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Surveillance Unattended Foliage Penetrating Radar for Border Control and Homeland Protection

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ABSTRACT: The increasing request for safety, security and environment protection at local and national level reveal the deficiency of the traditional surveillance and control centers to satisfy the needs and requirements of modern border control systems for homeland protection where land border is expected to be monitored as well as the maritime one. This is, for instance, the case of any land border affected by hidden immigration and/or illegal traffics as well as any small areas such as critical infrastructures or military/ civilian posts in forest or jungle environment characterized by vegetation. In such challenging environment, logistics constraints strongly recommend to have very low power devices able to operate months or years without maintenance. A such scenario should be the perfect place for implementing an Unattended Ground Sensors (UGS) network making use FOliage PENetration (FOPEN) radar for border control. The paper aims to present the basic characteristics and preliminary results of a Surveillance Unattended FOPEN (SUF) radar suitable for detecting moving targets, people or vehicles, in dense forest environment.

1 INTRODUCTION

Initial work for FOliage PENetration (FOPEN) radar systems dated back to the late-1960 to mid-1970 with meagre results due to foliage attenuation that limit the systems to short-to-medium-range operation and manned aircraft could not be adequately protected at those ranges. Later the development of wideband data links would enable significant processing and image interpretation on the ground till the late 1980s when the image collection community determined that Synthetic Aperture Radar (SAR) could provide acceptable and useful detection and characterization of forested regions, [1].

So far studies as been performed mainly using aerial platform equipped with SAR but now the focus is on ground based sensor systems able to detect walking personnel and moving vehicles with very low false alarm probability even in presence of unfavourable weather conditions (rain, wind) and/or local seasonal fauna. FOPEN sensor are characterized by using low frequencies, generally U-VHF bands (30-1000 MHz) suitable for radar operation in dense foliage environment where –on the contrary- traditional microwave radars in X, Ku bands (normally used for border control) suffer strongly form foliage attenuation and backscatter, [1] – [2]. FOPEN ground radar can be efficiently utilized in non heterogeneous environment too. For instance for coast surveillance in presence of vegetation near the water.

2 FOPEN PHENOMENOLOGY

FOPEN application involves a fundamental trade-off between resolution and foliage penetration capability:

high-resolution demands a high center frequency, but penetration of foliage demands a wavelength long enough to propagate through tree cover. FOPEN radars have typically operated at VHF or UHF. At higher frequencies, propagation through foliage introduces more severe imaging effects. The effects of propagation through foliage can be broadly separated into three categories: phase shift, the backscatter and the attenuation. Each of these effects contributes to a limitation in the radar ability to detect objects in foliage environment. Many studies have been carried out for SAR application, [3] – [6].

Random phase shift: phase variation is the random variation in the signal phase arising from propagation through a distributed, non-uniform medium (i.e., a foliage canopy). Phase shift would de-correlate the radar returns, the more the phase is corrupted, the less is the coherent processing gain and therefore the probability of detecting a surface target. An additional motivation for lower-frequency operation is related to the impact of phase variation that is more marked at higher frequencies (Phase shift (f) = Frequency (MHz) * 0.133).

Forest Backscatter: backscatter is the reflection of transmitted energy back to the sensor by interactions with single or multiple foliage elements or by interaction between these elements and the ground. Consider a radar spatial resolution cell containing windblown trees, such a cell contains both fixed scatterers (ground, rocks, tree trunks) and moving scatterers (leaves, branches). The returned signal correspondingly contains both a constant (or steady) and a varying component. The steady component gives rise to a DC or zero-Doppler term in the power spectrum of the returned signal, and the varying component gives rise to an AC term in the spectrum. Thus a suitable general analytic representation for the total spectral power density $Ptot(v)$ in the Doppler-velocity power spectrum from a cell containing windblown vegetation is provided by:

$$\left|P_{tot}(v) = \frac{r}{r+1}\cdot\delta(v) + \frac{1}{r+1}P_{ac}(v), \quad -\infty < v < \infty\right.$$

where v is Doppler velocity in m/s, r is the ratio of dc power to ac power in the spectrum, $\delta(v)$ is the Dirac delta function, which properly represents the shape of the dc component in the spectrum, and $P_{ac}(v)$ represents the shape of the ac component of the spectrum proven [5] to decay at rates close to exponential:

$$P_{ac}(v) = \frac{\beta}{2}\cdot\exp\left|\left(-\beta|v|\right)\right), \quad -\infty < v < \infty$$

where β is the exponential shape parameter that is a function of wind conditions and is largely independent of radar carrier frequency over the range from VHF to X-band. Foliage backscattering is more pronounced at high depression angles.

