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ASPECTS REGARDING THE USE OF ACTIVE SENSORS IN SURVEILLANCE MISSIONS

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Recent military conflicts have highlighted the importance of understanding the battlefield in order to maintain the initiative of organic forces while conducting combat operations. Active sensors placed on space and airborne platforms ensure ground surveillance and provide information for drafting the real images of the areas under surveillance. Information from active sensors represents the support for the decision-making processes and combat actions for all forces so that the enemy will be neutralized.

Active sensors are used by civilian actors to understand the processes and the natural phenomena on our planet, to determine their impact on human society, to identify and monitor the natural and manmade changes on the environment as well as to monitor the impact of human activity on the environment.

Keywords: air surveillance; radar; active sensors; syntetic aperture radar; inverse syntetic aperture radar; air threats; air surveillance systems.

In 1904 the German Federal Bureau of Inventions and Innovations issued the patent nr.165 546/1904 to the engineer Christian Hülsmeyer from Düsseldorf for the practical method publicly demonstrated in 1904 at Köln regarding the detection of metal objects placed at a distance with the use of electric waves (electromagnetic). The patent did not produce immediate impact, on the one hand, due to the lack of technical support for the development of equipment to detect metal bodies from a distance and, on the other hand, because the importance and the role it was meant to play in the development and modernization of human society was not foreseen by the intellectual elite from the early 20th century[1].

The First World War marked the beginning of the confrontations in the air environment, the aircraft being confirmed as the main combat means to gain control over the airspace in the theater of operations. In order to meet this goal, technical innovations transformed the aircraft into an effective combat means, capable of destroying the enemy's combat formations in the depth of the battlefield. More than that, the possibility to get undetected in the adversary's territory and attack his economic targets, which were relevant due to their military potential, resulted in the identification of technical and managerial solutions to ensure the discovery of air assets so that their minimal measuring range provided the necessary time for the protection of the targeted objective.

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The technical support from that period was not sufficient to build the radar. The technology used for the detection of aircraft consisted of passive, optical and acoustical, surveillance means which were the only means capable of providing information for the conduct of air defence operations against air attacks. Together with the aforementioned technical innovations, new concrete measures were implemented in order to create specialized structures to ensure the organizational framework needed to conduct activities to localize and identify air means, called *air surveillance and warning structures*. Basically, the air surveillance systems built by conflicting state where created based on similar concepts which involved the concentration of effort in the area of operations while in the depth of the territory surveillance was performed on the possible enemy lines of attack in order to protect objectives that were important to the war effort. The impact of the air surveillance system was demonstrated soon by the increase in the number of aircraft lost by the belligerent states compared to the same period before its use[2].

The period between the wars was characterized by advancement in the scientific and technological field which led to the development of transmitters that were powerful enough to ensure the detection of metal bodies at great distances with the help of electromagnetic waves. This technological breakthrough resulted in the building of radar and of air surveillance systems meant to detect better the air attack means of the enemy.

The Second World War confirmed the importance of radar in air defence, underlining its role in the airspace to provide data for conducting air missions. Permanent surveillance of the airspace led to the discovery and sound identification of threats by both adversaries according to the way in which combat was performed, thus giving them the necessary time to identify a response method and counteract the air enemy.

The end of the Second World War triggered the harsh competition between the two military powers, the USA and the USSR, to develop air surveillance systems to correspond in terms of their possibilities of detection to the evolution of the aircraft. At the same time, air surveillance systems were designed as the main element of a more complex system, meant to counteract the main threat to the air environment represented by ballistic and cruise missiles, and were created as the main source of information to meet this purpose. The diversity of threats from the airspace resulted in intensified scientific research to identify and develop new radar technology to ensure detection, that was superior to the currently used radars, as well as to identify new scientific principles and methods to detect threats in the air, land and maritime environment. A product of this research is remote sensing, which represents ”a number of technologies used to analyze from a distance data regarding objects or phenomena”[3], from the earth or the outer space. Remote sensing as a method of detection can be passive or active.

Passive remote sensing uses a large variety of passive sensors meant to collect, analyze and process the electromagnetic waves generated by natural or artificial sources, which are picked up directly or reflected by an object on the ground and which contribute to shaping its image after their processing.

