Passive Radar on Moving Platforms: Experimental Setup and First Results

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ABSTRACT

In this paper, we present our experimental passive radar setup for mobile platforms utilizing DVB-T as an illumination source and discuss the results of the observation campaign conducted on the Gulf of Finland. Finally, we outline our plans for a drone mounted passive radar array system.

1.0 INTRODUCTION

In recent years, there has been increasing interest in passive coherent location systems. Patria, a company with a long history in electronic warfare and passive sensor (ELINT, ESM) research, has developed a commercially available state-of-the-art passive radar system, MUSCL, that exploits both FM and DVB-T broadcasting signals for covert sensing and surveillance. However, volatile situations often require more mobile solutions. Consequently, interests have shifted to include sensor systems mounted on various mobile platforms operating independently, or as a part of larger surveillance sensor network. Therefore Patria has recently commenced a research project with a goal of developing a passive radar system for a deployment on moving platforms.

This paper is organized as follows: In section 2, the equipment used for maritime and ground-based trials and planned future upgrades are described.

The signal processing methods used for data post-processing are briefly outlined in section 3. In addition, we show the results of land-based trial during which the performance of the mobile car-mounted antenna array system was evaluated by observing a cooperative Cessna-172 airplane and a drone, in a signaling environment consisting of several interfering wind turbines.

To investigate peculiarities and challenges of the maritime environment, an observation campaign was launched on Gulf of Finland, surveilling both marine and airborne traffic by utilizing ship-based antenna array receiver tuned to DVB-T frequency band. In section 4 we present the results of our experiments and describe the issues we have encountered in our observation campaigns.

Finally, in section 5 we discuss our plans for developing a drone-mounted passive radar system, to be installed in a small commercially available drone, for detecting ground moving targets, airplanes, and UAVs.

2.0 MEASUREMENT SETUP

The equipment used in the observation campaigns comprises of an antenna array, a preamplifier, 8-channel receiver and a standard laptop with Thunderbolt interface for recording the signal for offline processing.

In Figure 1 the car-mounted passive radar system is shown. It consists of six antennas in a uniform linear array, spacing 0.5 meters. Two additional antennas on other side are used for capturing the reference signal. Individual antenna gain is approximately 9 dBi.

Striving for cost-effectiveness while maintaining sufficient performance, off-the-shelf components were used where possible. Moreover, the antenna structure was designed to easily erectable, as due to vehicle regularizations antenna support structure had to be transferred inside the van and deployed on-site.

Figure 1: Car-mounted passive radar system.

For typical DVB-T frequencies (470-700 MHz) antenna spacing is too sparse and grating lobes will occur (Figure 2), hindering the direction-of-arrival estimation and beamforming. Consequently, the antenna array shown in Figure 1 will be upgraded to allow unambiguous beamforming without grating lobes.

