Data Acquisition, Processing, and Visualization in Microwave Holography with Probe Tracking and Positioning on Video

A. Zhuravlev, V. Razevig, M. Chizh, S. Ivashov, A. Bugaev
Remote Sensing Laboratory
Bauman Moscow State Technical University
5, 2nd Baumanskaya, 105005, Moscow, Russia
azhuravlev@rslab.ru

A. Kokoshkin, V. Korotkov
Kotel'nikov Institute of Radioengineering and Electronics of RAS
1 Vvedensky Sq., 141120, Fryazino, Moscow Region, Russia

***Abstract*—This paper focuses on the development of the new holographic subsurface radar data acquisition technique in which the position and the polarization of the microwave probe are established by its tracking on video. This technique allows for adaptive interactive data acquisition when probe trajectory could not be predefined or be equally dense in the areas with no target. The data processing technique is based on an FFT-algorithm which allows interactive operation. The concept of data acquisition is demonstrated on the data obtained with a prototype of the system consisting of a holographic subsurface radar and a web-camera. Contrast markers are used to detect and track the antenna. Further development of the system is suggested. The augmented reality devices are considered as more suitable systems for the realization of the considered technique.**

***Index Terms*—Ground penetrating radar, holography, radar imaging, image processing, Microsoft Hololens, Google Glass.**

I. Introduction

The modern data registration methods for subsurface imaging are based on the sampling of a reflected signal on a regular grid by scanning along parallel equidistant lines with a radar antenna. In the data processing algorithms a probed surface is assumed flat and a specific relief is neglected. The requirement for signal acquisition on a rectangular grid significantly increases its complexity and duration, while the surface relief essentially raises the number of artifacts in the obtained radar image, which affects the possibility of obtaining the radar image of a hidden object, especially when the object of interest is located in a shallow subsurface layer. With this approach to data acquisition, the data processing and visualization are often carried out at a postponed moment, when an additional acquisition of data, if needed, invokes additional costs. This approach appears not only inefficient and unproductive, but also limits applications of the short-range and subsurface radars, such as localized object detection (the detection of mines in the ground, defects in structures and materials), inspection of objects with surface relief (monuments and cultural heritage buildings, composite materials), the sounding of objects with time-varying shape of their surface (inspection of people in motion, bioradiolocation).

The recent advances in augmented reality devices and 3D video sensors open new possibilities of acquisition, processing, and visualization of data for subsurface radars. Their capability of capturing and tracking moving objects, including the sounding scene, enables new subsurface radar sampling technique using arbitrary sparse signal samples allowing the maximum available number of degrees of freedom for one or more antenna probes. For example, an augmented reality device can track one or two antenna probes, registering their position and orientation with respect to the surface while simultaneously capturing the three-dimensional profile and texture irregularities of the probed surface. Thus, a set of the radar signal samples obtained at different points and bound to a three-dimensional topographic map of the probed surface, as well as an optical and/or infrared image of the scene, will be used as the input data for the radar signal processing and image reconstruction.

Real time data processing will enable adaptive interactive data acquisition when the samples are collected mainly in identified areas of interest, while the achieved additional degrees of freedom of one or two antennas (the height above the surface, orientation, the direction of polarization) will make possible a stronger suppression of artifacts caused by the surface relief, the presence of inhomogeneities in the medium, which may correlate with the surface irregularities, or by other foreign shielding objects.

It is worth mentioning that a video positioning system was already used for radar antenna tracking before [1-3]. The main objective of this paper is to point out that using emerging augmented reality devices, such as Microsoft Hololens and Google Glass, may result in a more advanced acquiring, transmitting, storing, and visualizing the data, because they already have all required components in one: a

3D video sensor, a computer, a wireless communication module, and a projector. Merging scanning sensors with an augmented reality device can create a new operator's experience and the way the data are collected, explored, and used.

In this paper a series of preliminary experiments is conducted to explore the adaptive data acquisition with a video positioning system and visualization. The video positioning system used in the experiments is based on monocular vision with a web-camera and the CALTag markers [4]. The RASCAN-5 radar system [5] was used to collect the data.