Active remote sensing uses specialized equipment meant to detect objects and phenomena with the help of electromagnetic waves generated artificially. These electromagnetic waves are reflected by the detected bodies and phenomena, the data obtained, and the images created with their help being based on physical applications and methods that are different to the ones of passive remote sensing. The specialized equipment used in remote sensing are the radar and the lidar. Regardless of the equipment used to artificially generate electromagnetic waves, the data obtained are processed and analyzed from in terms of their quantity and quality, thus obtaining the accurate image of the objects and phenomena under surveillance.

Surveillance through remote sensing is performed by passive and active sensors mounted on space, land or sea platforms, and the information obtained from them contributes to shaping the real image of the objects and phenomena in order to identify them rapidly. In this respect, in order to obtain an objective and clear representation of the elements from the area of interest sensors have to be placed at a certain altitude from the object in question, an important role being thus paid by space and airborne platforms which can fulfill this requirement.

The Cold War, that started after the Second World War between the two military powers, the arms race between the USA and the USSR, the accelerated development of nuclear capabilities and of their air carriers (ballistic missiles, cruise missiles, aircraft) led to the increased preoccupation of these states to create space surveillance systems. These preoccupations materialized in research and development programs to build space platforms (satellites, space shuttles, space station, etc.) to be used in surveillance and early warning missions. The possibility to use remote sensing sensors onboard space platforms for civilian purposes to detect phenomena, calamities or natural/ or man-made disasters, and to monitor them and determine their impact on the population from the area they affect, contributed to accelerating the development of space programs. Amongst the platforms that developed rapidly there is the satellite which carry surveillance sensors onboard. Relevant satellite development programs are the following: *Landsat program* (developed by the United States), *IRS program* (developed by India), *SPOT program* (developed by France), *ERS program* (European Union), *COSMOS program* (developed by the former URSS and continued by the Russian Federation).

Another category of platforms that ensure, the same as the space ones, the surveillance of large areas with no influence from the local landscape are the airborne ones. Airborne platforms used to this end are the following: aircraft, helicopters, airships and UAVs.

The sensors mounted on airborne or space platforms have similar technical characteristics, the differences being represented by the additions imposed by the environment in which they function, respectively the air or space one. Surveillance sensors onboard these platforms will use active and passive remote sensing to obtain data about objects and phenomena from the earth's surface. In this article, we will present the characteristics and importance of sensors with active remote sensing, stressing the importance of information provided by the sensors for shaping the real image of the area of interest.

Conflicts in the last decades have pointed out the role of the air forces in conducting military actions and in reaching the end state of war. Fulfilling the missions of the air force involves the synergetic actions of military structures which have had a major impact on the way in which military actions are conducted on the battlefield. The conclusions drawn from the analysis of these conflicts has convinced the military powers of this century that it is necessary to develop and implement new technologies to achieve air force superiority over a potential enemy. In this respect, air forces will be provided with weapons systems with highly disruptive potential, with powerful impact on the conduct of violent military actions[4].

These conflicts have highlighted the importance of sensor networks used to discover threats and provide information for their neutralization. Scientific and technological evolution has created the framework for building sophisticated networks capable of meeting the superior requirements of surveillance, while also being adapted to the modern battlefield. In the case of the air force, the complexity of the battlefield led to the integration of sensors in a unique system capable to provide the permanent surveillance of the airspace. The importance of this system is highlighted by its position of information provider regarding the threats detected in the airspace. This influence on military actions will contribute in the future to establishing the identification as an important factor in building the air power of a state. The role of the system of sensors was mentioned by the American general Harry H. Arnold who stated that ”the first essential of the airpower necessary for our national security is preeminence in research”[5].

The technological evolution of the air attack means of the enemy will impose as a necessity to adapt the air surveillance system to the new requirements of the operational environment. Improving the air surveillance system involves structural dynamics which is meant to reduce the impact generated by the development of the enemy's air attack means. At the same time, research and development efforts have to be made to create sensor systems with superior technological characteristics to allow the detection, tracking and identification of enemy's the air means. Among these sensors, an important role is played by the radar as the main means of airspace surveillance. The data provided by the system are transmitted to the processing centers where, after their analysis, they will build the real image of the airspace in the area of interest. Surveillance possibilities are dependent on the technical and tactical characteristics of radars and on the independent technological aspects such as the characteristics of the landscape in the area where the radar is located, placement towards the surveilled area and the type of platform on which they are mounted. From its creation, the radar has been the technical means with which the world states built surveillance and early warning systems capable to detect threats to national security in the airspace.

