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Radar and Optical Images Fusion Using Stripmap SAR Data with Multilook Processing

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***Abstract*—The paper presents the real-life data results of SAR and optical images data fusion. The fusion has been carried out for SAR images obtained in stripmap SAR mode using multilook processing with different methods of final image creation. The aim of the fusion was to enhance the target recognition capabilities on the Earth surface for a simple single-channel SAR receiver.**

***Keywords*—Synthetic Aperture Radar (SAR), focused SAR, multilook, multilook colour mapping, data fusion.**

I. Introduction

THE modern airborne surveillance and reconnaissance systems dedicated for Earth observation are mostly multisensor systems consisting of: optical camera, infrared camera (IF), Synthetic Aperture Radar (SAR), etc. [1]. The systems operators often have to monitor different sensors during the mission. As a result, the operator of the real-time observation systems may encounter difficulties to process the data coming from all sensors of the airborne platform, which can lead to undesirable mistakes or omissions during the mission.

The main goal of the presented paper is to show advantages of the data fusion of images obtained by an optical camera and a SAR system [2]. The fusion of such images provides increased interpretation capability of the observed Earth area with more complete view of the observed targets [3]. The different bands of the sensors, as well as the different method of signal processing in SAR systems lead to enhanced target detection and recognition [4], [5]. The improved target recognition of the area observed by sensors significantly helps the users to provide more successful missions both for military and civilian applications. Moreover, the data fusion reduces the amount of data which the system operator has to perceive during the mission since the images from multiple sensors are combined to provide result easier to handle and interpret.

The second aim of the work was to test the possibility of improving the interpretation capabilities of the observed Earth area for a simple single-channel SAR systems, which are still widely used by users worldwide in airborne surveillance and reconnaissance operation.

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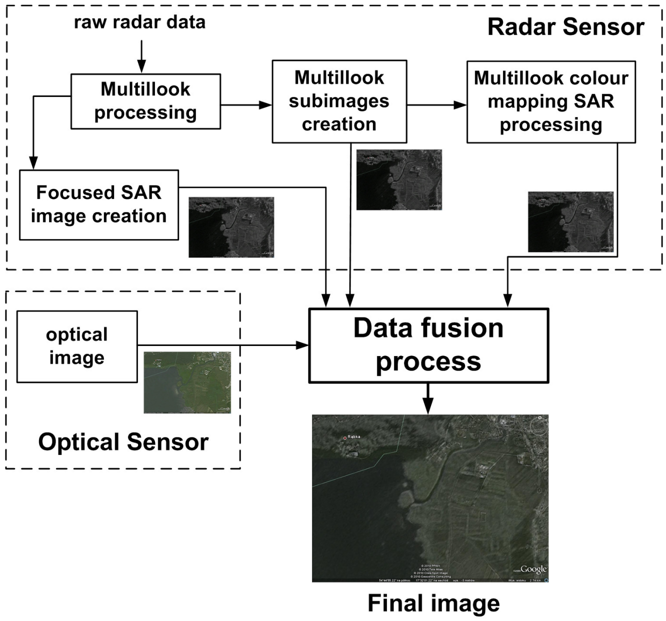

Fig. 1. Block diagram of the radar and optical images fusion algorithm.

II. Method Description

The whole method for the fusion of the optical and SAR images is presented in Fig. 1. The input of the data fusion block consists of optical image and three types of radar image. The radar images are created in three different modes of SAR processing: focused SAR, multilook SAR and multilook color mapping SAR.

In the first step, multilook processing is applied to a raw radar data collected in stripmap mode by single-channel SAR radar. The multilook processing uses N matched filters. Each matched filter is designed to concentrate energy from different part of the received SAR phase history, which is shown in Fig. 2.

The result of the multilook processing are N independent complex sub-images, which are used in further processing. The simplified block diagram of multilook processing is shown in Fig. 3.

In the second step of the whole fusion algorithm presented in Fig. 1, three images are created using three different methods.