II. Experimental Setup

The photo of the setup is shown in Fig. 1. It consists of a web-camera and a RASCAN radar system operating at 13.8 GHz. The upper round cover of the original radar system was changed for a flat lid to host a graphical marker. The radar transparent polyurethane deck over which the radar antenna moves is placed above a concealed object as it is seen in Fig. 2. The choice of the polyurethane deck and a pistol as the target was not directly relevant to a specific application case for a radar system. It was intended for simulating a possible scenario of using a radar system in combination with an augmented reality device, which will be applied in similar experiments as soon as such device appears on the market.

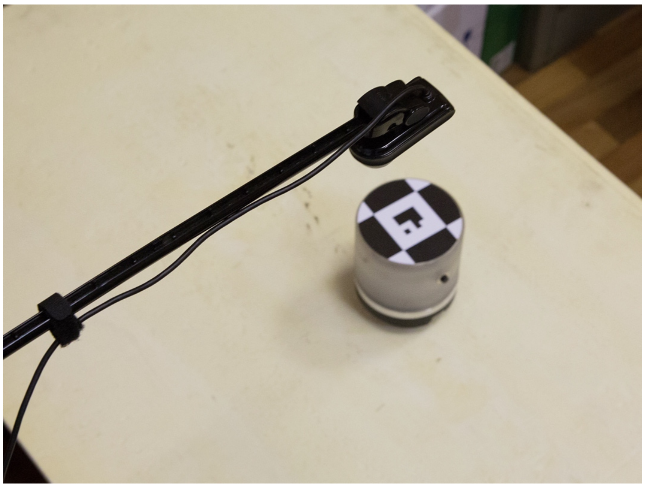

Fig. 1. Photo of the test bed with a web-camera and a radar antenna

The radar images demonstrated here are obtained by processing the recorded video and the radar signal not in real time. In the conducted experiments the recorded video file was processed frame by frame, detecting the CALTag marker on each fourth frame and calculating the position of the antenna center. The radar signal was preliminary obtained for the whole area of interest on a dense grid with a 5-mm sampling interval by the traditional way of scanning along parallel equidistant lines (C-scan) with the RASCAN radar at 13.8 GHz. These data were used as a look-up table to get the signal values in the positions of the antenna, obtained by video processing. Then the sparse signal samples along the trajectory path were interpolated to a dense square grid with the square size of 5-mm. The radar image was obtained by the Fourier-based back propagation algorithm given in [5]. The focusing distance, the parameter of the referenced data processing algorithm, was equal to 17.4 cm.

Fig. 2. Photo of the test bed with the target and the radar antenna

The obtained data were used to imitate the operation technique presented in the following section. The following section is written as if the data were recorded, processed, and displayed in real time.

III. Expected Operation Technique

The operator approaches the area of interest and starts moving the radar sensor to acquire the data over the area of interest. In doing so, the operator does not follow the predefined scanning pattern as it happens in modern radar systems with an accompanying scan mat with labels. The video system starts tracking the device as soon as the radar head appears in the sensor field of view. The Fig. 3 shows the initial moment when the operator approaches the area of interest.

An example trajectory of the radar sensor is given in Fig. 4. The trajectory starts from the upper left corner. The sampling points are marked with crosses along the path. The units along the axes are meters. The trajectory is divided in two fragments: the red path presents a "blind scan" when the operator just covers the area of interest to discover the points of interest, if any.

The result of processing the data acquired along the red path of the trajectory is shown in Fig. 5 as an overlay to the area of interest. The radar head and the arm are segmented against the background and laid over the layer with the radar image. This allows operator to continue acquiring data adaptively. The radar image can be updated periodically with the desired rate or as more data become available.