The advancement in science and technology contributed to this leapfrog in radar building. The diversity of detection means made them to be used in a number of military and civilian fields, which were difficult to anticipate even by the scientists and engineers that had built these systems. The number of radar applications for the civilian area resulted in its use in remote sensing. The radar for civilian applications, respectively remote sensing, uses wavelength that correspond to the microwaves because they propagate better in the atmosphere regardless of the existing conditions. In this field, the radar is used to obtain the images of the terrain as a result of the bodies on the ground surface reflecting electromagnetic waves, results which are used to create the maps, plans, or the images of the area under surveillance.

In this paper, we will approach the active sensors used in remote sensing and we will present their military and scientific importance. Active sensors can be grouped in the following categories: real aperture radars (side-looking airborne radars, scatterometres, altimeters, weather radars) and synthetic aperture radars[6]. Among the active sensors used in remote sensing we will discuss the side-looking airborne radar and the synthetic aperture radar.

Side-looking airborne radar, SLAR[7], is an active sensor mounted on airborne platforms. Aircraft has under its fuselage a fixed, long and thin antenna, which emits beams of electromagnetic waves side looking the direction of flight, scanning the earth's surface through the linear movement of the aircraft that carries it.

The first radars for ground surveillance used to scan the earth's surface by rotating the antenna, but the resolution of the images obtained as such was poor because of the limitations imposed by the constructions of the antennas. SLAR contributed to eliminating the aforementioned limitations, thus obtaining images of earth's surface with finer resolution. Until the 7th decade of the last century, the advancement in technology permitted the building of SLARS which functioned at 35 GHz and demonstrated, through the quality of the images provided, the potential of this sensor as an instrument of Earth observation[8].

The use of radars on space-based platforms was first intended to facilitate the docking of space ships at space stations and laboratories under safety conditions. Later on, radars were used on scientific missions (the study of Titan, of planet Venus, observations of earth's surface, etc.), but also for military purposes as a provider of high-resolution images.

SLAR provides a narrow directive characteristic, horizontally and a large one, vertically, which creates the image through the airplane movement, the illumination time length of the earth's surface depending on the speed of the airborne platform, the distance between the radar and the illuminated object and the width of the diagram on the horizontal axis.

Images provided by SLAR are obtained through an impulse of electromagnetic energy directed towards the earth's surface, which is illuminated under an oblique angle, thus allowing the clear visualization of objects or different structures or geological formations, in comparison to the images obtained from conventional aerial photos or the images obtained with the sensors onboard satellites. The recording of data provided by SLAR was performed differently according to the technological possibility that existed at a certain moment; so, initially, data was recorded on film with the help of cathodic tubes, later on, with the advancement in digital means, the recording was performed digitally, data being stored after having been transformed into digital data with the help of an analogue-digital converter.

Resolution of SLAR depends on the length of the impulse emitted and on the width of the directivity diaphragm of the radar. The length of the impulse determines the spatial resolution of SLAR (the ability to separate the pixels of the image perpendicular to the direction of flight) in the direction of its propagation. The capacity to detect the ground objects is influenced by the length of the impulse and the value of the incidence angle, the images with good resolution being conditioned by the generation of short length impulses. The resolution on the azimuth is determined by the width of the directivity diagram on horizontal axis, by the height at which the airport platform is located and by the physical dimensions of the antenna. In order to obtain very good azimuthal resolution, the antenna has to be of large dimensions, so it is necessary to compromise the dimensions and the height at which the airborne platform is located in order to obtain detailed images of the earth's surface illuminated by the radar. The large dimensions of antennas make them unusable onboard space platforms due to the high cost of launching them into space, so, in this case, the synthetic aperture radars are preferred because they need a smaller antenna in order to obtain a better resolution on azimuth.

The active sensors which use microwaves for detection, illuminating the area of interest using diaphragms with synthetic aperture, can be divided as follows[9]:

- synthetic aperture radars (SAR[10]);
- inverse synthetic aperture radars (ISAR[11]);
- interferometric synthetic aperture radars (InSAR[12]).