The first method is the classical focused SAR processing [6], [7]. This technique allows us to obtain high resolution radar image with achievable theoretical cross-range resolution equal to $L/2$, where L is antenna length. The focused SAR image is created by coherent summation of all N independent

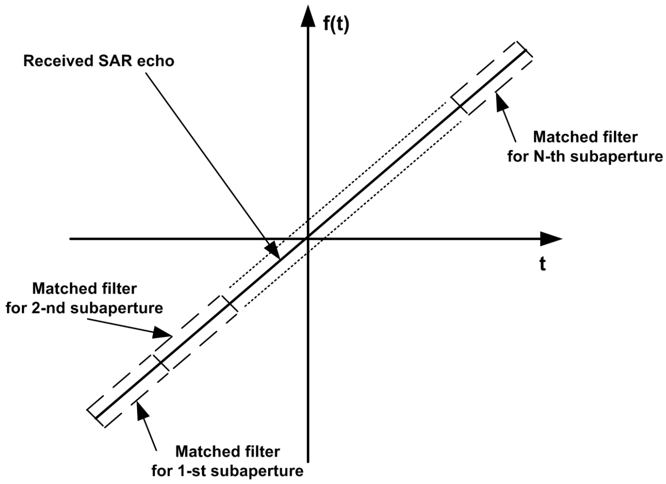

Fig. 2. Received SAR echo with marked sub-apertures matched filters.

SAR sub-images created by multilook processing. In the final step the absolute values (pixels intensity) of the complex image samples are calculated to create focused SAR image.

The second method is multilook image creation [6], [7], in which the final radar image is obtained by non-coherent summing of all independent SAR images created by multilook processing. As a result of this process, the radar image with N times worse resolution compared with classical focused SAR image is created. However, the non-coherent summing decreases so called speckle noise, which is characteristic to coherent imaging systems. Thanks to this the image has better radiometric quality despite the decreased cross-range resolution.

The third method used to obtain SAR image is multilook color mapping processing [8]. This method is used to increase target recognition capabilities in SAR images created by single-channel SAR system. In this technique RGB (Red, Green, Blue) colors are assigned to different parts of the received SAR phase history.

The optical images used in the data fusion process can be obtained using the camera mounted on the same platform as the SAR sensor. The optical images can be gathered at the same time as the SAR images. In this paper, however, optical

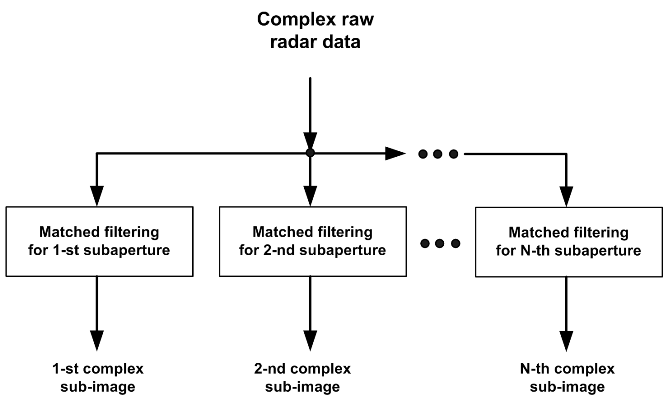

Fig. 3. Simplified block diagram of the multilook processing.

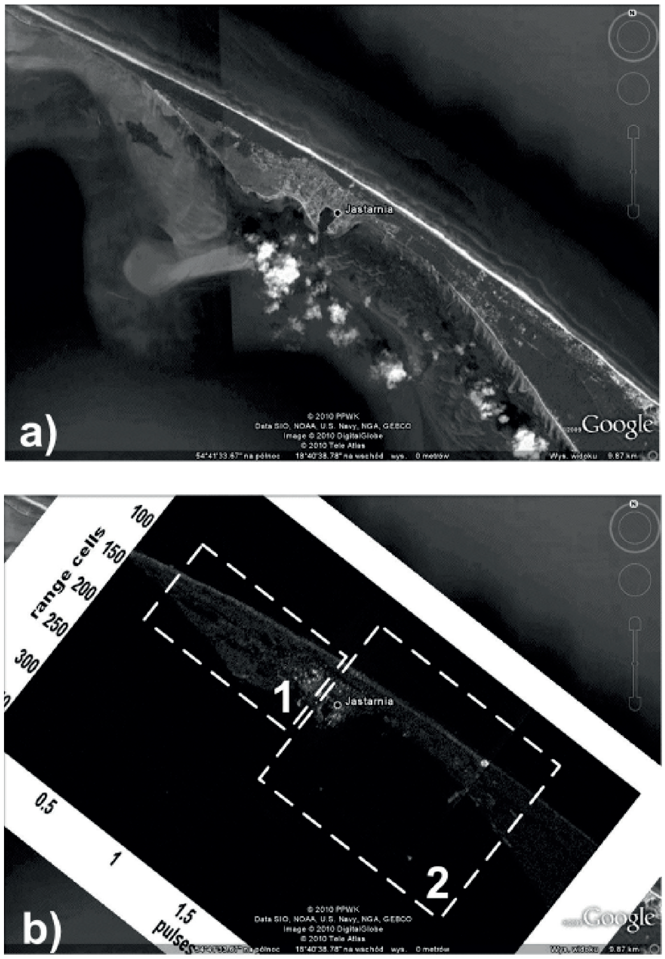

Fig. 4. Part of the Hel peninsula with Jastarnia town; a) optical image; b) SAR image with two areas marked for analysis.

