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RESEARCH OF THE POSSIBILITIES FOR SMALL OBJECT DETECTION USING SYNTHETIC APERTURE RADAR

Object detection is a very broad process belonging to many very different areas. Among them detection of objects that are lost or hidden in some landscape is the problem of great civil and military importance. Here we combine the nowadays very useful and applicable system, the Synthetic Aperture Radar (SAR) and investigate the possibilities for the object detection using SAR recordings. The starting points are the possibility of real-time analysis (RTA) performed in SAR applications and the very low dependence of the SAR recording on the atmospheric conditions. On the other side, starting points include also the finite resolution of the pictures obtained during recording as well as the finite level of fluctuations, i.e. noise, intrinsically present in the records. Further evaluation of these properties is done using physical properties of matter-radar wave interaction and the radar signal processing (RSP). The interplay among the characteristic distances of an object that is looked for, the surrounding vegetation or other forms in landscape and the radar wave-length are discussed. Such an approach would have a long standing objective of improving airborne instruments used in different purposes and could help in some of situations where processes done should be precise, reliable and fast.

1. Introduction

Modern traffic control includes a variety of monitoring systems. Recently SAR systems emerged as a powerful tool for traffic control, as well as for a range of other terrestrial (precise terrain mapping, vegetation analysis, deforestation, desertification, flood monitoring, plants growing, river mapping, polar ice mapping, pipeline inspection, city mapping, enemy forces localization and others) or extraterrestrial (Venus analysis, small objects passing near Earth recording and others purposes). These applications include a number of SAR principale varieties.

SAR system [1, 2] is a radar, usually airborne, emitting electromagnetic radiation -microwave beam (MB) on some particular area the airplane passes by. The scattered MB is detected almost at the same airplane position at which it was emitted. As airplane passes by, the points of emission and detection of MBs cover larger distances in airplane flight direction.

When the recording is finished, the distance airplane passed during recoiding is efiective antenna aperture A,

$$A=vt+2a,$$

which could be as large as several kilometres. Therefore, the aperture is made during flight Here v is the average airplane speed during time interval of recording t.

There are several reasons for recent rapid change of SAR systems usage. As the first reason, SAR is complementary visible or infrared sensors because of different physical properties of the atmospheric electromagnetic radiation propagation. While visible and infrared sensing are limited to clear sky and good weather conditions, microwave beams propagate with a little absorption through the atmosphere. Additionally, if visible light or infrared radiation used for sensing are emitted not by the Sun but by other objects (so called passive sensing) these methods are limited to usage during daylight On the other side SAR systems generate their own MB needed for sensing (so called active sensing). Because of these reasons there existed a need for SAR system. However, in order that SAR systems be available for RTA, a large demands on computational part were imposed. With the development in the computer technology the RTA become possible, what contributed a lot to intense SAR system usage. Additional problem that was solved was *speckle formation*, for which new algorithms had to be developed.

All subsequent processes done on the data collected are parts of the RSP. The data should be combined and transformed in order to eliminate the influence of variations in relative distance position of various reflector parts and in relative airplane motion.

From the first SAR measurement, dated back to 1954, the SAR went through research and development process, which is far from being finished yet [2,3]. Nowadays, SAR systems are mounted on airplanes and satellites (like ERS-I, RADARSAT, TOPSAR).

Prevalently, usage of SAR included relatively large objects. The possibility of using SAR systems for detection of small objects emerges naturally. Here, a small object is defined as the one the picture of which is of the order of at most a pixel in the final form of recording. Such a possibility could contribute to preservation and enhancement of traffic safety through fast localization of crashed airplanes, lost vehicles and other similar tasks.

In this paper a possible modification of the typical SAR system, needed for such a task is described and discussed, in the following section. The third section summarizes results and gives lines for future development.

2. *Application of Scattering Techniques in Radar Digital Signal Processing*

In this section possible consequences of appliance of SAR system for small object detection is discussed having in mind that RTA RSP of SAR collected data should be possible. Usually, only some large area containing the object is known. Therefore, on the operational level, the problem is to localize efficiently the object looked for. Here *efficiently* means as fast as it could be done. But, if SAR system imaging is used, then the object is looked for through the detection of its characteristics, its fingerprint, found after suitable processing of the SAR records. This way, the object localisation in the real space is transferred into the pattern recognition in the virtual space a set of SAR records of original terrain. Schematically, the process described is shown in Fig. 1.

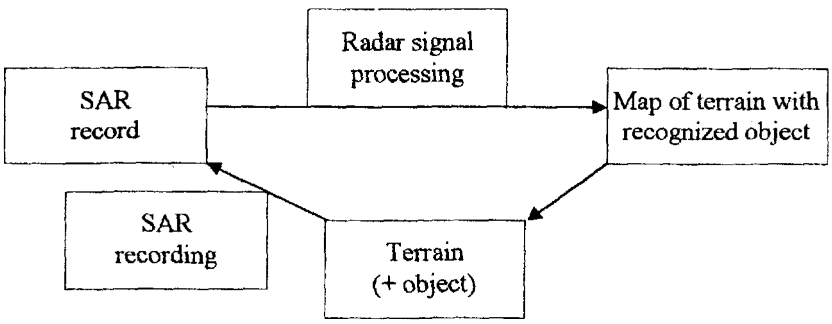

Fig. 1. SAR system organization for object localization

The origin of the process shown on Fig. 1. is the situation on the terrain where some, yet non-located, object exists. The SAR system gives the record of the terrain that contains, yet unknown, information about the object and the terrain. Using various algorithms for signal processing (presumably digital), the needed information is extracted and (me ends with the object recognized in the precisely known position. The object coordinates are used to establish a physical contact with the object, which is the final step in the process.