The fixed clutter returns can have a dc component (zero Doppler) raising up to 60-70 dB above the noise level.

Doppler spectra, in order to perform efficient clutter rejection, two values of thresholds can be used: i.e.1 m/s in case of light air (wind speed: 1-7 mph), 2 m/s in case of windy/gale (wind speed: 15-60 mph).

Foliage Attenuation: propagation through foliage leads to attenuation of the radar signal in part by absorption and in part by the scattering of transmitted energy away from the target and sensor. Foliage attenuation increases significantly with frequency. Two-way HH polarization signal attenuation reported in [6], [7] for a 30° depression angle increases from 5.5 dB at UHF to 17.0 dB at L band and to 33.6 dB at C band. Foliage attenuation tend to be more severe at smaller depression angles. This is due primarily to the increase in foliage path length as depression angle decreases [6], [7]. Foliage attenuation exhibits a slight dependence on polarization. In particular, attenuation tends to be slightly larger for VV polarization than for HH polarization .This is especially noticeable at lower frequencies [7], at which attenuation is primarily driven not by leaves and branches, but instead by tree trunks, most of which are vertically oriented.

3 GROUND SURVEILLANCE UNATTENDED FOPEN SYSTEM

3.1 *SYSTEM description*

The surveillance of critical perimeters is one of the most important issues in Homeland security and protection systems. Ground surveillance needs are relevant across multiple scales, from border protection applications (hidden immigration, illegal traffic, narcotraffic) to small areas protection (critical infrastructure, military/civilian posts). Furthermore, this infrastructure can be fixed or mobile. The security and protection systems must be able to provide full coverage continuously in a variety of cluttered environments, such as forest or jungle domains. However, most existing systems have been developed using airborne SAR and are not suitable for 24h operations.

In this article we propone a land surveillance system based on ***ground sensors***, eventually interoperating with airborne sensors, with capabilities to detect walking personnel and moving vehicles. The proposed system architecture provides the capabilities of:

- ***detection, localization, tracking and recognition*** of people and vehicles irregularly entering in a forested area of land borders.
- ***adaption*** of the system configuration and deployment to optimize performance in response to changing environmental conditions.
- ***multilayer data fusion*** and system operating capability by providing the situation awareness and control to prevent and manage suspicious behavior.
- ***Easy to use*** and ***low cost*** solutions with ***LPI*** (Low Probability Intercept) capabilities to not be detected before the target is detected.
- ***Multi-scale Common Picture capability*** which will provide different pictures of the region of interest with different fields of view at different resolutions and time scales.

The proposed system architecture is depicted in Figure 1. The proposed system is composed of a set of subnets that are geographically distributed along the boundaries of a wide area to be controlled, such as the border of a nation. The subnets are composed of homogeneous sensors connected with wireless or wire links. Each subnet ensures the exchange of data between local clusters of sensors. The Figure 1 shows the subnets composed of two types of Fopen radars: Unattended Ground Sensor (UGS) and Fixed Tower Ground Radar (FTGR) that will be described in the section 3.3. However, the type and configuration of the sensors to be employed in the others subnets can be selected on the basis of the characteristics of the site under consideration. The system architecture has the advantage to be ***modular and scalable*** and it can be organized with different level C2 centers (local, regional, national), depending also on the size of the considered boundaries.

