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Radio Fence: Unauthorized Signal Localization on Amateur Radio Band

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Abstract: Misuse of amateur radio frequencies by non-licensed transmitters leads to interference, problems and security threats for the amateur radio communication services. In this work, we introduce Radio Fence that is a low cost compact radio direction finding (RDF) solution that helps locate suspicious radio frequency transmissions in the amateur radio bands. Radio Fence uses directional antennas, software-defined radio receivers, GPS sensor, and signal angle estimation algorithms to determine the direction of arrival of RF signals. With the help of triangulation and trigonometric techniques, the geographical location of the signal source can be calculated. The prototype implementation of Radio Fence includes rdfs (radio direction finder system and host system). Experimental evaluation demonstrates the feasibility of accurate signal localization for educational and regulatory use cases.

I. INTRODUCTION

Amateur radio communication is widely used not just by hobbyists but also in emergency situations and technical experimentation. But one problem that comes up is unauthorized transmissions. These signals can interfere with licensed users and sometimes make communication unreliable.

Most professional direction-finding systems are not really made for students or small projects. They are expensive, complicated, and not easy to set up. Because of that, we wanted to build something simpler which still does the job.

So the idea behind this project is pretty straightforward — detect the direction of a signal and then try to figure out where it is coming from. The system uses signal strength and antenna movement to estimate direction, and then applies basic geometry to locate the source.

II. RELATED WORK

Radio Direction Finding has already been used in many areas like defense systems, aircraft navigation, and telecom operations. There are several well-known techniques such as phased arrays, Yagi antennas, Doppler-based tracking, and TDOA methods.

These systems are quite accurate, no doubt, but they also come with higher cost and complexity. That makes them difficult to use in student-level projects.

With the availability of SDR platforms like RTL-SDR and GNU Radio, things have become more accessible. People can now experiment with RF systems without needing very expensive equipment, which is honestly what made this project possible.

III. METHODOLOGY

A. Hardware Design

The system is built using small RDF nodes. Each node works on its own and detects signals independently. A Raspberry Pi is used for processing, and an RTL-SDR is connected to receive signals.

For direction detection, we designed a parabolic antenna setup. The antenna is mounted on a rotating platform using a stepper motor. This allows it to scan signals from all directions.

AGPS module is also added so that each node knows its own location. All this data is then sent to a central system over network.

B. Signal Detection

The way direction is found is actually simple. The antenna keeps rotating and at each angle, signal strength is measured. The angle where signal strength is highest is taken as the direction of the source.

It's not perfect always, but it works good enough in most cases. Small variations can happen depending on environment and noise.

C. Real-Time Data Transmission

The RDF node continuously sends collected data to a central host system using UDP/IP communication. The transmitted parameters include:

- 1) Angle of Arrival (AoA)
- 2) Signal gain
- 3) GPS coordinates
- 4) Center frequency
- 5) Bandwidth
- 6) Node identification

This enables centralized monitoring and supports multi-node synchronization for improved accuracy.

D. Software Implementation

The system software is built using:

- 1) Python-based processing
- 2) RTL-SDR for signal acquisition
- 3) Motor control algorithms
- 4) GPS data processing
- 5) PyQt-based graphical interface
- 6) CesiumJS for 3D visualization

The host interface provides:

- Real-time radar sweep display
- Signal strength monitoring
- Remote control of frequency and bandwidth
- Live mapping of RDF nodes
- Visualization of signal source direction

At present, one RDF node has been successfully integrated with live map visualization.

E. Triangulation Model

To find the actual location of the signal, we use triangulation. Basically, if two nodes detect the same signal from different directions, we draw lines in those directions.

Where those lines meet is the estimated position of the transmitter. This method works better when signals are clear and there is less interference.

IV. RESULTS AND CURRENT PROGRESS

We were able to build and test a working prototype of the system. It can detect signals and show their direction in real time.

Some of the main things that are working include:

- Signal direction detection using antenna
- Continuous rotation scanning
- Real-time signal strength measurement
- GPS tracking
- Data transmission to host system
- Visualization on map

The system is not extremely precise, but it gives a good approximation which is useful for this type of setup.

A. Real-Time Radar Visualization

While working on the antenna design, we initially tried a few different options like horn and helical antennas. But in practice, they were not very suitable for our use case, mainly because of frequency constraints and size issues.