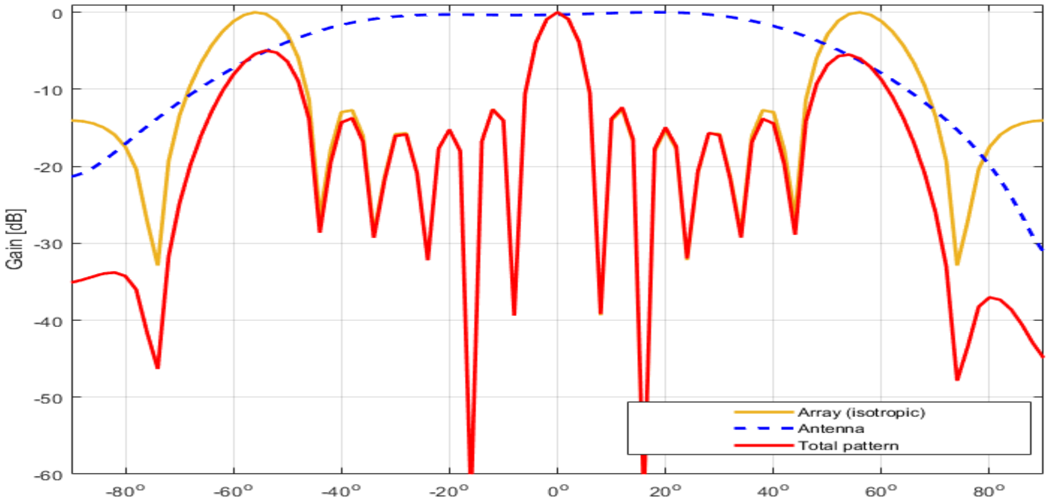

Figure 2: Radiation pattern of the antenna array. Sparse antenna spacing causes grating lobes at ±55 degrees.

3.0 SIGNAL PROCESSING

The acquired signal is subjected to the standard processing chain: coherent sampling, IQ-demodulation and filtering. The signals from all the channels are recorded by a laptop for further offline processing.

The DVB-T signal from the reference antenna is decoded and reconstructed [1] , making the use of OFDM-based clutter cancellation methods feasible. In particular, the ECA+ method [2] have proved to be effective in cancelling the direct signal and clutter/interference discretes present in the surveillance channel. After the direct signal removal, signal is subjected to either reciprocal filter [3] or matched filtering [4]. In most of our trials reciprocal filter is preferred, but matched filtering is occasionally used when target distance is longer than the cyclic prefix of OFDM symbol, as the SNR loss of reciprocal filter becomes unacceptable. Finally, after beamforming the signal is sent to CFAR processor [4].

Clutter spreading due to platform motion is a major concern in mobile passive radar. While the application of the Displaced Phase Center Antenna (DPCA) method [5] facilitates target detection inside the clutter region, its dependence on the accurate knowledge of receiver velocity and vulnerability to antenna mismatches causes the performance to be inconsistent.

Other space-time adaptive processing (STAP) methods offer more flexibility and tolerance for receiver errors, but stochastic STAP approach requires a good estimate of covariance matrix from secondary data which, due to heterogeneous clutter environment is often unachievable. In particular, the abundance of wind turbines on the surveillance area further deteriorates clutter estimation and hence target detection. In our trials, stochastic STAP performance was inferior to DPCA. However, in some cases RD-STAP [6] clearly outperforms DPCA (Figure 5), but at the cost of computing power and time. A feasible alternative for stochastic STAP methods is the direct data domain STAP [7], which uses only information from the range cell under test. However, prior knowledge of target direction and velocity is required.

To validate the performance of our equipment and the signal processing chain, we observed a cooperate Cessna-172 aircraft using the car-mounted radar system moving at velocity of 40 km/h. In Figure 3 detections and bistatic route of the aircraft is displayed. Since the airplane moved in exo-clutter region, false detections from clutter are not suppressed. Rotor modulation is clearly visible at bistatic distances of 4-9 km. Figure 6 shows the detections associated to the true route and the observation geometry.

Second ground-based observation trial was conducted in January 2023. Receiver distance from the 50 kW DVB-T transmitter was 32 kilometers and the movement speed of the passive radar receiver was 60 km/h. There were several wind turbines at bistatic distances of 1.0-2.5 km. Matrice S900 drone acted as a cooperative target. As seen in the Figure 4 (top), drone is not detectable in endo-clutter region. However, after DPCA processing Figure 4 (bottom) drone becomes tractable. Nevertheless, the DPCA fails to remove clutter from the border region, likely due to antenna calibration issues. In comparison, RD-STAP processed scene is displayed in Figure 5.