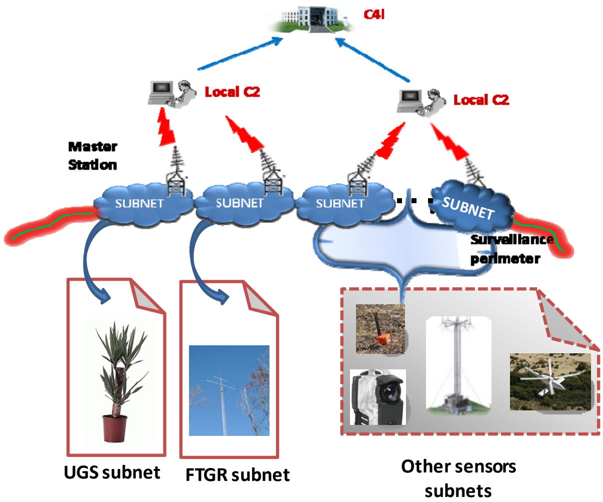

Figure 1. System architecture of GROUND SURVEILLANCE UNATTENDED FOPEN SYSTEM

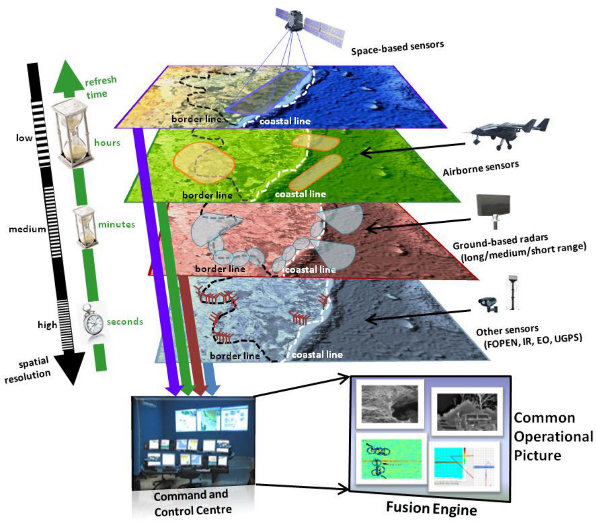

Figure 2. Multi-scale approach for hierarchical architecture of System to provide Common Operational picture.

The size of the region, the nature of the border and the complexity of the scenario require the provision of different pictures of the region with different field of view at different resolution and time scales, suggesting a multi-sensor/***multi-scale approach*** integrated in a hierarchical architecture of the whole system, an example is shown in Figure 2.

Typically a global field of view of the whole region is necessary at the higher Command and Control (C2) level to capture the overall situation. A higher level of resolution and refresh rate is necessary at the lower and local level to analyze and control in depth each single zone of a region.

Therefore the surveillance segment may be structured according to a multilayer architecture where layers realize different trade-offs in terms of field of view and granularity and refresh time. All data collected by the sensors are exploited by the fusion engine, [8]. It is responsible to track and classify relevant entities present in the scenario and to provide a high quality representation of the situation. Cameras can also be used to this end as they are usually fully integrated with the rest of the system and could be presented on top of the cartography on the operator console, cf. Figure 3.

Figure 3. Cameras presentation on operator console, live data.

3.2 *Subnet Description*

Each subnet ensures the exchange of data between local clusters of sensors. In 0the architecture of a UGS subnet is shown. Each node is a FOPEN radar sensor with a very small coverage region (purple cyrcles). The typical detection range of a single sensor is 100 meters. The surveillance perimeter of a subnet can be extended up to several kilometers by deploying a fixed number of sensors (eg. 50-150). The target can be detected by more than one sensor, in order to provide the multistatic coordinates.

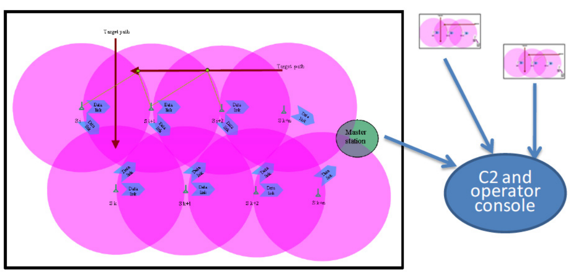

Figure 4. UGS subnet concept

Adjacent sensor nodes are connected together via a low power RF link (blue arrows). Each sensor forwards the information to the nearest sensors (to assure alternative paths in the case of fault) and in the end the information is sent to a ***master station***, via the short range radio link. The master station performs data fusion and medium range connection with the other master stations, or the C2 centre.

3.3 *FOPEN RADAR DESCRIPTION*

Logistics constraints drive the technology to very low power devices, that are able to operate for several months or years, without maintenance. Another important issue is, together with a good probability of detection, the low false alarm probability that is requested to be lowered up to 1 false alarm per day, or lower, even in presence of bad weather conditions (rain, wind) and/or local seasonal fauna.

The main requirements/constraints addressed are the range of the detections, which is reduced by the attenuation due to foliage and the low antenna height, that is usually limited to 1-2 meters for logistic purposes. Moreover, logistic constraints drive the technology to very low power devices. Considering that photovoltaic cells are not suitable for installation on the ground in the forest and that the radars must be able to operate for several months or years, without maintenance, power consumption must be kept at minimum level, and the emitted power must be kept at a level of several mW. Camouflage and anti-tamper are often required, and, since the number of displayed sensors can be high (50-150 for each subnet) very low cost is a mandatory requirement.

