Forward Scattering Micro Radar efficiency analysis for different landscapes

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Abstract

Multiple trials have been conducted to estimate the performance of a ground-based short range forward scattering radar (FSR) in different landscapes. Target detection capability has been considered against the influence of several factors affecting to the radar power budget: two-ray path wave propagation loss for different distances between radar transmitter and receiver, the presence of vegetation clutter, and system operational frequency.

Introduction

In the last few decades there has been a booming growth of *ad hoc* wireless networks, comprising a number of unattended sensors for area surveillance and monitoring [1–5]. Different physical principles (acoustic, seismic, electromagnetic and optical, etc.) are typically used in the network sensors.

Sensor networks are widely used for defense applications in area and perimeter protection, border security and situational awareness [6–9].

Any type of sensors has its own implicit features and disadvantages; their detection capabilities may be limited depending on luminance, weather conditions, terrain configuration and target screening by vegetation, fog and smoke.

The use of distributed FSR sensors connected by a wireless network can give advantages in small and stealth targets detection [10]. It may easily be deployed and operated in remoter areas. The same radio technology is used for network communications and for target sensing as well. Thus, sensors should be compact, lightweight and durable. These features enable sensors to be dropped from remotely operated moving platforms, such as unmanned aerial vehicles (UAV). Radio sensors are capable of working under snow, sand and dust.

Research on a ground-based FSR network has been conducted at the University of Birmingham for the last few years. This work started from the theoretical and experimental study of automatic target classification (ATC) using the FSR principle [11–17]. Later on, the concept of a ground-based FSR for ground targets detection and recognition was formulated and a study of FSR was performed in different aspects of wave propagation, target characteristics, power budget and data processing algorithms [18–24].

The goal of this paper is to analyze the results of experimental testing of FSR and estimate the capabilities of human target detection (as most “difficult” target of interest) in different landscapes and at different system carrier frequencies within the VHF and UHF bands.

FSR system peculiarities

The concept of a micro-sensor FSR network for situational awareness in ground operations was described in detail in [25]. FSR sensors are able to detect and recognize ground targets such as personnel and ground vehicles entering the network coverage area. In this network each sensor (node) has a separate receiver and transmitter, so the transmitted signal of one of them is received neighbouring nodes, creating the forward scatter radar configuration with a number of radar pairs (Fig.1).

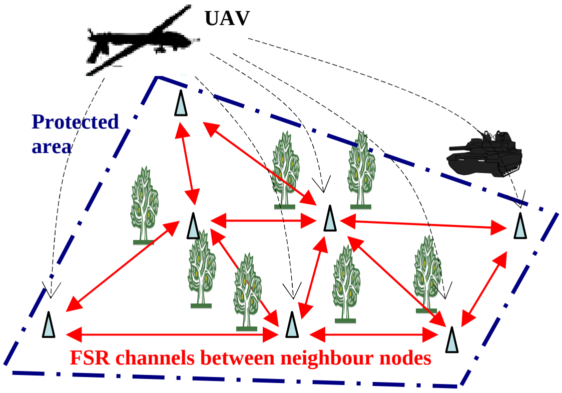

Figure 1: The concept of the FSR micro-sensors radar network

There are a number of peculiarities distinguishing the proposed system from existing ones. We will consider only few of them which are important for the topic of this paper:

A. *Free drop of sensors requires omni-directional antennas*

Dropped sensors are situated directly on the ground surface in random positions and randomly oriented in space. Thus, the sensor should utilize an omni-directional antenna system to establish the radar and communication channels with neighboring nodes placed in unknown directions.

B. *Different system tasks require different operating frequencies*

One of the key issues for the FSR system is the choice of operational frequencies.

It was shown that wave propagation above the ground surface may be well approximated by the two-ray path model [22] even for low antenna heights (when sensors lie directly on the ground surface). Propagation loss increases rapidly with distance (proportionally to d^4). For the signal scattered from a target, the received power decays proportionally to d^8. That is because of the two propagation paths – from the radar transmitter to the target, and from the target to the radar receiver.