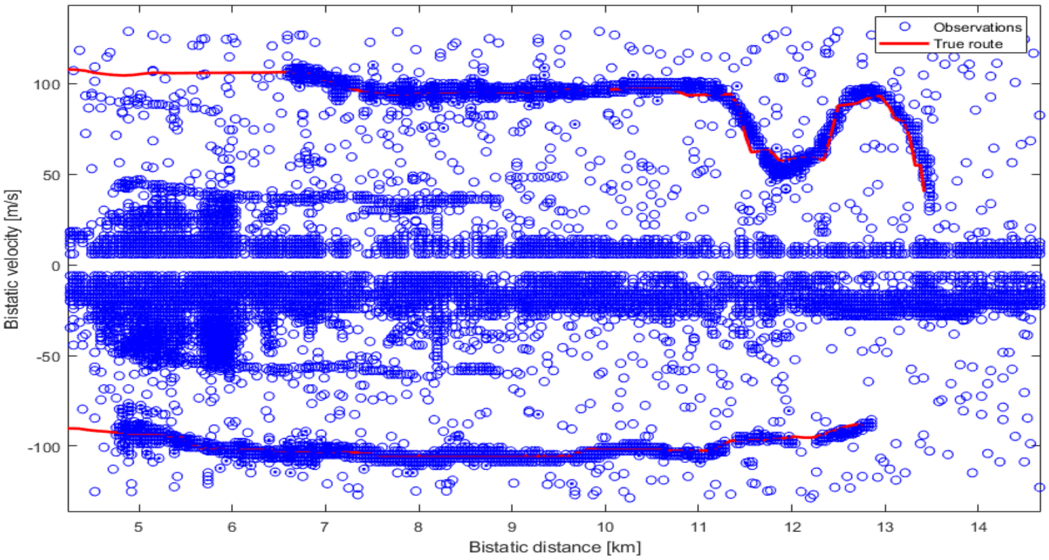

Figure 3: Detections and Cessna-172 true route. Rotor modulation is clearly visible at bistatic distances of 4-9 km.

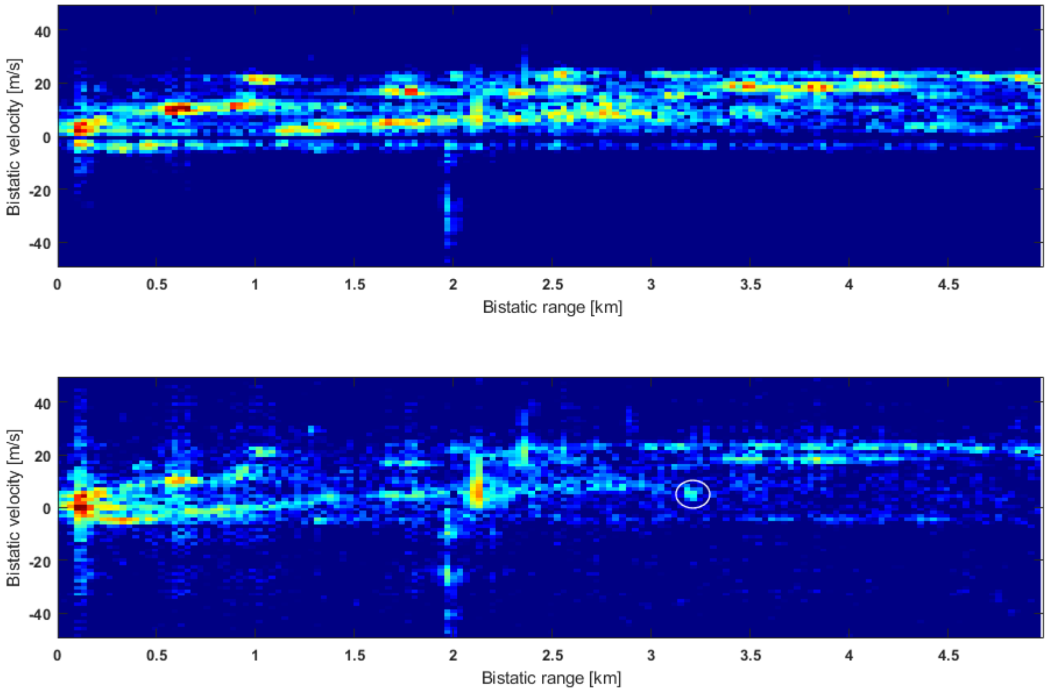

Figure 4: Drone among clutter and interfering wind turbines. In the lower image DPCA is applied and drone position is circled.

