On the Use of Augmented Reality Devices for Subsurface Radar Imaging

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Abstract— The idea of using the emerging augmented reality (AR) devices with scanning contact sensors is considered in this paper. This concept is illustrated by the experimental setup which includes a holographic subsurface radar as a contact sensor, web-camera, and personal computer. The data acquisition is accomplished by tracking the radar antenna tagged by an AR-marker. The radar image is updated periodically in real time as more data samples become available, making the data acquisition adaptive. It is shown that the use of a video-based tracking system may increase the data acquisition speed by a factor of ten in comparison with the traditional scanning approach which requires collecting data along consecutive parallel lines over the whole area before calculating the radar image. The data visualization with AR removes the problem of radar data mapping from the computer screen to the probed scene. Further advantages of using AR-devices, which may influence the signal processing, including data from different sensors, are suggested.

1. INTRODUCTION

The current data acquisition technique with the ground penetrating radars working at gygahertz frequencies requires precise positioning of the order of a wavelength which is usually achieved by odometry. Considering a C-scan, it is common practice to use a mat with a line pattern that facilitates the time consuming data acquisition, which is usually repeated at perpendicular polarization. Implementations exist where an optical system reads contrast path marks on the scan mat. This does not decrease the amount of work required to get the data samples either, because the regular sampling grid obtained by scanning along parallel equidistant lines still remains.

In the data processing algorithms it is usually expected that the signal samples are present on a dense regular grid making the data acquisition in most cases redundant: every fragment of the probed surface obtains equal sampling density even when a large area of the probed surface later becomes of no interest. No matter what physical principle the positioning system is based on, the data visualization happens on a stand-off display with the persistent inconvenience of mapping the discovered areas of interest from the screen back to the surface.

Another limitation of traditional data acquisition and processing comes with the requirement that the data samples to be located on a plane or a simple geometric surface. Variations of the surface height are not usually taken into account during signal processing, which could be otherwise improved and applied to surfaces with a changing curvature.

It seems that these limitations can be removed by enabling fast data acquisition without using a fixed-sized scan mat, employing adaptive interactive scanning with variable sampling density (less samples in the areas of no interest), convenient visualization with augmented reality, which should decrease analysis and interpretation time, solving the problem of mapping the discovered objects of interest to the probed surface. It is foreseen that the expected appearance on the market of consumer wearable augmented reality devices can influence the traditional technique of collecting data with scanning sensors and visualization.

In this paper, this concept is illustrated by the use of the holographic subsurface radar only. It can also be generalized to other contact sensors that register physical fields in two or three dimensions. It is expected that the demonstrated technique of combining the augmented reality devices and subsurface radars can be useful in the following areas: surveys with ground penetrating radars, demining, cultural heritage inspection, non-destructive testing, screening people in motion for concealed objects [1, 2], bioradiolocation, etc..

2. AUGMENTED REALITY DEVICES

Among currently developed wearable AR-devices to implement the mentioned approach to the data acquisition and visualization with contact sensors, Microsoft Hololens is notable as it is fully autonomous with a built-in processor and an operating system, which can handle the data processing for the sensor. In the form-factor of glasses with head-mounted display it would enable the operator to move the contact sensor freely enabling adaptive data acquisition: more scanning happens only in discovered places of interest rather than blindly over a sufficiently large initial area. In contrast to smartphones and tablets, which are frequently used as a platform for augmented reality, a head-mounted display overlays the results onto the image of the scene without distracting operator's attention to a stand-off display.

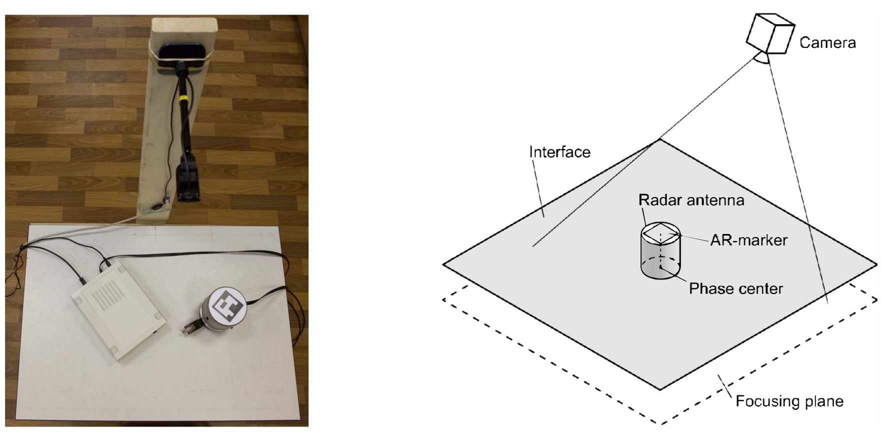
Among the tasks of the AR-device to be used with scanning contact sensors are: binding the incoming data in 2D or 3D depending on the sensor type and its use, probed surface relief capture, sensor data processing. Immediate advantage of employing an AR-device with a contact sensor is the increase in performance by faster deployment, data acquisition, visualization, and analysis.