It was also shown that propagation loss is dependent on frequency. For example, the use of 70 MHz carrier frequency instead of 870 MHz gives an advantage of about 30 dB in the target signal's received power [22]. In addition, EM waves having a lower carrier frequency follow terrain and penetrate foliage much better.

On the other hand, the radar carrier frequency cannot be too low. This is because the efficiency of a small antenna, as well as target RCS, decreases in inverse proportion to the wavelength [20]. It is now considered that frequencies in the low part of the VHF band (60-80 MHz) are most suitable for target detection and data communication between nodes.

Target classification requires a decrease in radar wavelength, because differences between targets may be better sensed if the wavelength is less than the characteristic dimensions of the target's shape. The first experiments on car recognition were made on carrier frequencies around 2450 and 870 MHz [10-17]. Similar experiments are currently being conducted at frequencies in the UHF (434 MHz) and VHF (135-173 MHz) bands [26].

Therefore, the selection of the FSR operational frequencies is determined by many factors. The goal of the experimental study is to estimate FSR performance at any of the abovementioned bands.

C. *FSR system has no range resolution and mostly affected by clutter*

The FSR channel has no range resolution. Target detection is only feasible by processing its Doppler signature [22]. It is possible to use long integration times for target signals in order to obtain a sufficient signal-to-noise ratio (SNR) and signal-to-clutter ratio (SCR) at a low radiated power.

When the radar site is surrounded by vegetation, foliage (branches and leaves) also sways with the wind and creates clutter masking the target signal. Foliage clutter is picked up from the whole volume illuminated by the sensors due to the use of omnidirectional antennas,. Thus, the FSR system is more affected by clutter than conventional radar with range resolution and directed antennas.

The main difference of foliage scatterers is in the nature of their movement: vegetation does not travel in any direction; it only sways around a fixed position. It is known that swaying foliage creates clutter in Doppler frequency band occupied by target. The clutter power spectrum was shown as rather narrowband (0.3-0.5 Hz) [10], slightly depending on carrier frequency [27] and season, as well.

The understanding of the vegetation clutter creation mechanism and the experimental verification of clutter spectral properties for different FSR carrier frequencies in VHF, UHF bands was the subject of [28].

Here we present some results of human target measurements against clutter in different conditions.

Test equipment

A multi-channel testing equipment (Fig.2) was developed for trials. It contains a few channels operating at different frequencies in the VHF and UHF bands (64, 151 and two separated channels at 434 MHz). Receiver (RX) and transmitter (TX) utilizes omni-directional, vertically-polarized monopole antennas, except the directional Yagi antenna in the 434-2 channel (Fig.2), which is used for comparison with the omni-directional antenna (434-1 channel). Transmitted power is 10 dBm.

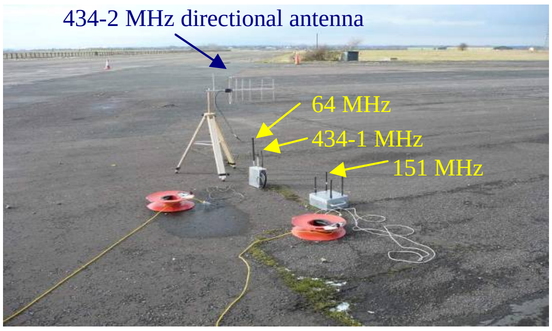

Figure 2: Multi-channel testing equipment on airfield test site

Test sites

There are three test sites:

- An old airfield - flat runaway, free of foliage (Fig.2)
- Senneleys Park, flat grass field surrounded by foliage (Fig. 3 (a));
- Lickey Hills park, country dense wood area - flat and rough terrain (Fig. 3 (b)).

(a) (b)

Figure 3: Testing sites

Test technique

The experiments and data processing consisted of three major steps:

- Data acquisition;
- Evaluation of signal-to-clutter ratio;
- Signal processing: clutter filtering, signal compression and speed estimation [23].

Analysis of the results

The limited scope of this paper does not allow discussion of all the results obtained in the trials. We will only illustrate some of them below.