images from different source and taken at different time will be used. The radar imagery comes from airborne SAR trials over the Polish coast of the Baltic sea [1], [9]. The optical images, on the other hand, come from the Google Earth database. The data fusion process presented in Fig. 1 is dedicated for merging the image data obtained by optical camera and SAR system. However, the fusion can be easily extended to merge data from other sensors mounted on the airborne platform, e.g. Infrared (IR) camera.

The fusion of the data from optical camera and radar involves two steps:

- Geometrical alignment,
- Images merging.

To perform the first step, precise information regarding the geographical coordinates of the optical and radar images has to be provided. The images have to be free of any geometrical distortions, and they have to be projected onto the same reference plane. Moreover, resampling of the images has to be carried out to obtain common positions of the pixels.

The merging of the aligned images can be performed in different ways depending on the type of optical and radar data. Usually, the optical images are true-color images, i.e. colors on the image correspond to the colors perceived by human

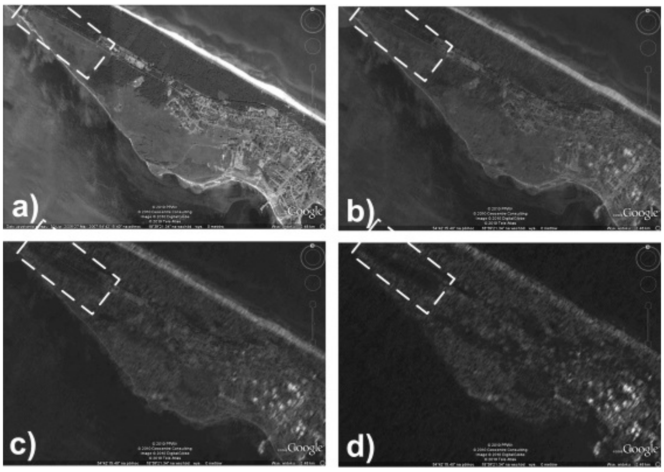

Fig. 5. West part of Jastarnia town; a) optical image; b) fusion of the optical and SAR images; c) fusion of the optical and SAR images; d) SAR image.

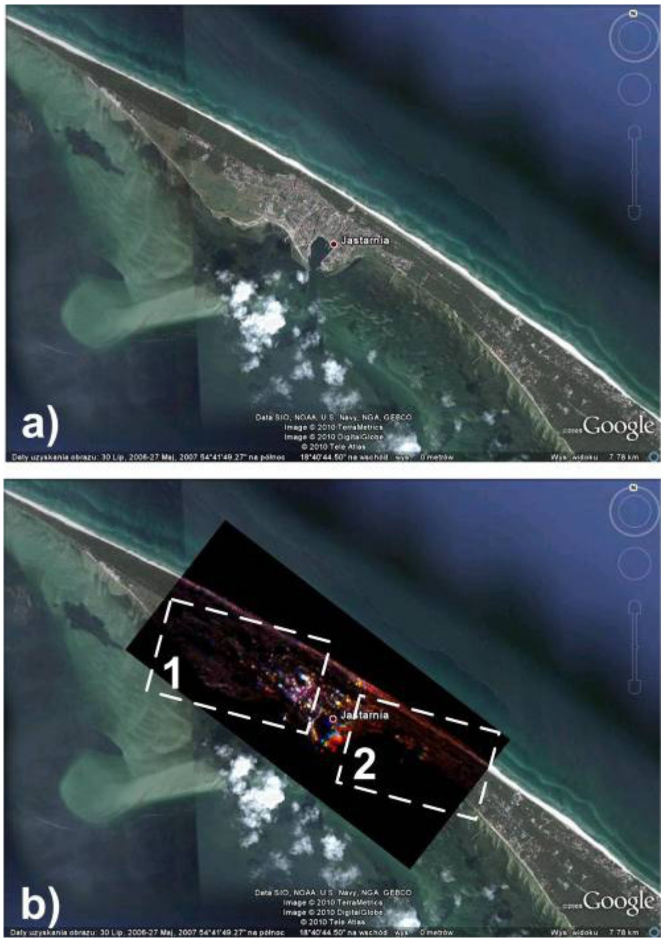

Fig. 7. Part of Hel peninsula with Jastarnia town; a) optical image; b) multilook colour mapping SAR image with marked two analyzed areas.