The availability of 3D surface relief capture as well as an optical image of the surface can be used in the data processing algorithms to mitigate the artifacts if the visible irregularities given in any available channel (RGB, depth, or intensity) correlate with certain patterns in the radar signal. Such a suppression technique can be model-based, i.e., a model relates visible structures in one of the channels and the obtained radar signal, which is filtered in accordance to the found correlations. Additional mitigation of artifacts may come with adaptive data acquisition when probe position and orientation is adjusted appropriately to the environment. For example, if one uses a linearly polarized antenna, it can be oriented immediately to the best advantage.

In this paper, the holographic subsurface radar RASCAN [3] is considered as a sensor with a web-camera-based tracking and visualization system to assess capabilities of a future system on the basis of an AR-device. On the use of a web-camera to track a ground-penetrating radar antenna is reported in the following recent works [4–6].

3. EXPERIMENTAL SETUP

The system consists of a RASCAN system, which includes the control unit and the antenna unit, operating in the frequency band 6.4–6.8 GHz, a web-camera, and a personal computer. The mentioned components apart from the personal computer are shown in Figure 1. The upper cover of the radar antenna has a contrast AR-marker, which is detected and tracked on video. The AR-marker and its detection code was based on the project *python-ar-markers* [7]. The experimental setup was built to simulate operation of the radar system without traditional limitations imposed by the use of a marching wheel. It is expected to implement functionally the same system with a wearable AR-device as it becomes available on the consumer market.



(a) (b)

Figure 1. Experimental setup. (a) Photo. (b) Geometry.

The geometry of the setup is shown in Figure 1, where the antenna with a contrast AR-marker is situated in the field-of-view of the camera. The camera is calibrated following the standard procedure with a chess board from OpenCV, so its internal parameters are known with distortion coefficients. In the experiments here the camera remains stationary in respect to the scene all the time. The position and ID of the AR-marker in 3D is calculated after detecting its vertices on each video frame. The position of the antenna phase center has a constant transition vector in respect to the AR-marker and it is this point that is stored together with the in-phase and quadrature (I/Q) samples of the radar signal.

In the current implementation of the software, the I/Q samples are accumulated in an array with the size equal to the resolution of the camera, which was equal 640 by 480 pixel and did not limit the plane view resolution of the radar system in its operating frequency band with the camera orientation close to nadir. The focusing plane in Figure 1 is the plane at the distance D from the interface. This distance is the parameter of the reconstruction algorithm given in [8], which is used for the processing of microwaves holograms.

The stream of video frames and I/Q samples is interrupted every few seconds to update the reconstructed radar image by processing the accumulator array. During this step the radar data are interpolated to a square grid in the scan plane as it is required by the used data processing method [8]. This reconstruction algorithm is FFT-based and interrupts the data acquisition thread for small unnoticeable time intervals. These interrupts do not prevent comfortable interactive operation with the radar and can be fully eliminated by making the data processing in a parallel execution thread.

The operation with the radar begins with setting up the camera so that the fragment of the surface to be scanned is in its field of view. The sensor is immediately recognized as it appears on the scene. It is suggested that the scan begins without knowing a particular fragment of interest. This fragment is discovered by a blind sparse scan, which reveals the area with a concealed object as shown in the left column of images in Figure 2. Upon discovering the area of interest, the operator continues to scan the area, rotating the antenna and changing the direction of polarization observing the periodically updated radar image. The rotation of polarization reveals horizontal structures in the hidden object as shown in the middle column of images in Figure 2. Additional scanning in the area occupied by a hidden object increases the resulting resolution of the radar image as seen from the right column of images in Figure 2. In this experiment, a foil-cut letter R with the height of 11 cm and the width of 9.5 cm attached beneath the table cover was used. The value of parameter D, the focusing distance in the applied data processing algorithm, is shown in each radar image and was chosen interactively.