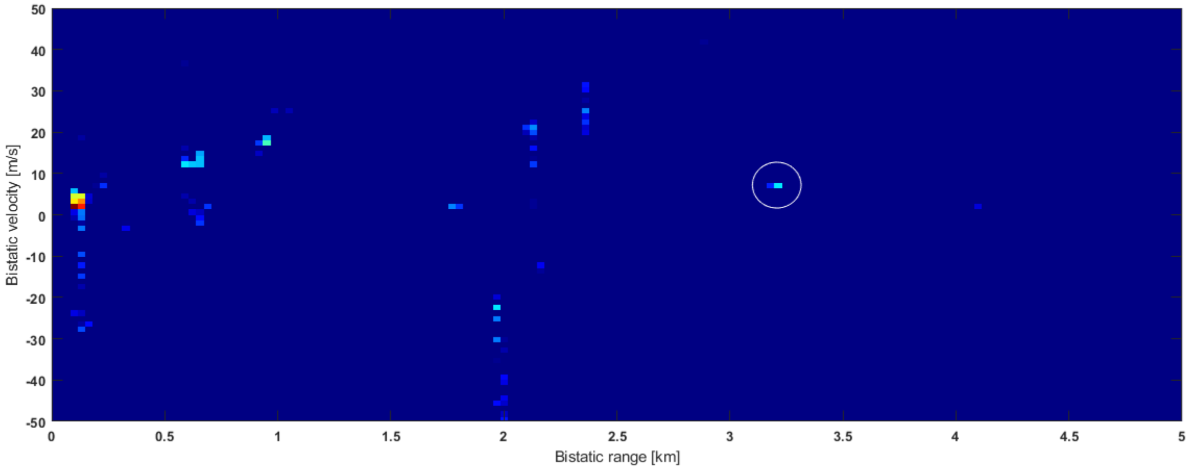

Figure 5: RD-STAP removes most of clutter present in Figure 4, but the false detections caused by the wind turbines are still visible.