eye. The radar images from a single-channel SAR system are usually grayscale images. In the case of multilook color mapping SAR [8], the images are false color, where colors are assigned to different parts of the Doppler history of the target. The merging of optical and radar images can be carried out for example by [3]–[5]:

- Simple overlay of semi-transparent images with their original coloring schemes,
- Optical and radar images can use different color spaces,
- One of the images can correspond to the intensity of the final image, the other to the color.

In this paper we used the first approach – a simple merging of the images with different transparency factor was applied.

III. Results

The results of the image fusion from optical and radar sensor are presented in Fig. 4 – Fig. 13. For the test the data from different areas has been chosen.

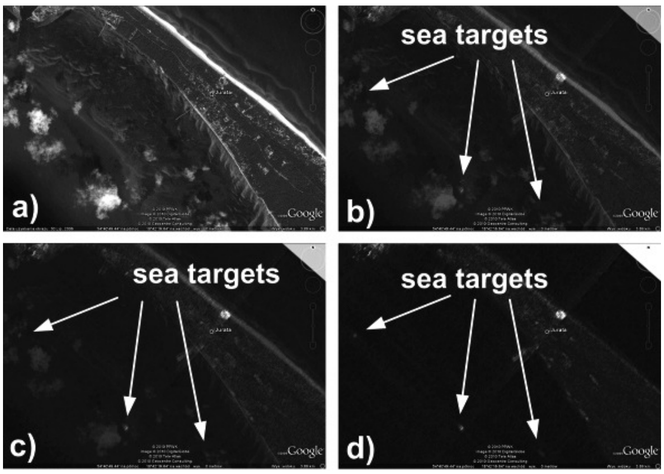

Fig. 6. East part of the the Jastarnia town; a) optical image; b) fusion of the optical and SAR images; c) fusion of the optical and SAR images; d) SAR image.

Fig. 4 shows the optical and SAR images of a part of the Hel peninsula on the Polish coast. In the figure two different areas for which the fusion has been carried out are marked. The results of image merging are shown in Fig. 5 and Fig. 4.

Fig. 5 shows the fusion results of optical and SAR images of the first area marked in Fig. 4. In Fig. 5b and Fig. 5c the data from Fig. 5a (optical image) and Fig. 5d (SAR image) has been merged with different degree of transparency.

In Fig. 5 the land area has been marked, where for different degree of image transparency the users can observe more complete view of the analyzed area. The shadows visible on SAR images created 3D visualization capabilities by additional height information.

The results of the fusion for the second area marked in Fig. 4 can be seen in Fig. 6.

For the analyzed part of the Hel peninsula the fusion of optical and multilook color mapped SAR images also has been carried out. The obtained result are shown in Fig. 7. For the analyzed Earth surface two different areas have been marked. The zoom of these areas are shown in Fig. 8 and Fig. 9.

Fig. 8 shows the fusion of optical and SAR images of the first area marked in Fig. 7. In Fig. 8b and Fig. 8c the data from Fig. 8a (optical image) and Fig. 8d (multilook SAR image) has been merged with different degree of transparency. Different

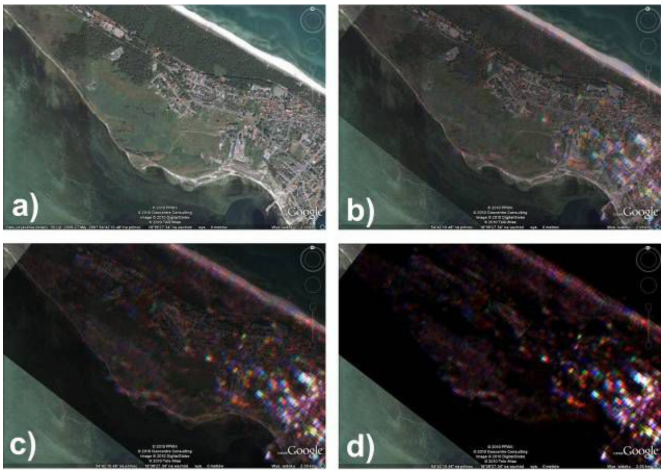

Fig. 8. West part of the the Jastarnia town; a) optical image; b) fusion of the optical and multilook colour mapping SAR images; c) fusion of the optical and multilook colour mapping SAR images; d) multilook colour mapping SAR image.