Since the system operates in the VHF and UHF amateur bands (around 145 MHz and 435 MHz), antenna dimensions became a major concern. Larger wavelengths meant physically bigger structures, which were not easy to mount on a rotating setup.

To deal with this, we switched to a parabolic reflector-based design. A dual-band antenna was placed at the focal point, acting as the feed. This helped in concentrating signals coming from a particular direction, improving gain without making the system too bulky. Overall, this setup gave a good balance between size, usability, and performance.



Fig. 1. Real-time radar sweep showing signal gain variation with antenna angle

B. Antenna-Based Direction-Finding System Performance

The parabolic reflector plays an important role in improving direction detection. It focuses incoming RF signals onto the feed antenna, which increases the received signal strength when the antenna is aligned correctly.

During testing, we could clearly notice a peak in signal strength when the antenna was pointing towards the transmitter. This made it easier to estimate the Angle of Arrival (AoA) with reasonable accuracy.

Compared to other antenna configurations we looked at earlier, this design turned out to be more practical. It is compact enough to be mounted on the rotating platform and still provides decent directional performance for both frequency bands.



Fig.2. Custom parabolic directional antenna

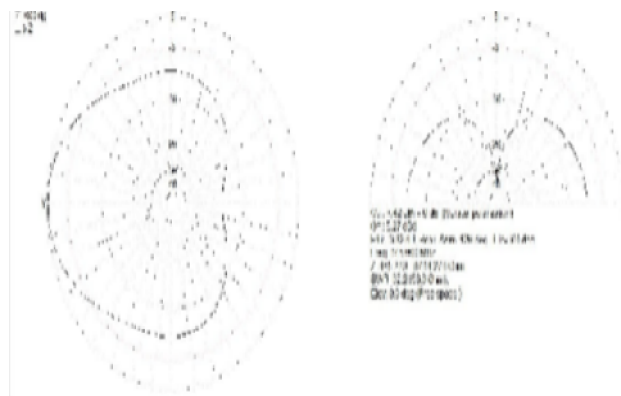


Fig.3.1. Azimuth–Elevation Radiation Pattern of the Proposed Antenna

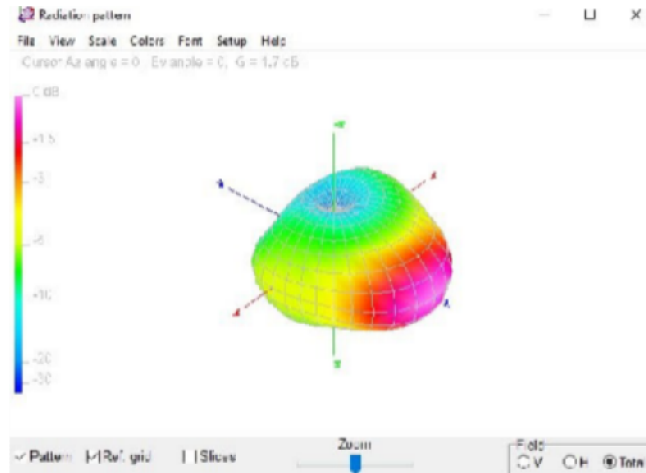


Fig.3.2.Three-DimensionalRadiationPatternofthe Antenna

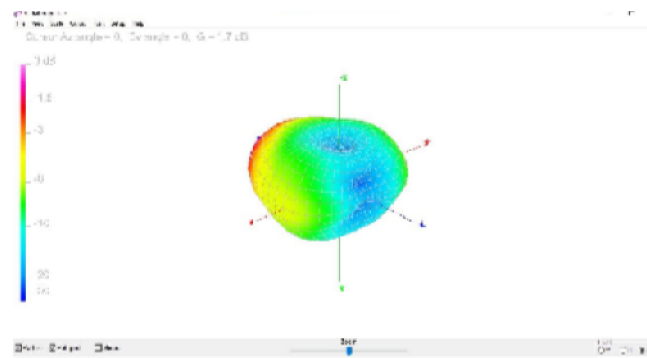


Fig. 3.3. Three-Dimensional Radiation Pattern of the Antenna

C. Real-Time Mapping and Node Visualization

To better understand what the system is detecting, a real-time mapping feature was added. Using a 3D map interface, the position of the RDF node is continuously updated based on GPS data.