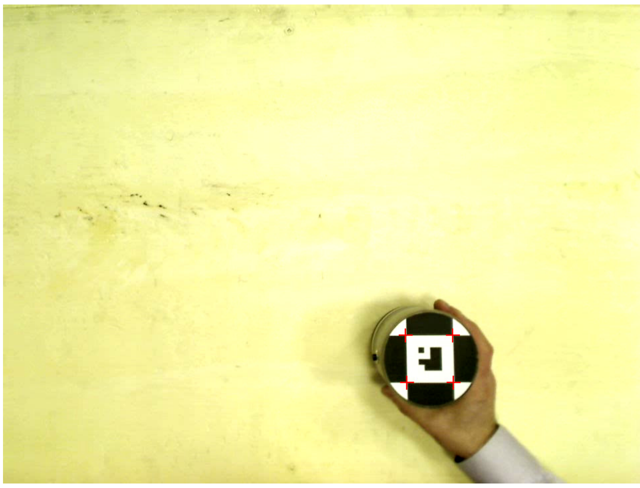

Fig. 3. The operator approaches the area of interest and starts scanning

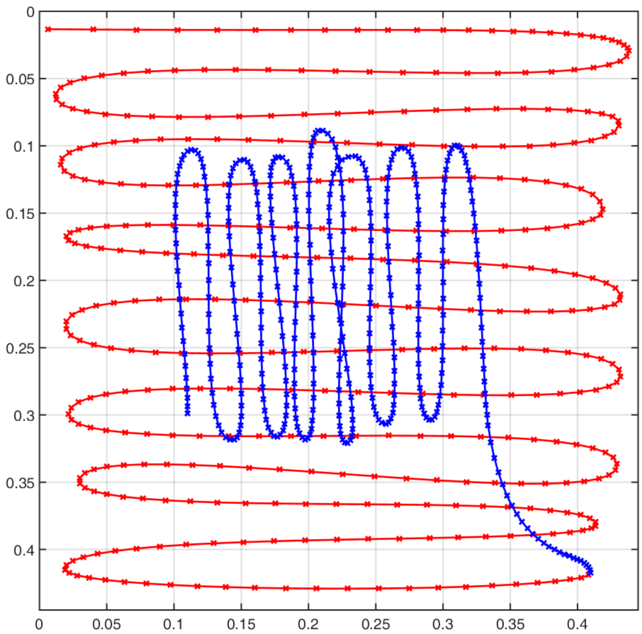

Fig. 4. The trajectory of the radar head captured by video

The bright anomaly seen in Fig. 5 in the middle of the image becomes a point of interest and urges the operator to adapt the rest of the trajectory, marked blue in Fig. 4, to obtain the radar image with a better resolution for a small area in the middle of the scene, which allows eventually identifying the object. The updated radar image that was obtained by processing the data samples along the whole scan path (the red part and the blue part in Fig. 4) is given in Fig. 6. Now, the anomaly becomes a clearly seen pistol.

The data are stored with the image of the surface, whose natural texture can be used to apply augmented reality technique to update the overlaid radar image as the operator moves around the scene. In the case when the surface has no natural features visible in optical images, additional graphical markers (with different identification codes) can be placed on the surface.

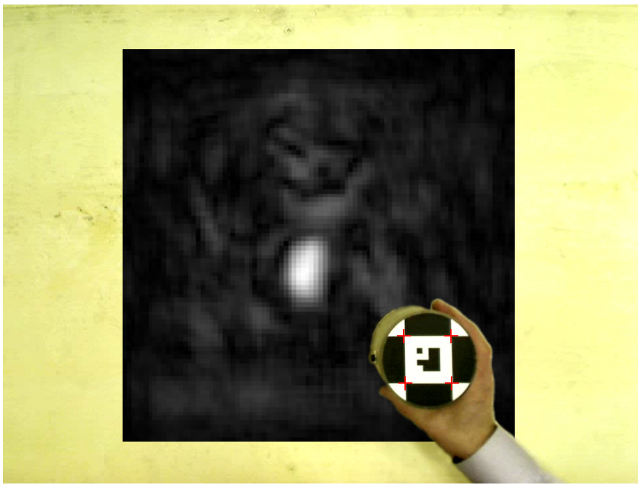

Fig. 5. The radar image obtained after a "blind scan" overlaying the area of interest