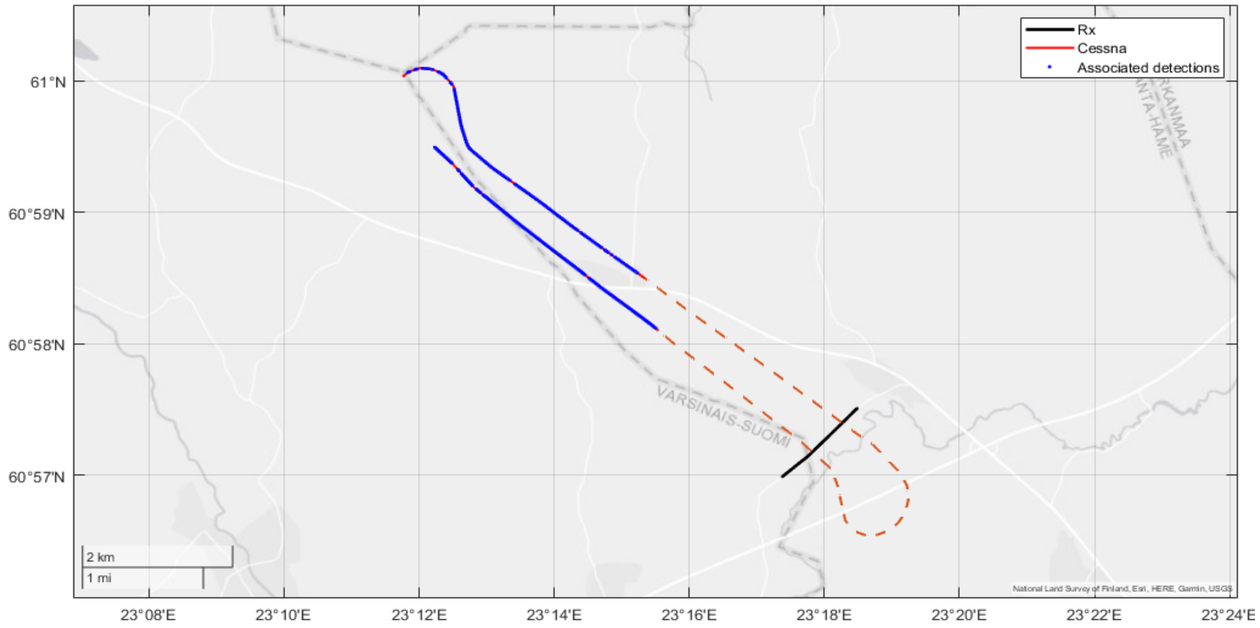

Figure 6: True route of Cessna-172 and the associated detections in blue.

4.0 MARINE OBSERVATIONS

The vessel chosen for marine trials was a transport ship of length 30 m with 12 knots cruising speed. The car-mounted antenna array was loaded onboard and secured on the deck (Figure 7), allowing car's suspension system to attenuate vibrations caused by the engine and ship's motion.

The illumination signal was acquired from a 50 kW DVB-T transmitter operating on 674 MHz frequency. For better reference signal reception, the reference antenna was mounted on a pole and turned towards the TV tower. Observation geometry is depicted in Figure 8. The surveillance ship moved along east-west route to observe ships entering and leaving the Helsinki harbour, and west-east route to surveil air traffic of Helsinki-Vantaa airport.

During the observation campaign, the sea was relatively calm and sea clutter almost nonexistent outside the endo-clutter region, causing only occasional false alarm in CFAR processor. Due slow cruising speed, the spreading of clutter was constrained to a few range cells around the zero doppler line.

In Figure 9, results of ten-minute observation run are illustrated. The routes of cargo ships were obtained from AIS data. It is notable that almost all the targets were observed, barring the two ships that were too close the 0-doppler line and whose detections were consequently removed along the direct signal interference.

In addition to marine traffic, we had opportunity to observe occasional aircrafts. In Figure 10, true routes and associated detections of some passenger aircrafts are displayed: Embraer E190 (FIN6AU) and Airbus A320 (FIN7AC, FIN7RX) near the Helsinki-Vantaa airport, Airbus A320 (AUA1472) landing on Tallinn Airport, and ATR 72 (FIN1KE) over the sea. Unfortunately, due to recording equipment malfunction, we lost significant portion of our observations pertaining to these aircraft. It is likely that without data corruption covering of these routes would have been more complete.

Further maritime trials are planned to be scheduled in spring 2023. By using a faster and more maneuverable ship, we are hoping to observe targets in a more challenging environment.

Figure 7: Passive radar system used in the marine observation campaign.