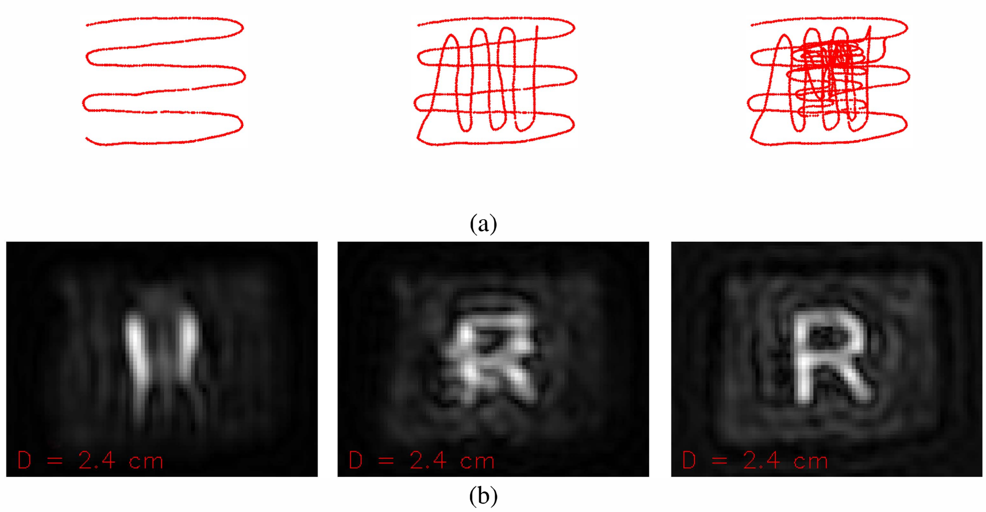
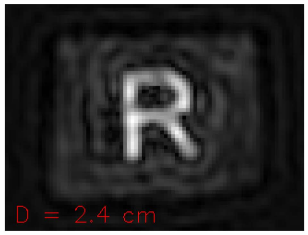
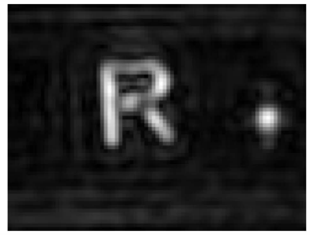


Figure 2. Obtaining a radar image by adaptive scanning: (a) sampling points along the scan path, (b) corresponding radar image.

It is interesting to compare the right radar image in Figure 2 obtained by adaptive scanning with the image of the same target obtained by the traditional way, when the same area is scanned by a series of equidistant parallel lines. This couple of images is shown in Figure 3. The acquisition times for these images are equal to 1 minute and 9 minutes for the adaptive and traditional scan respectively. The horizontal fragments in the letter R in the right image are distorted due to antenna polarization being in one direction during the traditional scan. The bright spot on the right from the letter R corresponds to the hole in the table. It did not fall in the adaptive scan.

The resulting radar image can be blended with the image of the surface revealing the actual position of the hidden object. The Figure 4 shows the radar image overlayed with a transparency level onto the probed surface. The overlayed radar image should be recalculated if the camera





(a) (b)

Figure 3. Comparison of the radar images obtained by adaptive scanning for around 1 minute (a) and by traditional way for around 9 minutes (b).

moves within the scene (the external parameters of the camera changing). The tracking of the scene in the video and projecting the obtained radar image can be accomplished in the current setup using natural landmarks of the scene or additional AR-markers with different ID's to distinct them from the one on the antenna cover. The task of tracking the portion of the scene should be easy with the AR-device API, because this is its basic function.

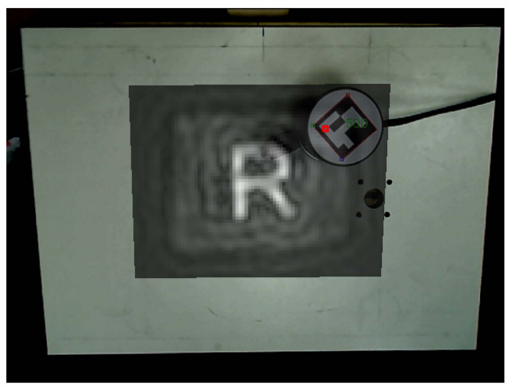


Figure 4. Displaying the results with augmented reality.

The described approach to data acquisition with the holographic radar as an example allows significantly decrease the signal acquisition time compared to the traditional method. The mapping of the obtained radar image to the probed scene comes naturally with the camera and display. It is expected that using an augmented reality platform will make the whole process convenient and may also influence the signal processing itself. For example, the 3D video sensor on board of an AR-device may capture the topography of the probed surface, which can later be used to mitigate artifacts arising in the radar data at reconstruction. The representation of the data obtained with a contact sensor with augmented reality allows natural visual presentation of physical fields in situ, facilitating interpretation and analysis.

4. CONCLUSION

The expected appearance of augmented reality devices, such as Google Glass and Microsoft Hololens, on the consumer electronic market opens new possibilities of using various scanning sensors requiring precise positioning. This paper demonstrates some examples of using the holographic subsurface radar in a test setup which also includes a web-camera and a personal computer. It was experimentally shown that using this hardware platform the data acquisition time can be decreased by a factor of ten. The additional data obtained by a 3D video sensor, which can be a part of an AR-device, can be used in data processing, suppressing artifacts that would otherwise appear if neglecting the relief of the surface. In the same way, heterogeneous data, obtained with other sensor types, can be processed simultaneously. It is expected that monuments and cultural heritage objects can benefit from the development of the described technique due to substantial decrease in data acquisition time for a variety of contact sensors, enabling collecting and storing heterogeneous information about the object for further thorough analysis.

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