The synthetic aperture radar is a type of SLAR, actually its technological development, which is designed to generate maps or images of the areas on the earth's surface illuminated by the electromagnetic beam emitted by it. The synthetic aperture improves the resolution on azimuth of the radar and compared to SLAR this resolution would correspond to a larger antenna.

The concept of synthetic aperture radar was introduced in 1951 by Carl Wiley, for the Goodyear company from the United States, and it represented a significant advancement in radar technology. In Europe, the first studies were conducted in France in 1960 while the first experimental flight took place in 1964[13].

The use of SAR into the outer space began in 1978 when on 26th July NASA launched the SEASAT satellite which had onboard an L-band SAR. The first Soviet S-band SAR was placed on KOSMOS 1870 satellite on 25th July 1987 and in 1991, 16th July, the first European remote sensing satellite ERS-1 was put into orbit having a C-band SAR onboard[14].

SAR represents a coherent radar system placed on airborne platforms which uses the flight of the platform to simulate a large antenna in order to obtain high resolution images. From the elements presented above we can deduce the advantage offered by SAR in terms of high-resolution images, but also its dependency on the platform trajectory, meaning that it is mandatory to keep straight trajectory and constant speed during the whole surveillance period of time.

Mounting a SAR onboard space platforms and its operation in orbit involves great expenses. The benefits offered by SAR on a space platform and the fine quality of images it provides justify these costs. This type of SAR has the following advantages compared to other categories of sensors mounted on space platforms:

- possibility of surveillance and detection under any weather conditions;
- possibility of surveillance and detection at night;
- possibility of detection of certain phenomena that cannot be detected with other categories of sensors;
- global coverage, repeated according to the flight parameters of space platforms;
- possibilities of long-term surveillance of the areas of interest[15].

In the last decades, the progress of SAR building technology regarding radar electronics and the digital processing of data has contributed to improving the performance of these surveillance systems. SAR's high potential made it to be used on numerous remote sensing military and civilian missions thus ensuring the collection of high-resolution data in areas that are difficult to observe with the use of other sensors. An example, in this respect, is the German satellite TerraSAR[16] and the Italian satellite COSMOS SkyMed Second Generation[17] which have on board SAR with a minimum resolution of 0.25 m and respectively of 0.8 m according to the dimensions of the area under surveillance.

The civilian surveillance missions which use SAR are the following: oceanography, hydrology, weather changes, seismology, agriculture and forestation, urban areas, etc.

The inverse synthetic aperture radar is a version of SAR which detects targets from the area of interest without the movement of the radar, this having a fixed position, while the synthetic aperture of the radar is created by the movement of the target. ISAR possesses the advantage of permanently maintaining under surveillance a certain area of interest so it is used from the operational point of view to detect vessels, aircraft and space objects[18].

ISAR can be used to complete the image data provided by other sensors such as passive optical sensors or active systems based on the detection with the use of laser in case of bad weather conditions which may influence their possibilities of detection.

ISAR's are used frequently onboard aircraft which execute marine patrol missions to provide high quality images which allowed them to detect maritime vessels, military or civilian aircraft, missiles, while other radars provide only data about these objects without being able to identify them.

On space missions ISAR is used to provide images of the asteroids from the solar system giving the scientific community precious information on their shape and trajectory.

The interferometric synthetic aperture radar was developed by Jet Propulsion Laboratory to detect ocean streams or moving targets.

Later developments of radar made it possible to determine the height, so it was used for the precise measurement of different landscapes. Interferometric synthetic aperture radar has two antennas that receive the reflected electromagnetic impulses which combine the changes that appear with greater precision. Radar interferometry measures the differences of phase between two radar echoes associated with the same image pixel, but measured by two different systems along different directions with the two antennas onboard the surveillance platform. In other words, SAR interferometry is based on a combination of two SAR images of the same area or target obtained from slightly different points, thus resulting a new image called interferogram.