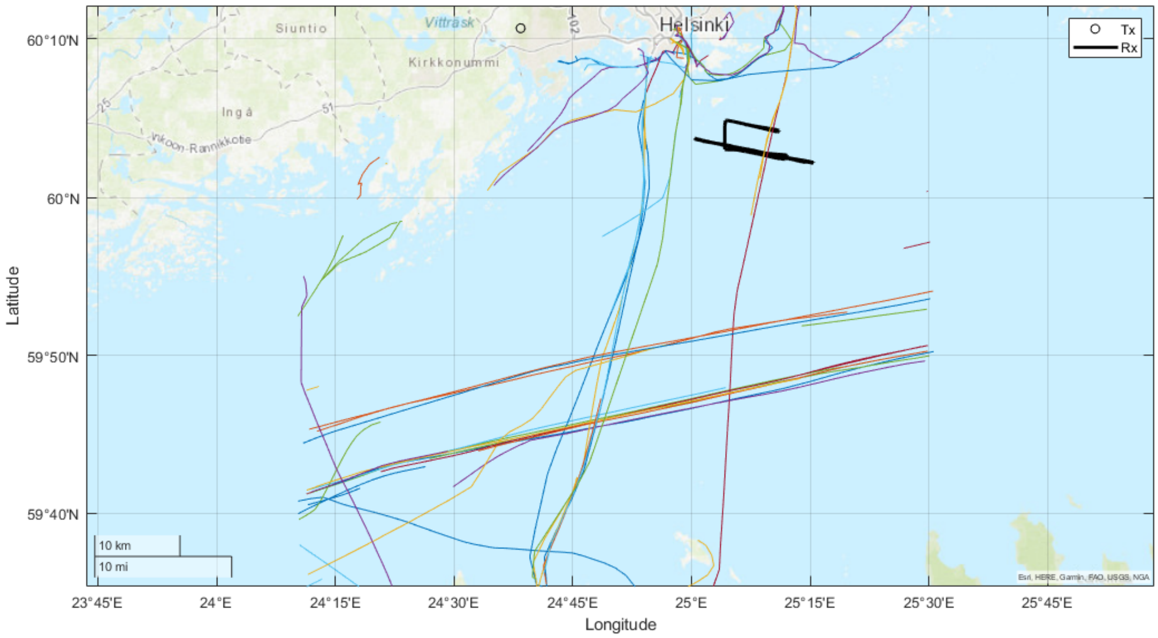

Figure 8: Position of the receiver and the typical shipping routes.

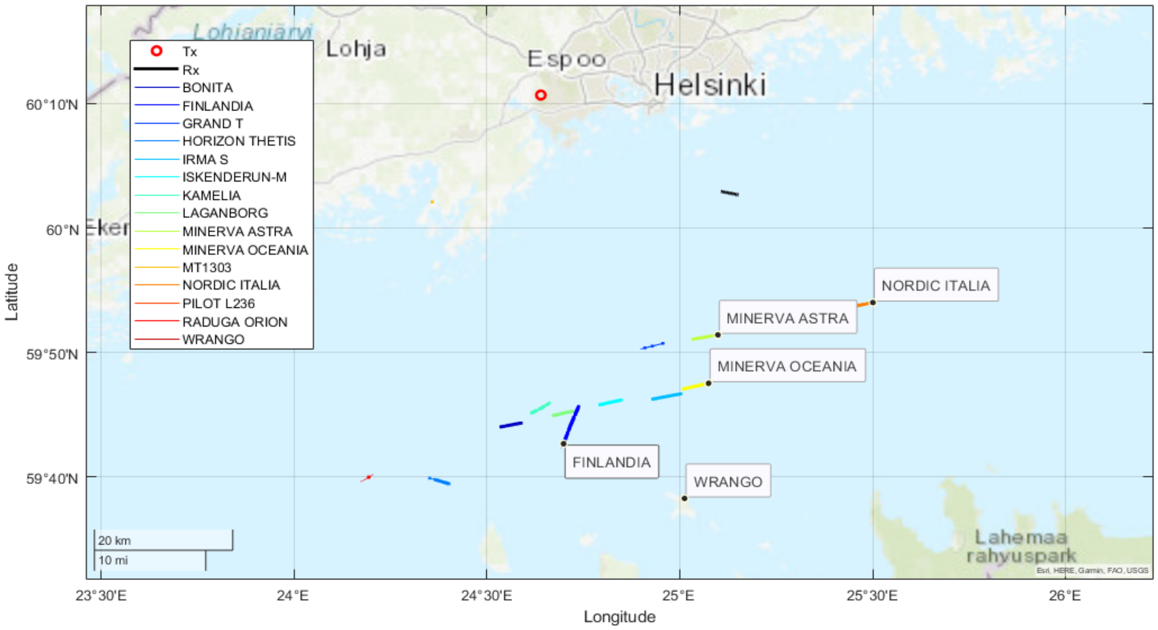

Figure 9: Cargo ship routes and their associated detections on Gulf of Finland.