In Fig.4, examples of target signatures measured on the background of clutter are shown for different carrier frequencies (Senneleys Park; baseline distance 100 m; human target moving across the baseline with speed ~2 m/s). For comparison the modelled signal corresponding to evaluated target signature parameters of Fig.4 for 64 MHz channel is presented in Fig. 5. The modelling comprised following consecutive steps: signal simulation based on two-ray propagation model, clutter modelling and superposition with simulated signal and, finally, filtering of the composed signal according to the hardware parameters.

We must stress here that without correct modelling of the reference signal which has to be used in optimal signal processing coherent detection could not be possible.

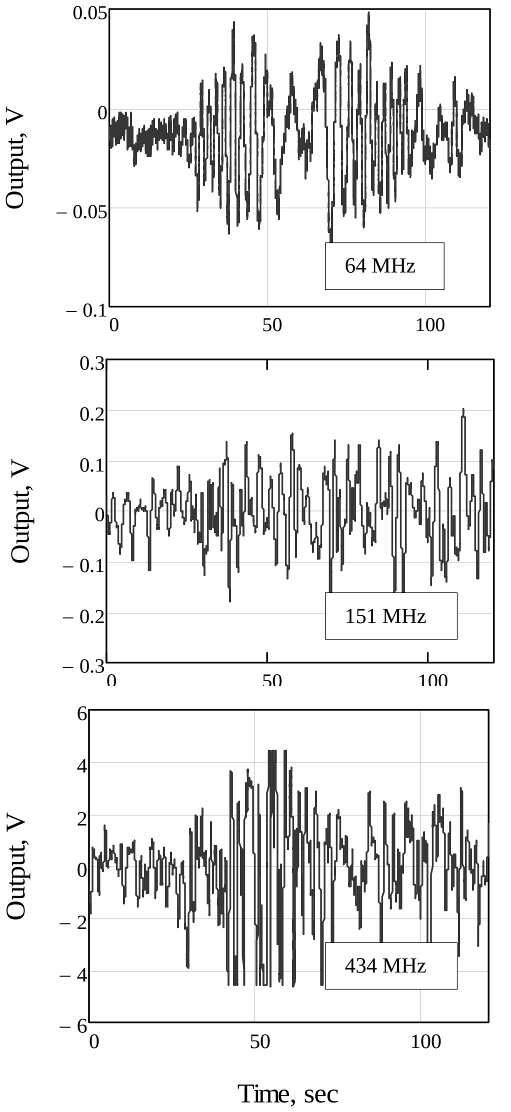

Figure 4: Example of target signatures measured on the background of clutter

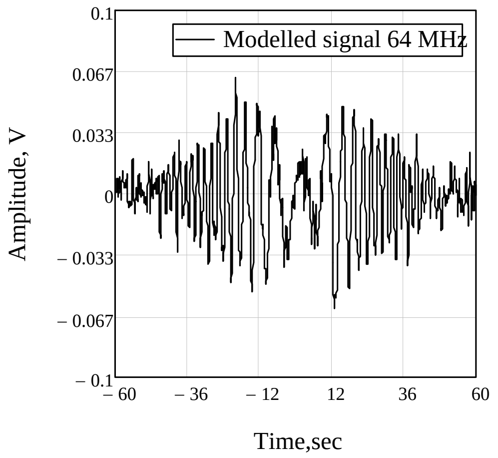

Figure 5: Simulated signal

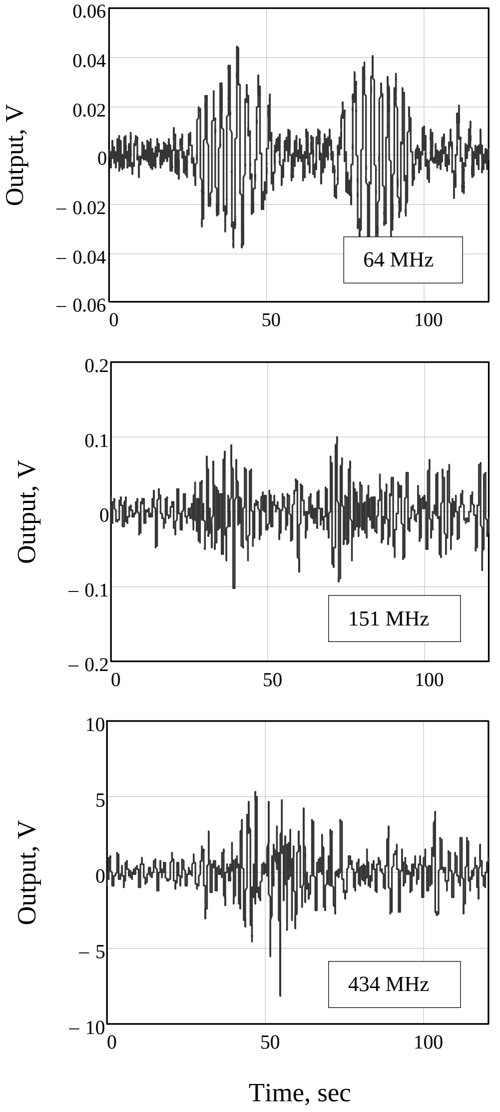

Figure 6: Target signatures after clutter filtering

It is seen from the Figure 4 the target signal exceeded the clutter background at low frequency (64 MHz), but was practically fully masked by clutter at higher frequencies.

Clutter filtering by a LPF (4-th order Butterworth, 0.5 Hz cut-off) may improve SCR (Fig.6). A coherent signal-processing [23] scheme using a bank of filters matched to the target estimated speed and baseline crossing point gives target “chirp” signal compression up to 10-20 dB above the uncompressed value.

Compressed outputs of matched filters show better SCR (Fig.7) and target could be detected.