The detected signal direction is shown as a line originating from the node. This makes it easier to visually interpret where the signal might be coming from instead of just looking at numbers.

It also helps when observing signal behavior over different locations, which is useful during testing.

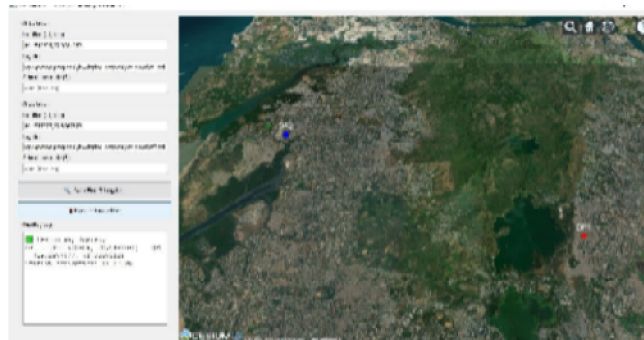


Fig. 4. Live Cesium map visualization of RDF node and detected signal direction

D. Triangulation Simulation

To check how well the system can estimate the source location, triangulation was tested using simulations. Multiple RDF nodes were placed at known coordinates, and each node provided a direction based on its AoA measurement.

These directions were plotted as lines, and their intersection point was calculated. The entire process was visualized in real time using the mapping interface.

From the results, it was clear that using two nodes gives much better accuracy compared to a single node. Still, small errors can happen depending on signal conditions and alignment, so results are not always perfect.

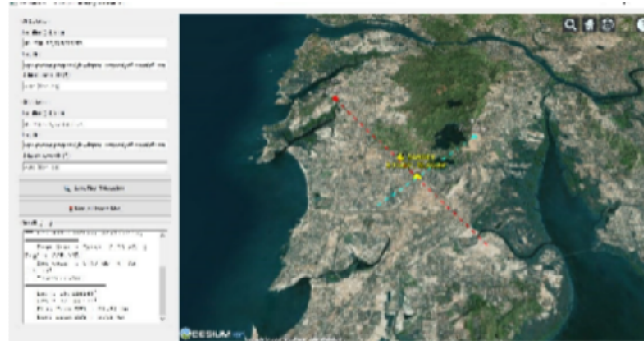


Fig. 5.1. Real-Time Cesium Map Showing RDF Node Position and Detected Signal Direction

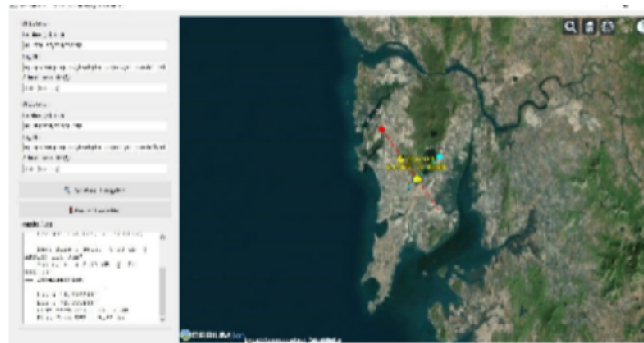


Fig. 5.2. Multi-Node Direction Visualization for Signal Localization on Cesium Map

E. System Integration and Data Communication

All the different parts of the system—SDR, antenna rotation, GPS module, and communication—were integrated and tested together. The node continuously sends data such as signal direction, strength, and location to the host system. This allows real-time monitoring without much delay. The system runs smoothly most of the time, although sometimes small delays or fluctuations can be noticed.

Overall, the integration shows that a distributed RF detection system like this can actually be built using low-cost components. It may not be perfect, but it works well enough for practical understanding and basic applications.

V. DISCUSSION

One good thing about this system is that it is low cost and portable. Compared to professional RDF systems, it is much easier to build and use. But there are some limitations also. Signal reflections can affect accuracy, and calibration of antennas is important. Also with only one node, location estimation is not very accurate.

Using two or more nodes improves results a lot, so that is something to expand in future.

VI. CONCLUSION

In this project, we built a simple system to detect and locate unauthorized radio signals. The idea was to make something affordable but still useful.

The results show that it is possible to estimate signal direction and location using basic components like SDR, GPS and directional antennas. While it is not perfect, it works well enough for learning and small-scale applications.

VII. ACKNOWLEDGMENT

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