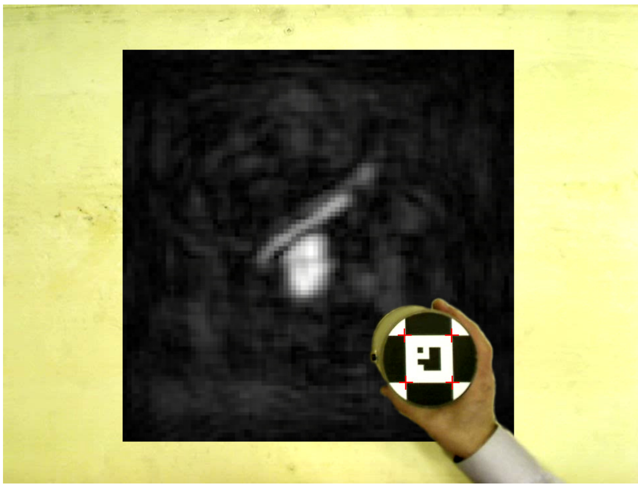

Fig. 6. The radar image obtained after an additional scan around a discovered point of interest

The demonstrated adaptive data acquisition technique with the help of an augmented reality device can substantially decrease the data acquisition time and facilitate data analysis. It is convenient to compare the radar images obtained with the described data acquisition technique and with the classic approach when initial data are acquired by scanning along parallel lines. These radar images are shown in Fig. 7. The upper row of images in this figure was obtained for the red trajectory path in Fig. 4 that had 379 samples. The middle row was obtained using 757 samples that belonged to both red and blue paths. The in-phase components for these cases are obtained by interpolating the sparse data along the paths onto a dense grid of 90×90 nodes with the step of 5 mm along both axes. The hologram in the lower row of images in Fig. 7 represents the classic approach, in which the data were initially obtained on the dense grid with the above parameters, resulting in 8100 samples. The reconstruction of the radar image for the last case was done with no data interpolation.

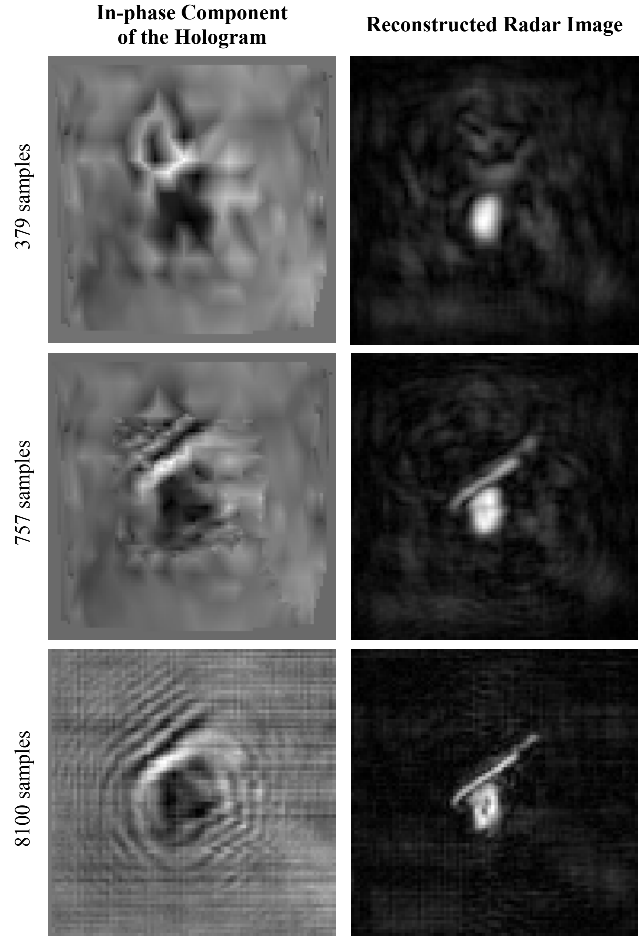

Fig. 7. Dependence of the radar image quality on the number of initial samples

The best resolution in the demonstrated radar images is obtained with the data acquired on the dense grid because only the dense grid conveys the ripples on the hologram that are responsible for the sharp details in the reconstructed radar image. To compensate this effect, it is possible to perform a denser sampling along the scan pass using all available frames. Another option is to apply a proper interpolation function that is more suited to the registered interference patterns and the sounding geometry. The advantage of using a video system for positioning is that it allows acquiring the data approximately ten times faster than with the classic approach.