colors of the fused SAR image obtained in multilook color mapping technique improved the interpretation capabilities of the observed Earth surface. The results presented in Fig. 8b and 6c provide more comprehensive view of the analyzed area in comparison with the images obtained from a single sensor presented in Fig. 8a or Fig. 8d.

Fig. 9 shows the results corresponding to the second area marked in Fig. 7. In Fig. 9b and Fig. 9c the data from Fig. 9a and Fig. 9d has been merged with different degree of transparency. Results presented in Fig. 9 show that the fusion of the optical and multilook color mapped SAR images allowed us to clearly identify some circular targets.

For further tests the data fusion of the other part of Polish coastline has been chosen. Fig. 10 presents the optical and SAR images of part of the area around Łeba city. In Fig. 10b two different areas have been marked for which the fusion has been carried out. The results of images merging has been shown in Fig. 11 and Fig. 12.

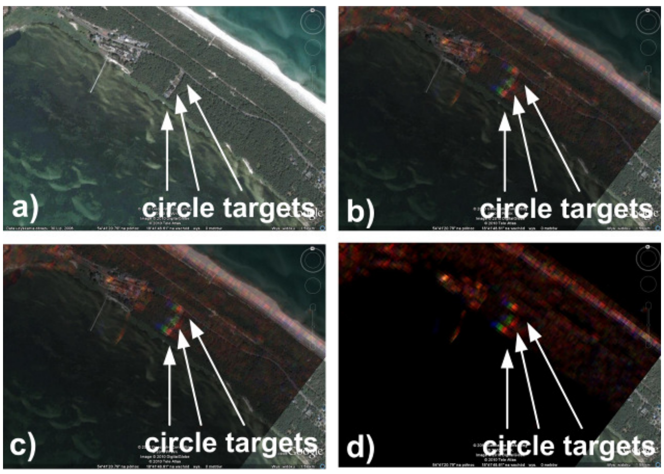

Fig. 9. East part of the Jastarnia town; a) optical image; b) fusion of the optical and multilook colour mapping SAR images; c) fusion of the optical and multilook colour mapping SAR images; d) multilook colour mapping SAR image.

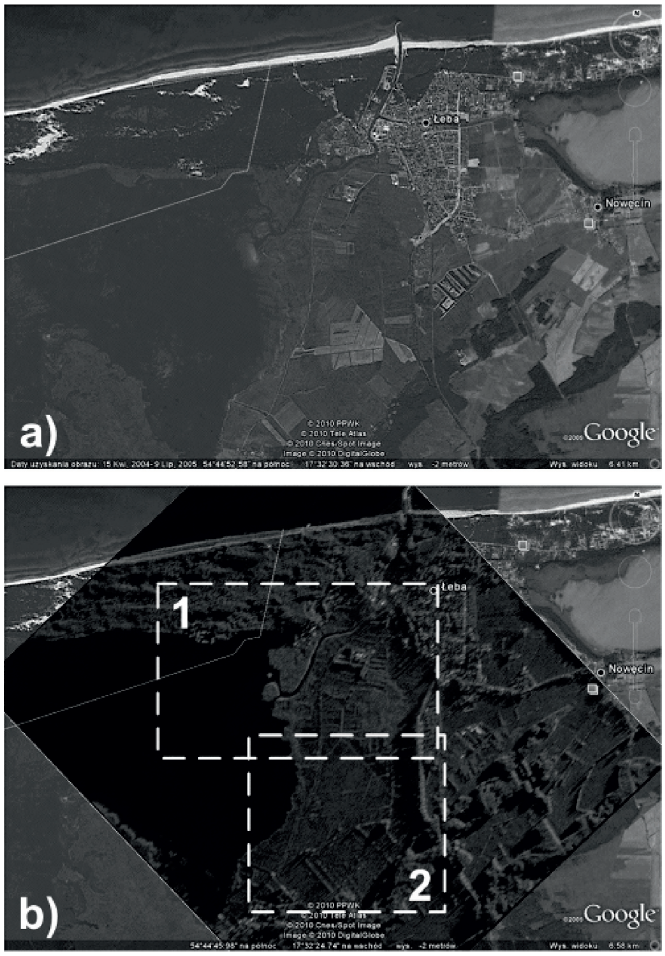

Fig. 10. Łeba town and surrounding area; a) optical image; b) multilook SAR image with marked two analyzed areas.