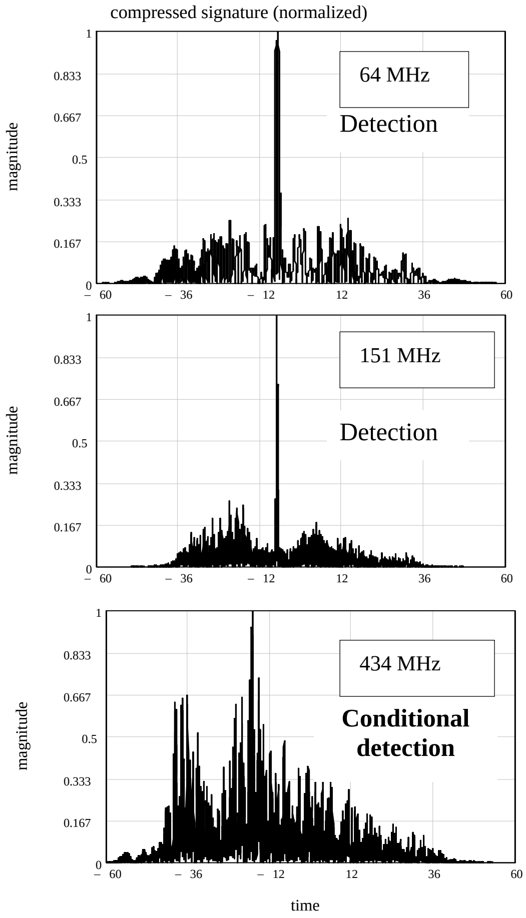

Figure 7: Target compressed signals

All records of measured target signatures have been processed by the same compression procedure. As a result, the estimated human detection ranges are shown in the table as a function of clutter conditions for different landscapes.

Detection range, m			Conditions
64	151	434	
> 300	200-300	150-200	Open space, low wind clutter – airfield
>150	150	100	Open space, medium foliage clutter – Sennelleys Park,
150	100	100	Dense forest, small foliage clutter – Lickey Hills

The estimated target detection range is much less than the one defined from the receiver’s sensitivity. So, clutter is the main factor limiting the FSR detection range. Simply increasing the transmitter radiated power will not give any improvement in the system performance due to the increase in clutter power, accordingly.

Conclusions and future work

The experimental study shows that the FSR signal is clutter limited rather than noise limited.

Computer simulations based on theoretical modelling are in a good agreement with measured data and can be used for system performance analysis.

For the considered conditions the distance of reliable human target detection on the background of clutter is 100-200 m.

SCR is enhanced as carrier frequency decreasing. This makes lower operating frequencies more preferable.

Our plan to the future is to study the system performance in real conditions, including different types of targets, environments and terrains.

Acknowledgments

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