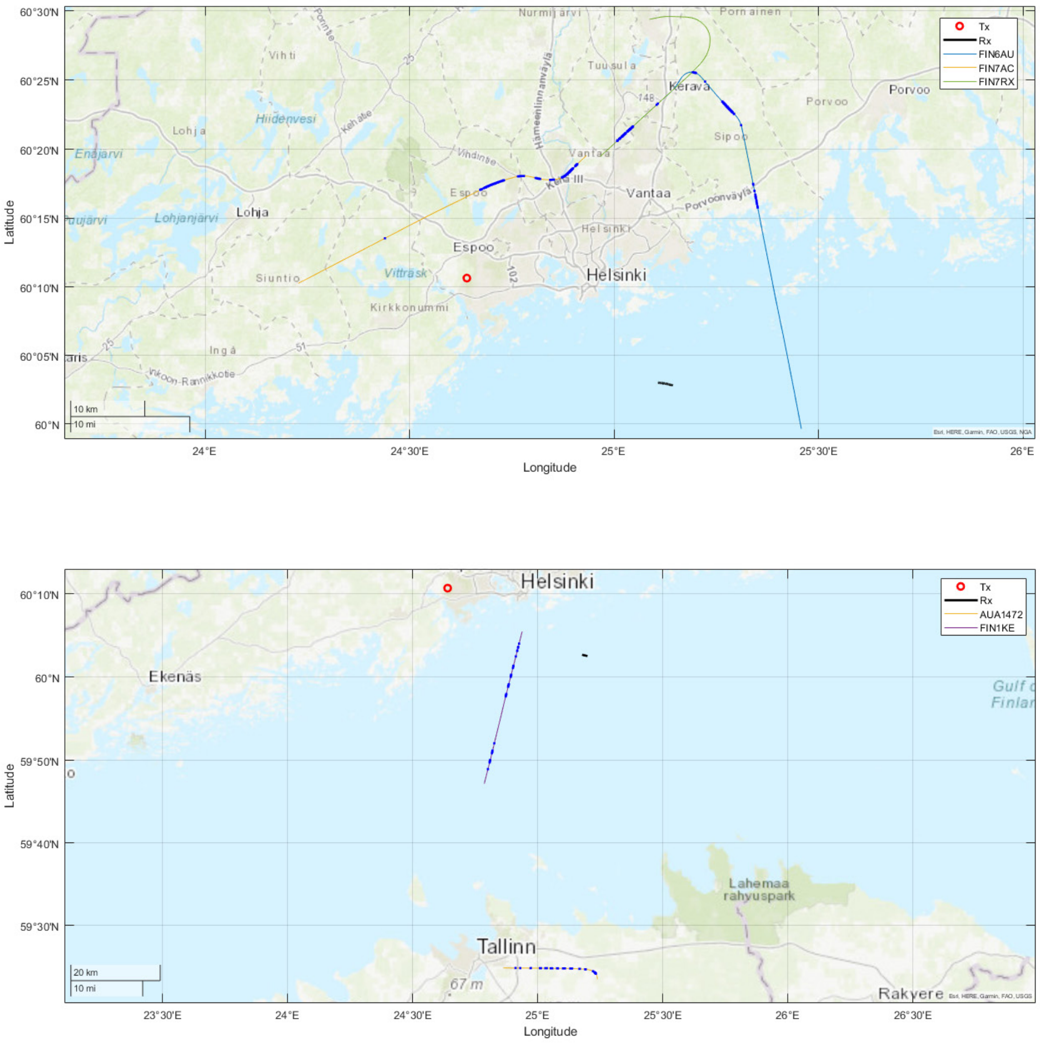

Figure 10: True routes of the aircrafts and their associated detections.

5.0 DRONE MOUNTED PASSIVE RADAR

The ultimate goal of this research project is a fully scalable system deployable on drones and other mobile vehicles. For the first prototype, a Great Shark 330 VTL drone manufactured by Foxtech was selected. The nominal payload is 4 kg, which is sufficient for 8-channel receiver, batteries, and 8 antennas. It has 4 upward facing rotors for vertical take-off and landing (VTOL) and one backward facing rotor for cruising.

