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Wireless Power Transfer Using Beamforming

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Abstract

This study oriented project explores the concept of wireless power transfer using beamforming techniques. Wireless power transfer has gained significant attention in recent years due to its potential to revolutionize the way electronic devices like smartphones, IoT devices, Neuralink are powered. Beamforming, a technique that focuses electromagnetic waves towards a specific direction, can enhance the efficiency and range of wireless power transfer systems. The project aims to investigate the feasibility and performance of a wireless power transfer system that utilizes beamforming and Ultra-Wideband (UWB) technology for device localization. The study employs theoretical analysis, block diagrams, and thorough research to design a system capable of achieving WPT goals using Beamforming. The findings demonstrate the potential of beamforming in improving the efficiency and range of wireless power transfer, while UWB technology enables accurate device localization. The project highlights the significance of this technology in various applications, including consumer electronics, industrial automation, and medical devices.

Introduction

1. **Background and motivation:** Wireless power transfer has emerged as a promising technology to eliminate the need for cords and batteries in electronic devices. The convenience and flexibility offered by wireless power transfer have the potential to transform various industries. However, the efficiency and range of current wireless power transfer systems are limited. Beamforming techniques have been proposed to address these challenges by focusing the electromagnetic waves towards the receiver, thereby increasing the power transfer efficiency and range.
2. **Objectives and scope of the project:**
    - To study the principles and techniques of wireless power transfer and beamforming
    - To investigate the use of UWB technology for accurate device localization
    - To identify potential applications and future research directions
3. **Overview of wireless power transfer and beamforming:** Wireless power transfer involves the transmission of electrical energy from a power source to a receiver without the use of wires. The most common methods of wireless power transfer include inductive coupling, resonant coupling, and electromagnetic radiation. Beamforming is a technique that uses an array of antennas to create a focused beam of electromagnetic waves towards a specific direction. By concentrating the energy towards the receiver, beamforming can significantly improve the efficiency and range of wireless power transfer systems.
4. **Significance of the study:** This study contributes to the advancement of wireless power transfer technology by exploring the integration of beamforming and UWB localization. The findings of this project can guide the development of efficient and long-range wireless power transfer systems that can be applied in various domains, such as consumer electronics, industrial automation, and medical devices. The study also highlights the potential of UWB technology for accurate device localization, which is crucial for the optimal performance of beamforming-based wireless power transfer systems.

Device Localisation Techniques

Parameter	WPS	UWB	RFID	IR Sensors
Accuracy	Moderate (1-10 meters)	High (<30 cm)	Moderate-High (depends on type)	Moderate-High (depends on setup)
Range	Moderate (up to 50 meters)	Moderate (10-30 meters)	Short-Long (up to a few meters for passive tags, up to 100 meters for active tags)	Short (up to 10 meters)
Infrastructure Needs	Existing Wi-Fi network	Requires UWB transceivers	Requires RFID tags and readers	Requires IR emitters and receivers
Cost	Low (uses existing infrastructure)	High (specialized equipment)	Low for passive tags, high for active tags and readers	Low-Moderate (common components)
Power Consumption	Low	Moderate-High	Very low for passive tags, moderate for active tags	Low
Line of Sight	Not required	Not strictly required, but beneficial	Not required for passive tags, beneficial for active tags	Required
Environmental Impact	Susceptible to signal interference	Susceptible to multipath and obstructions	Susceptible to electromagnetic interference	Susceptible to ambient light and obstructions
Scalability	High	Moderate	High for passive tags, moderate for active tags	Low-Moderate
Data Rate	High	High	Low	Low-Moderate
Security	Moderate (encryption possible)	High (difficult to intercept)	Moderate-High (depends on implementation)	Moderate (can be line-of-sight)

UWB was selected due to:

Higher Accuracy, Reduced Interference, Dedicated Spectrum, Energy Efficiency, Scalability and Stability.