Fig. 11 shows the fusion of optical and multilook SAR images of the first area marked in Fig. 10. In Fig. 11b and Fig. 11c the data from Fig. 11a and Fig. 11d have been merged with different degree of transparency. The results presented in Fig. 11b and Fig. 11c show that the fusion of the optical and multilook SAR images allowed for visualization of more targets (roads, paths, fields boarder, trees, etc.) in comparison to the images obtained from single sensor presented in Fig. 11a and Fig. 11d.

Fig. 12 shows the fusion of optical and multilook SAR images of the second area marked in Fig. 10. In Fig. 12b and Fig. 12c the data from Fig. 12a and Fig. 12d have been merged with different degree of transparency. Similarly to the results presented in Fig. 11, the results shown in Fig. 12b and Fig. 12c reveal that the fusion of the optical and multilook SAR images led to improved visualization of numerous targets (roads, paths, fields boarder, trees, etc.), in comparison to images obtained from a single sensor presented in Fig. 12a and Fig. 12d.

Fig. 13 presents the result of data fusion of optical and SAR images obtained in multilook and multilook color mapping techniques. The usage of the fused multilook color mapped

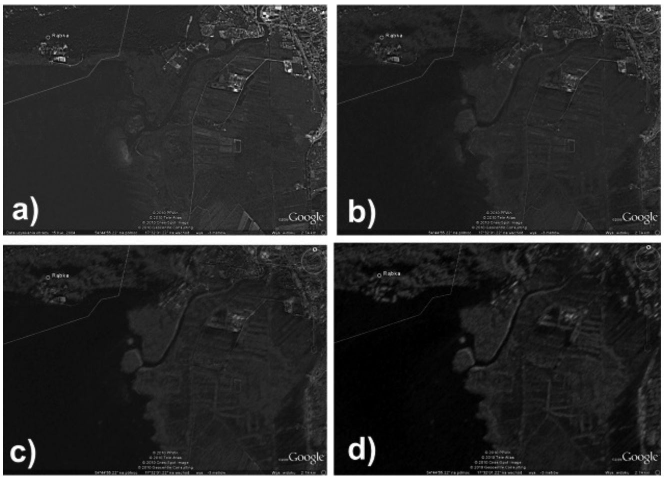

Fig. 11. North part of the area surrounding Łeba town; a) optical image; b) fusion of the optical and multilook SAR images; c) fusion of the optical and multilook SAR images; d) multilook SAR image.

technique significantly improved the recognition capabilities of different targets in comparison to data obtained only with optical sensor or in classical SAR mode. Moreover, the shadow effect which appears in the SAR images creates an impression of 3D depths of the fused images.

IV. Conclusions

In the paper the results of data fusion of optical and single-channel SAR images have been presented. As a reference, optical images from the open database Google Earth have been used. The results presented in the paper are very promising. They show that the usage of fusion of data obtained by a simple single-channel SAR radar with the optical images leads to improved target recognition in SAR images. Applying the data fusion in the airborne systems can be very useful for both military missions (surveillance, reconnaissance, etc.) and civilian application (rescue operation, oil slick detection on the sea surface, etc.).

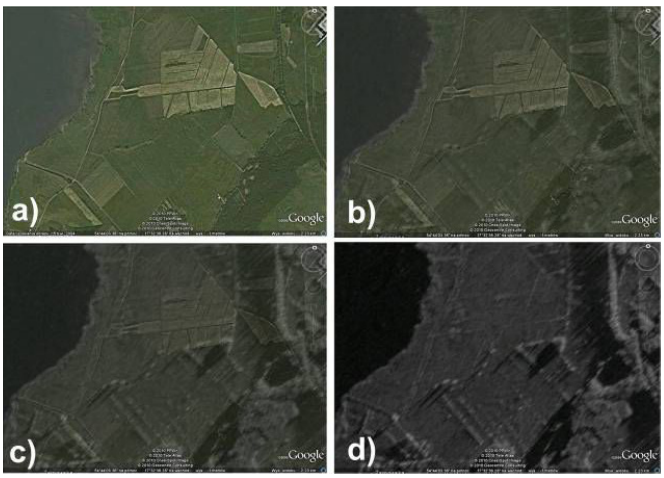

Fig. 12. South part of the area surrounding Łeba town; a) optical image; b) fusion of the optical and multilook SAR images; c) fusion of the optical and multilook SAR images; d) multilook SAR image.

