is critical in evaluating the effectiveness of the trained model in real-world scenarios. The live input data is fed into the model, and the output is compared with the actual voltage gain measured at the given angle. This stage can reveal any discrepancies between the model's predictions and the actual output, allowing for further refinement of the model. Overall, the testing stage is crucial for determining the practical viability of the machine learning model for predicting voltage gain at a specific angle.

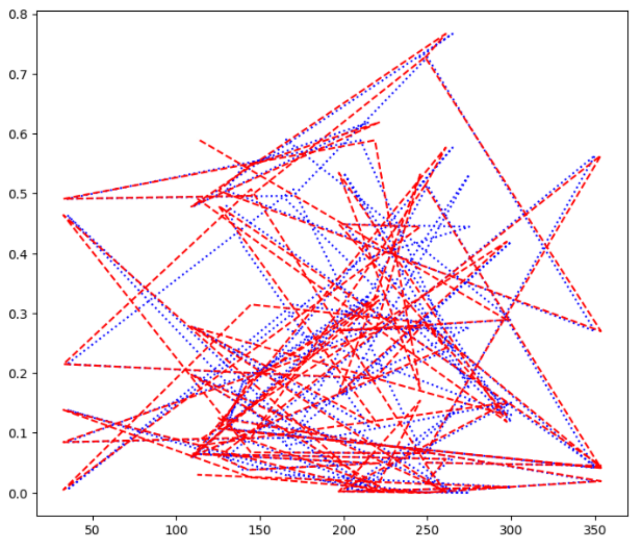
```python
ser = serial.Serial()
ser.baudrate = 9600
# ---:Try to connect with arduino microcontroller:---
is_connected = True
# is_connected = connect_arduino(ser)

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...")
```

Results

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



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 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-based object orientation can be used in robotics for object detection, tracking, and manipulation. For example, in autonomous robots, RF signals can be used to identify the location and orientation of objects in their environment, enabling robots to navigate, grasp, and manipulate objects with greater accuracy and efficiency.

Automotive and Autonomous Vehicles: RF-based object orientation can be used in automotive and autonomous vehicle applications for object detection, localization, and tracking. For example, RF-based orientation can be used in advanced driver-assistance systems (ADAS) to detect and track objects around a vehicle, enabling features such as collision avoidance, lane keeping, and parking assistance.

Navigation aids: RF signals can be used to create a navigation system that helps blind individuals navigate through indoor or outdoor environments. For example, RF beacons can be installed at key locations, such as doorways or intersections, to provide orientation cues. A blind person can carry a receiver that detects the RF signals from the beacons and provides audio or tactile feedback to indicate the direction or distance to the target location.

Industrial Automation: RF-based object orientation can be used in industrial automation applications for object detection, picking, and placing. For example, in manufacturing or warehousing environments, RF-based orientation can be used to accurately locate and orient objects on conveyor belts, assembly lines, or storage racks.

Limitations

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

a) Line of Sight (LOS) Requirement because RF signals are typically transmitted in straight lines and can be obstructed by obstacles such as walls, buildings, and other objects. This means that for accurate orientation using RF signals, there must be a clear line of sight between the transmitter and the receiver.

b) Environmental Interference affects RF signals by interference from other RF devices or environmental factors, such as electromagnetic noise, competing signals, and signal jamming. This interference can disrupt the accuracy of object orientation measurements, particularly in crowded or complex environments.

c) Hardware used for transmitting and receiving RF signals, such as antennas and sensors, can also introduce limitations. Factors such as antenna design, placement, and quality can impact the accuracy and reliability of orientation systems.

Conclusion

In conclusion, the problem statement involved collecting data on voltage gain at specific angles for an antenna setup using an Arduino microcontroller and saving it in a CSV file. The next step was to use machine learning algorithms to train this collected data and predict the voltage gain at any angle within the range of collected data. Polynomial regression was found to be the most effective algorithm for this regression problem. Finally, the trained model was tested using live input data to predict the voltage gain at a particular angle, providing a practical evaluation of the model's effectiveness.

This project showcases the potential of machine learning algorithms in solving complex problems in antenna design and optimization. It also highlights the importance of careful data collection and processing to ensure the accuracy and reliability of the trained model. Overall, the project provides valuable insights into the use of machine learning in antenna design and lays the groundwork for further research in this area.

The orientation estimation of objects using RF signals is a promising and rapidly evolving field that has the potential to revolutionize many industries and applications. Ongoing research and development efforts in this area are likely to lead to further advances and breakthroughs in the coming years.

THANKS