Empowering UWB Data with a Backpropagation Algorithm:

The following code was used to generate synthetic data for a smartphone located at coordinates: (5,8,2).

```
import numpy as np

import pandas as pd

room_length = 10

room_breadth = 10

room_height = 5

smartphone_x = 5

smartphone_y = 8

smartphone_z = 2

anchor1_coords = np.array([0, 0, 0])

anchor2_coords = np.array([room_length, 0, 0])

anchor3_coords = np.array([0, room_breadth, 0])

num_data_points = 1000

data = []

for _ in range(num_data_points):

    noise_x = np.random.normal(0, 0.1)

    noise_y = np.random.normal(0, 0.1)

    noise_z = np.random.normal(0, 0.1)

    smartphone_coords = np.array([smartphone_x + noise_x, smartphone_y + noise_y, smartphone_z + noise_z])

    dist1 = np.linalg.norm(smartphone_coords - anchor1_coords)

    dist2 = np.linalg.norm(smartphone_coords - anchor2_coords)

    dist3 = np.linalg.norm(smartphone_coords - anchor3_coords)

    noise_dist1 = np.random.normal(0, 0.05)

    noise_dist2 = np.random.normal(0, 0.05)
```

```
    noise_dist3 = np.random.normal(0, 0.05)

    dist1 += noise_dist1

    dist2 += noise_dist2

    dist3 += noise_dist3

    data.append([dist1, dist2, dist3, smartphone_x + noise_x, smartphone_y + noise_y, smartphone_z + noise_z])

df = pd.DataFrame(data, columns=['anchor1_dist', 'anchor2_dist', 'anchor3_dist', 'smartphone_x', 'smartphone_y', 
'smartphone_z'])

df.to_csv('synthetic_uwb_data.csv', index=False)
```

Then a model was trained on this data and it was used to predict the location of the same smartphone based on the data stored in the CSV file. Code for the model:

```
import numpy as np

import pandas as pd

from sklearn.model_selection import train_test_split

from sklearn.preprocessing import MinMaxScaler

from keras.models import Sequential

from keras.layers import Dense


data = pd.read_csv('synthetic_uwb_data.csv')

X = data[['anchor1_dist', 'anchor2_dist', 'anchor3_dist']]

y = data[['smartphone_x', 'smartphone_y', 'smartphone_z']]

scaler = MinMaxScaler()

X_scaled = scaler.fit_transform(X)


model = Sequential()

model.add(Dense(64, activation='relu', input_shape=(3,)))

model.add(Dense(32, activation='relu'))

model.add(Dense(3, activation='linear'))
```

```python
model.compile(optimizer='adam', loss='mse')

model.fit(X_scaled, y, epochs=100, batch_size=32)


anchor1_dist = 9.61201413421608

anchor2_dist = 9.606368479035721

anchor3_dist = 5.8270497371371475


input_data = np.array([[anchor1_dist, anchor2_dist, anchor3_dist]])

input_data_scaled = scaler.transform(input_data)


predicted_location = model.predict(input_data_scaled)


print("Actual Location:\n X: 5\n Y:8\n Z:2")

print("Predicted Location:")

print("X:", predicted_location[0][0])

print("Y:", predicted_location[0][1])

print("Z:", predicted_location[0][2])
```

It gave the following output:

```
Actual Location:
X: 5
 Y:8
 Z:2
Predicted Location:
X: 5.0279903
Y: 7.945837
Z: 2.02369
PS D:\UWB-Backpropagation\V2>
```

For more details, refer to the full presentation: RF WPT using Beamforming by Deven Jain

References

- https://airfuel.org/wireless-charging-standards/
- https://www.hindawi.com/journals/scn/2021/8817569/
- https://www.lumenci.com/research-articles/ultrawideband#:~:text=How%20UWB%20Senses%20Object%20Motion%20and%20Its%20Relative%20Position%3F
- https://www.mdpi.com/1424-8220/20/21/6278#:~:text=angle%2Dof%2Darrival%20of%2
- https://atmosic.com/wp-content/uploads/2021/11/ATM3-Product-Brief-ATM32xx-PB-0056.pdf
- https://www.mouser.com/applications/rf_energy_harvesting/
- https://www.allaboutcircuits.com/technical-articles/wireless-rf-energy-harvesting-rf-to-dc-conversion-powercast-hardware/

Conclusion

In conclusion, this study oriented project has successfully explored the concept of wireless power transfer using beamforming techniques and UWB technology for device localization. Through theoretical analysis, research and block diagrams, a comprehensive understanding of the principles, techniques, and performance of a beamforming-based wireless power transfer system has been achieved. The study has provided valuable insights into the potential of this technology and its application in various domains. With the completion of this project, a solid foundation has been laid for the future development and implementation of efficient and long-range wireless power transfer systems. The knowledge and understanding gained from this study will serve as a guiding light for the actual construction of a wireless power transfer system using beamforming, bringing us one step closer to realizing the vision of a wirelessly powered future.

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