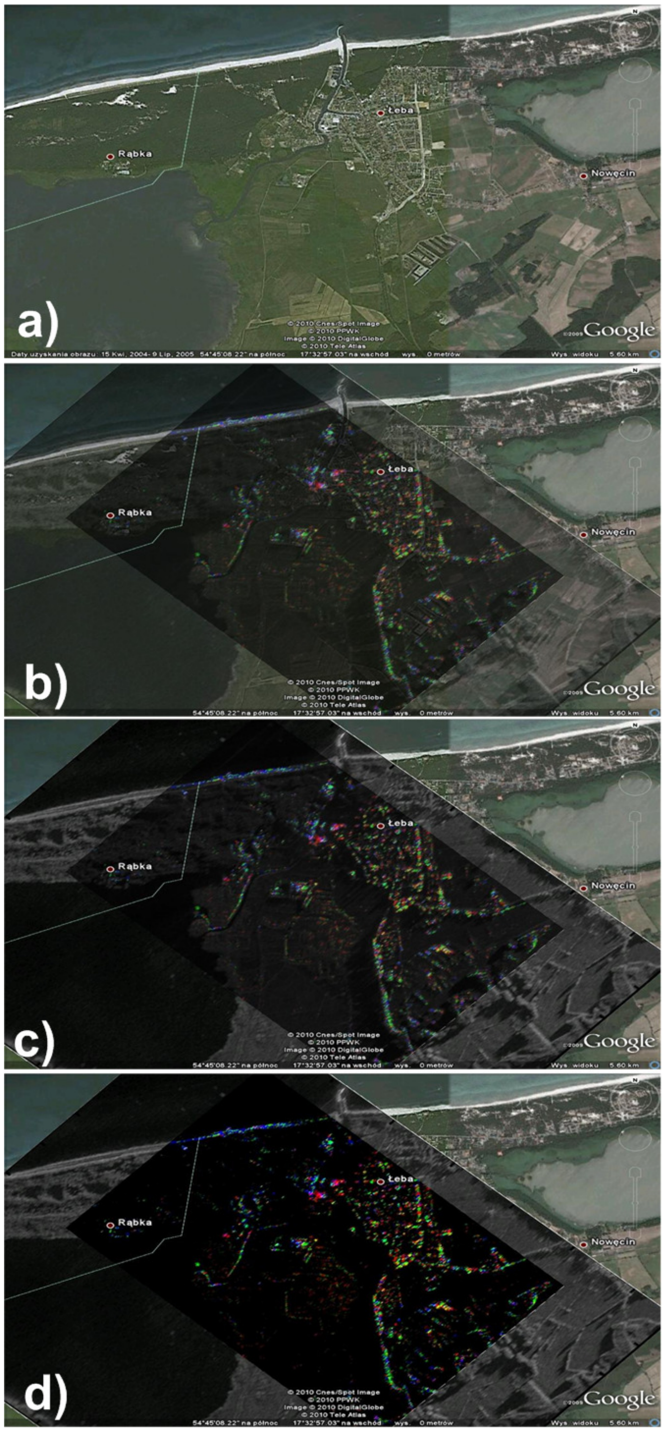

Fig. 13. Łeba town and surrounding area; a) optical image; b) fusion of the optical and multilook SAR and multilook colour mapping SAR images; c) fusion of the optical and multilook SAR and multilook colour mapping SAR images; d) fusion of the multilook SAR and multilook colour mapping SAR image.

In the paper the optical images taken from the Google Earth database have been used. In practical applications, the database of the optical images has to be created by the user. As an alternative, for the missions which take place during good weather conditions (without fog, clouds, etc), the optical camera mounted onboard of the flying platform can be used as a reference for SAR images. In such case the data acquisition process and data processing can be performed on the data collected by radar and camera at the same time.

The data fusion presented in the paper can be easy extended for merging data from multiple sensors. Applying more advanced SAR processing, such as polarimetry or interferometry can further improve the interpretation capabilities of the observed Earth surface.

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