IV. Conclusion

The described methods of acquiring radar signal samples, data processing and visualization using augmented reality devices can also be used with other contact sensors for solving a wide range of scientific and engineering problems. The data visualization system based on augmented reality methods will be able to display heterogeneous data not limited to radar images only. This will provide opportunity of archiving the collected measurements more completely enabling their further thorough representation and analysis using traditional computer visualization techniques and their subsequent replenishment by the data obtained with the same or other sensors. It is supposed that cultural and historical monuments can benefit from the development of such a technique first of all.

The appearance of augmented reality devices and their ability of capturing the scene and the moving sensor in 3D enables an advanced data processing methods, in which the captured relief of the scene will be used in the data processing algorithms, resulting in the radar images with minimal artifacts.

Another possibility of enhancing the data acquisition is to use two independently moving antennas that form a bistatic configuration. The data processing algorithm should handle newly emerged degrees of freedom, in comparison to a single transmit/receive antenna. The suppression of artifacts can be enhanced by adjusting the strategy of scanning using these degrees of freedom with interactive and adaptive data acquisition: mutual position of antennas, direction of polarization, position of antennas in respect to the interface, etc.

The further development of the outlined technique may result in the appearance of the information systems that permit collecting and visualizing heterogeneous data concerning the object of interest, computer systems enabling the augmented reality to generate synthetic images displaying the information obtained by detectors and field sensors that is not perceived by human senses directly.

Merging 3D computer vision with radar systems may result in the appearance of new devices and technologies, for example, an imaging handheld radar for the detection of prohibited metal and dielectric objects under clothing, a microwave system for screening of freely moving people [6-7], a method for evaluating the permittivity of a sample with an arbitrary surface boundary, advanced bioradars, etc.

Acknowledgment

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References

[1] M. Sato and K. Takahashi, “Deployment of dual-sensor ALIS for humanitarian demining in Cambodia,” Proc. SPIE 8709, Detection and Sensing of Mines, Explosive Objects, and Obscured Targets XVIII, Baltimore, Maryland, USA, 2013.

[2] P. Falorni and L. Capineri, “Optical method for the positioning of measurement points,” in 8th International Workshop on Advanced Ground Penetrating Radar (IWAGPR), Florence, Italy, 2015.

[3] F. J. W. Podd, A. J. Peyton, and D. W. Armitage, “GPR combined with a positioning system to detect anti-personnel landmines,” in 8th International Workshop on Advanced Ground Penetrating Radar (IWAGPR), Florence, Italy, 2015.

[4] B. Atcheson, F. Heide, and W. Heidrich, "CALTag: High Precision Fiducial Markers for Camera Calibration," in 15th International Workshop on Vision, Modeling, and Visualization, Siegen, Germany, November 2010.

[5] A. V. Zhuravlev, S. I. Ivashov, V. V. Razevig, I. A. Vasiliev, and A. S. Bugaev, "Holographic subsurface radar RASCAN-5," in 7th International Workshop on Advanced Ground Penetrating Radar (IWAGPR), Nantes, France, 2013.

[6] A. Zhuravlev, V. Razevig, I. Vasiliev, S. Ivashov, and V. Voronin, "ISAR for concealed objects imaging," in Proc. SPIE 9401, Computational Imaging XIII, San Francisco, California, USA, February 2015.

[7] A. Zhuravlev, V. Razevig, S. Ivashov, A. Bugaev, and M. Chizh, "Microwave imaging of moving subjects by combined use of video-tracker and multi-static radar," in IEEE International Conference on Microwaves, Communications, Antennas and Electronic Systems (COMCAS), Tel Aviv, Israel, November 2015.