The VTOL rotors will be turned off during cruising, minimizing interference caused by the rotating carbon fiber blades.

The antennas will be Yagi-style, at least four in side-facing ULA or NULA-configuration, with an additional reference antenna for capturing the direct signal. The downlink implementation is still under consideration. On-board processing power is constrained by strict payload and battery requirements, but on the other hand, without pre-processing, the required downlink bandwidth is unsustainable. The first test trial will be conducted in late summer or autumn 2023.

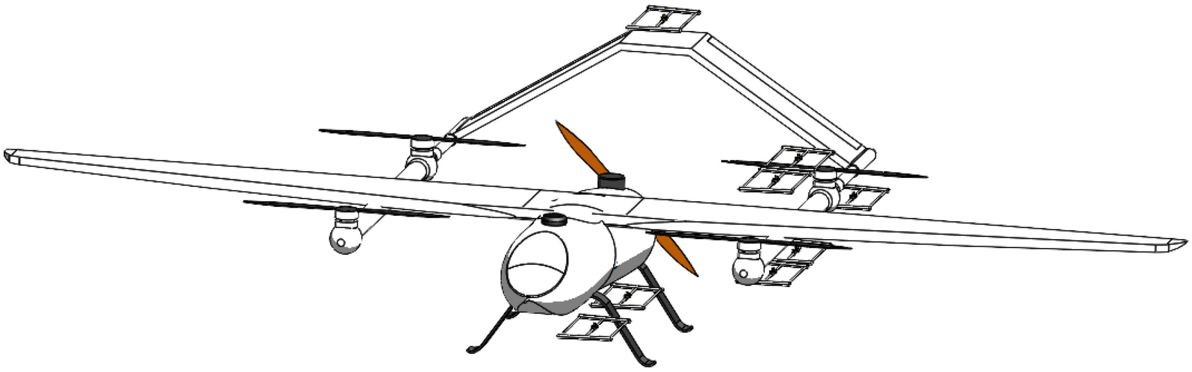

Figure 11: An illustration of possible antenna positions.

6.0 CONCLUSIONS

We have described the results of our observation campaigns with moving passive radar demonstrator and outlined the planned future data acquisition campaigns. Based on achieved results, it is obvious that the mobile passive radar holds promise, in particular if receiver can be miniaturized sufficiently to mount it in a portable drone. However, interfering signal sources and clutter spreading are challenging phenomena, requiring compensation methods that offer consistent clutter cancellation performance and almost real-time operation. Furthermore, it is still unclear at what extent clutter effects can be mitigated by the usage of multistatic observations combined with tracker predictions.

7.0 REFERENCES

[1] M. K. Baczyk and M. Malanowski, “Decoding and reconstruction of reference DVB-T signal in passive radar systems,” in *11-th INTERNATIONAL RADAR SYMPOSIUM*, 2010.

[2] S. Searle, D. Gustainis, B. Hennessy and R. Young, “Cancelling strong Doppler shifted returns in OFDM based passive radar,” in *IEEE Radar Conference (RadarConf18)*, 2018.

[3] M. Glende, “PCL-Signal-Processing for Sidelobe Reduction in Case of Periodical Illuminator Signals,” in *International Radar Symposium*, Krakow, 2006.

[4] M. Richards, Fundamentals of Radar Signal Processing, McGraw-Hill, 2014.

[5] J. Ward, “Space-Time Adaptive Processing for Airborne Radar,” in *IEE Collequium on Space-Time Adaptive Processing*, 1998.

[6] R. Klemm, Principles of Space-Time Adaptive Processing, IET, 2006.

[7] T. K. Sarkar, “A deterministic least-squares approach to space-time adaptive processing (STAP),” *IEEE Transactions on Antennas and Propagation,* vol. 49, pp. 91-103, 2001.