Despite the low cost, the performance of the radars must be good enough to detect with high probability walking personnel and moving vehicles, with a Low Probability of Intercept (LPI) and a low false alarm probability, less than 1 false alarm per day, even in presence of bad weather conditions (rain, wind) and/or local seasonal fauna.

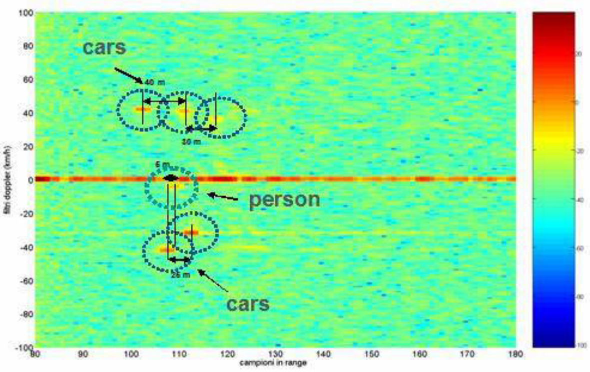

Figure 5. Range-Dopple measurement in urban scenario

Experimental result in urban heavy traffic scenario has been conducted as a preliminary analysis to validate the prototype sensors. Results were encouraging and has been demonstrated resolution of 6 m for person and less then 30m for cars, cf. Figure 5. In this article we propose an innovative ground based FOPEN UHF/VHF radar family composed by the following types:

- ***UGR*** (Unattended Ground Radar): FMCW radar, with an advanced digital processing that have a Low Probability of Intercept (LPI) capabilities and a minimum power consumption. The emitted power is of several mW. UGR are deployed with an antenna height that is usually limited to 1-2 meters for logistic purposes in a forested environment. Camouflage and anti-tamper can be satisfied. The typical detection range of a single sensor is 50-100 meters, depending on the environment.
- ***FTGR*** (Fixed Tower Ground Radar): FMCW radar, with an advanced digital processing. FTGR are deployed on medium height tower (eg 25 m). The emitted power is in the order of 1W. The FTGR requires a low power supply and can be powered by photovoltaic cells. The typical detection range of a single sensor is 1-5 km, depending on the environment.

4 CONCLUSION AND FUTURE WORKS

In the era of budget constraints and time pressure we are living nowadays the requests for low-power, unattended border control systems are increasing. The technology progress make possible to integrate UGS and FTGR in different system solutions and combinations according to scenario and users needs even in demanding environmental conditions like a forest.

U-VHF radar sensors are under developing at Selex's premises following preliminary encouraging results partially presented in this work.

REFERENCES

[1 M. E. Davis "Foliage Penetration Radar: Detection and Characterization of Objects Under Trees" SciTech Pub. Inc., ISBN 978-1-891121-00-5, New York, USA, 2011

[2] B. T. Binder, M. F. Toups, S. Ayasli, and E. M. Adams, *SAR Foliage Penetration Phenomenology of Tropical Rain Forest and Northern U.S. Forest*, Proc. IEEE Int. Radar Conference, 1995, pp 158–163

[3] M. E. Davis, Developments In Foliage Penetration Radar Radar Conference 2010 IEEE, 10-14 May 2010 pp: 1233, Washington.

[4] M. N. Roy, S. Swamp, R. K. Tewari, Radio Wave Propagation Through Rain Forests of India, IEEE Transactions on Antennas and Propagation, vol. 38, no. 4, April 1990

[5] J. B. Billingsley, Low-Angle Radar Land Clutter, SciTech. Pub. Inc., 2001, New York

[6] M. E. Davis, Foliage Penetration Radar: Detection and Characterization of Objects Under Trees, SciTech. Pub. Inc.,

[7] J. G. Fleischman, S. Ayasli, E. M. Adams, and D. R. Gosselin. Part I: foliage attenuation and backscatter analysis of SAR imagery. IEEE Transactions on Aerospace and Electronic Systems, 32(1):135-144, January 1996

[8] Z. Pietrzykowski, J. Uriasz, "Knowledge Representation in a Ship's Navigational Decision Support System", TransNav – Int. Journal on Marine Navigation and Safety of Sea Transportation, ISSN 2083-6473, ISSN 2083-6481 (electronic version), Vol. 4, No. 03 - 2010 pp. 265-270