The main advantage of the SAR system in the process is its all-day, all-weather capability of recording. Hence, the process lasting, i.e. efficiency as is described above, is determined by the RSP. However, the set of alghorithms available for signal processing is a rather large one, containing many sophisticated procedures, what gives additional impetus to the operational development of this kind of SAR applications.

The object detection using SAR systems belongs to a class of SAR applications where the precise properties of the area recorded are not important, variant A on Fig. 2. It was done using the non-locality of the object, a consequence of its dimensionality [4]. Here this kind of non-locality is not available. In the object detection the resolution is a crucial factor. The higher the resolution the larger the number of pixels which brightness and contrast is modified by the object presence. Then correlations found during RSP could lead to a small false alarm rate.

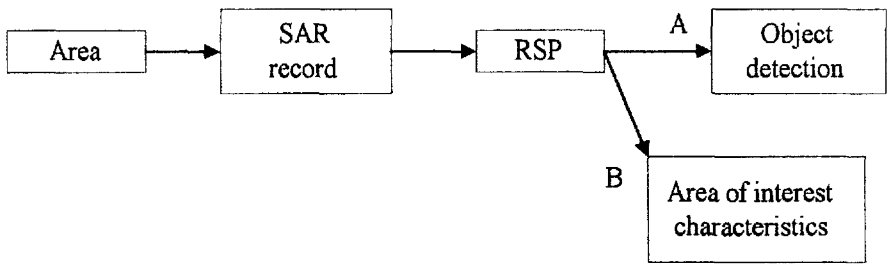

Fig. 2: Differences between *object detection* (A) and *area mapping* (B) SAR applications

However, this, in principle simple scheme, suffers from influence of a large number of factors lowering its probability of detection. Probably the largest is the influence of unknown orientation of the object and its possible plastic deformations. Because of this, a possibility for including some data base of the object looked for is questionable.

As an example, we discuss the possibility of recognizing a metal object in the area covered with vegetation. The metals are characterized with almost total reflexivity for MB. Therefore, if one knows the metal object shape, its scattering by MB is easily constructed using the geometric optics [5-7]. The differences between the intensity and/or brightness of pixel containing metal object reflected MB and pixels containing records of vegetation (of dielectric nature) have some characteristic levels that can be inferred using some previously done modeling. After suitable convolution of the differences on various pictures a kind of reduction of the object location is possible, in that (me ends with several locations (in ideal case only one) that needs additional recording. Let P denote the value of the quantified property of the pixel.

Further, let $p_k(i, j)$ be its value for the place in the area with the coordinate (ij) in the suitably defined net and

$$\overline{p}_k(i, j) \equiv \frac{\sum\limits_{(m,n)\neq(i,j)} P_k(i,j)}{\sum\limits_{(m,n)\neq(i,j)} 1}$$

the average value of the property at the place (i, j). The index k denotes the number of the picture in the record. Here, the average is calculated using values of P at the locations close enough to (i,j) but *excluding* (i, j) coordinate. Therefore, it is the assumed value of P that would occur on average at the location (i, j). For this average, the number of neighbouring places is important because it is determined with various properties of the vegetation, like correlation among the objects found in the vegetation. Then, the possible object locations are the ones for which the expression

$$\sum_k \left[P_k(i,j) - \bar{P}_k(i,j)\right],$$

where the sum over k is over all the pictures in the record, has at least two local extremes. This is so because if there is metal object, it usually has some plane surfaces. They allow normal reflection of MB and negligible scattering in other directions. Therefore, its influence could be seen as relatively sharp local maximum when the picture is taken in the airplane position such that MB is perpendicular to the object surface, and as relatively broad local minimum in one of other positions. The influence of this location on value of P in neighbouring locations, realized through the averaging, is lowered because a larger number of locations is included in the averaging.

Further evaluation of the proposed SAR system based on small object detection should use theoretical modelling and experimental verification. Theoretical modelling uses properties of scattering of MB on bodies of various shapes and compositions [5] and for a suitably generated terrain enables generating of the SAR system record.

3. Summary and Conclusions

SAR systems are powerful modem devices enabling all-day, all-weather detailed monitoring and recording of terrain characteristics. Here, the possibility for small object detection using SAR systems is discussed. It is shown that this problem is naturally transformed into pattern recognition during signal processing. This enhances the possibility for successful

SAR systems based on small object detection application. Some problems accompanying it are addressed. Future experiments are needed to put precise range of efficient application of SAR systems for small object detection.

References

1. *Oliver C. J.*, Information from SAR Images // Journal of Physics D, 24, 1991.–P 1493-1514,

2. *Slatton K. C. et al.*. Modelling Wetland Vegetation Using Polarimetric SAR, http://www.csr.utexas.edu/rs/boll.litml,

3. *Vasconcellos K.* and *Frery A. C.*, Improving Estimation for Intensity SAR Data / Inteistat, 4 (2), 1988.– P. 1-25,

4. *Hellwich 0.*, Line Extraction from Synthetic Aperture Radar Using a Markov Random Field Model / Microwave Sensing and Synthetic Aperture Radar, 2958, 1996. – P. 107–116,

5. *Ivanov E. A.*, Difrakcija Elektromagnitnih Voln na Dvuh Telah (in Russian),// Nauka i Tehnika.– Minsk, 1968.

6. *Jackson J. D.*, John Willey & Sons, Classical Electrodynamics, 2nd ed., Chapters 7-9.– New York, 1975.

7. *Mishchenko M. L, Travis L D., Mackowski D. W.*, T-matrix Computations of Light Scattering by Nonspherical Particles'. A Review // Journal of Quantitative Spectroscopy and Radiative Transfer. 55, 1996.– P. 535–575.

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