The positioning of antennas on the carrier platforms is performed according to the missions they have to fulfill, so for detection and analysis of movement targets the, InSAR antennas are positioned horizontally on the carrier platform along a line that is parallel to the ground so that the echo signal from a Moving Target is different from the one received from a fixed target. Antennas mounted vertically on the carrier platform receive echo signals reflected by a target, so InSAR is used in this configuration to determine the height of the terrain from the illuminated area. In practice, there are two constructive variants of InSAR, respectively with two antennas on the same platform or with just only one.

InSAR with one antenna onboard the carrier platform has a simple configuration, but the creation of the image using interferometry involves passing twice over the area under surveillance. In order to obtain a precise image of the area one must know with great precision the position of the antenna to be able to overlap the images obtained after two fly-bys. It can be inferred that a major problem of this type of InSAR is wind velocity which can modify the platform's trajectory (if there is an airborne platform) and implicitly the image of the area under the radar surveillance[19].

InSAR with two antennas onboard the carrier platform is a more costly configuration due to the two antennas, two receiver channels and the two sets of analogue-digital converters. Obtaining the image of the scene through interferometry is a simple task, at one fly-by, because the two images that have to be overlapped are obtained by the simultaneous collection of data and the real time processing[20].

InSAR has a multitude of civilian and military applications because the information provided results in precise images of the areas under surveillance. Among the civilian applications that use this type of radar we should mention first the space ones of mapping the planets which are in Earth's proximity, even if later on this activity was extended to our planet as well. The data obtained in case of the Earth are used to detect the movements of the ground due to earthquakes, in the study of volcanoes to determine the changes of the earth's crust associated with volcanic eruptions, changes in the distribution of magma, monitoring landscape, monitoring the glacier structure, changes in ice dynamics, monitoring the highways, railways, elements that are specific to urban development, etc. In the military field, an important role is played by this radar in creating highly precise topographic maps, in the detection of important military objectives from the enemy territory, in determining precise target location, etc.

From the military point of view, SAR, regardless of its variants, is a source of extremely valuable data which, when processed, provide the necessary information support for creating detailed and more precise maps of the areas in question, including the urban ones, for detecting and determining the category and characteristics of combat means as well as the timely identification of enemy's intended actions.

Knowing the operational situation on the battlefield is the key to its dominance. Obtaining detailed and precise images will contribute to increasing the level of adaptability to the battlefield. If the commander knows the location of the enemy, his forces and weapons systems he will have an excellent tactical advantage which will take the form of the detailed planning of actions and the increase in the efficiency of his command and the actions of his troops. SAR potential to obtain very precise data will result in accurate operational images which will contribute to gaining information supremacy over the enemy. In this respect, the adaptability of organic troops will increase when it comes to existing situations and the requirements of the battlefield, imposing his own combat manner to the enemy and thus maintaining the initiative during conflict. More than that, the advancement in information and communication technology has created a powerful bond between information and action. In this respect, the information support for all the battlefield structures will ensure the coordination of actions against the enemy.

The threats from the air environment are a permanent danger to state security being a factor that has determined the great powers to take action and create a complex surveillance system, capable of discovering threats in any part of the globe. SAR is a more recent sensor which became an important element in surveillance systems being able to provides the accurate image of the areas of interest, effect that will contribute to combating and neutralizing threats. In this respect, surveillance in and from the air with the help of a large variety of sensors mounted onboard airborne platforms will be a permanent mission that will ensure the detection and identification of the elements on the earth or sea surface as well as the small air means that fly at low altitudes. The data provided will give the real time image of the area of interest thus providing the information support that is necessary for the decision-making process and the military command at all levels.

In conclusion, we can state that active sensors mounted on airborne or space platforms are useful tools for the surveillance of the earth's surface. The capacity of these sensors to determine with great precision the changes at the level of earth's crust and identify the early signs of a natural phenomenon with impact on human activity in the area where it produces is actually the main reason for its intensive use in surveillance missions. The data provided contribute not only to understanding natural phenomena, changes produced due to human activity, but also to monitoring and determining the impact of human activity on the environment and to identifying the pathways of sustainable development with reduced impact on it. As far as the military environment is concerned, these sensors will ensure the knowledge of the battlefield, providing the commanders with relevant information for the decision-making process, for striking the enemy's objectives at the right time, for obtaining and maintaining information superiority and, last but not least, for dominance of the battlefield by obtaining and maintaining the initiative of decision and action while conducting military operations.

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