High Resolution Imaging with a Holographic Radar Mounted on a Robotic Scanner

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Abstract— Ground penetrating radars operating at high frequency are currently used for subsurface investigation. The data are generally collected by manual scans and this is a time consuming process and it is also affected by errors in spatial positioning of the data. In this work, we present an innovative approach by devising a robotic scanner that is remote controlled. The robot scanner operates with a high resolution 3.6–4.0 GHz multi-frequency holographic radar antenna of RASCAN type. The paper describes the advantages of this new instrument in different applications fields (civil engineering, archaeology, land mine detection) with high resolution images of shallow objects and virtually zero set up time for the experiments.

1. INTRODUCTION

The holographic radar of RASCAN 4/4000 type has been demonstrated as a useful instrument for producing images with high spatial resolution from subsurface dielectric constant discontinuities [1]. The comparison of the incident monocromatic field and the reflected field from a buried shallow object is the basic holographic principle that in this case is implemented at five microwave frequencies between 3.6 and 4.0 GHz. The measured phase variations between the incident and received fields at different locations on the scanning surface create a sinusoidal modulated baseband signal that can be used to produce gray scale images. From an electromagnetic viewpoint these images are not complete holograms because RASCAN-4 provides only the amplitude information of recorded signals while the actual hologram is complex. However the images have a spatial resolution that is about a $\lambda/4$, where λ is the wavelength in the investigated material at the emitted frequency f_i [2]. Generally the holographic radar transmits and receives signals at different discrete frequencies in order to avoid null responses from targets at depths and frequencies that produce phase values that cancel the two sinusoidal functions [1]. The standard method for scanning a surface is the manual scan similar to that used for high frequency impulse GPR: This is a rather time consuming task as the experiments need a spatially-referenced grid along which the antenna head is moved manually. The line grid can be inscribed on a thin dielectric mat (Plexiglas, rubber, or paper). This accessory is certainly useful but use is limited to rather small areas of investigation (typically less than 1 square meter) and require a skilled and concentrated operator to avoid deviations in the manual movement of the antenna head. Larger surfaces of several square meters are difficult to scan manually with accuracy and require a long time to set-up the reference system. A different approach to overcome this limitation is the development of a robotic scanner where the holographic radar head is moved automatically with high spatial accuracy (better than 1 mm) guaranteed by the optical encoders connected to the mechanical movements. An area is covered by the composition of a lateral fast (50 cm/s) movement and the advancement slow (programmable speed from 2 to 5 mm/s) motion by two wheels connected to DC motors. This approach is particularly suitable for the compact and light weigh (400 grams) holographic radar head that must be moved fast.

In this way the robot scanner can spatially oversample the reflected field and produce averaged low noise images of subsurface objects, while the operator remotely designates the area to be investigated. A research field where robot scanners have been developed is humanitarian demining [3–7]. Development of this new microwave subsurface scanner mounted on a robotic platform will also aid in the rapid diffusion of robotic products into daily life, which will also decrease the price of these technologies. The complete system is depicted in Figure 1.

2. APPLICATION TO RAPID SURVEYING OF A CONCRETE PAVEMENT

A common application of subsurface radar is scanning of concrete pavements for detection of reinforcing bars or mesh, and other buried structures. An investigation was required on an old concrete

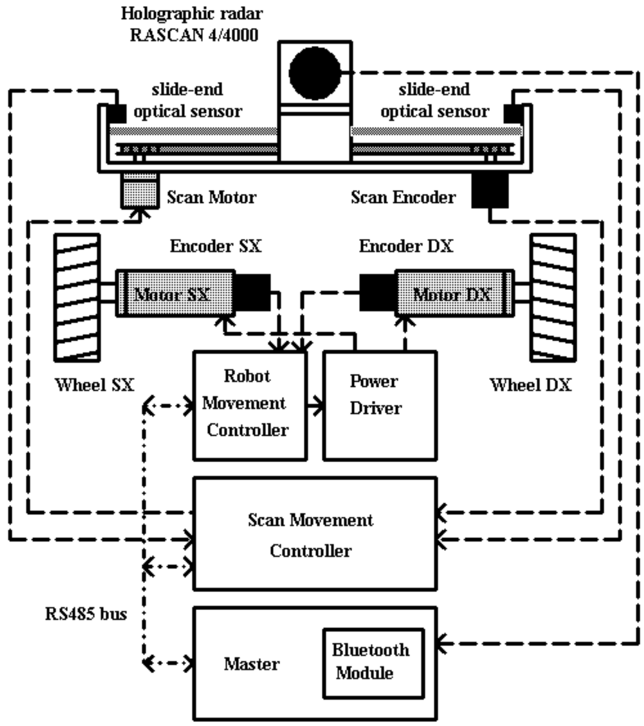

Figure 1: Block schematic of the robotic scanner with holographic radar. The three electronic units communicate in real-time by a standard RS-485 bus (dot-dashed line). Power DC lines and encoder connections are shown by the dashed line.

pavement where the metal reinforcing grid was at about 60 mm depth. Because some cracks are visible on the surface, the survey intended to check for structures underneath the mesh. The construction details of the pavement were lost, and detection of reinforcing bars with a commercial pacometer instrument was unsuccessful in the presence of the continuous magnetic field from the shallow mesh. The robot scanner was used to acquire an image of 1 m length by 33 cm width with 5 frequencies (3.6; 3.7; 3.8; 3.9; 4.0 GHz), with spatial sampling 2 mm and advancement motion speed of 2 mm/s. Hence the length of 1 m is covered in 500 s. This is the total time for doing the survey because no extra time was needed to set-up the experiment.

Figure 2: Robotic scanner operating on a concrete pavement. Note the separation line between two concrete pours.

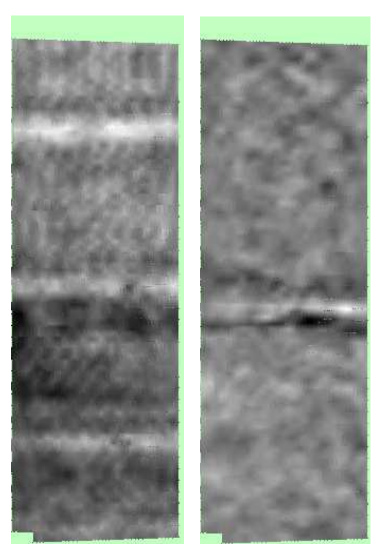

Figure 3: Parallel (a) and cross polar (b) holographic radar images at 3.7 GHz. Pixel size 2 mm, image dimension 1 m $\times$ 0.33 m.

The images were acquired from both the parallel- and cross-polarized transmitter-receiver antenna pairs. The two images corresponding to 3.7 GHz were selected because they show with better contrast the presence of buried structures. In Figure 2 the robotic scanner is in operation on the concrete pavement.

From the parallel image in Figure 3, we can detect three horizontal features about 30 cm apart. The central one was the only horizontal feature detected by the cross-polar channel at the same position; this central feature can be easily interpreted by visual inspection of Figure 2 as the separation line between two concrete pours. The upper and lower horizontal features in the parallel output channel are certainly buried structures underneath the metal mesh, that at this frequency, given the depth of the mesh, is invisible, and thus does not interfere with the holographic response of the two deeper structures. Planned repetition of this survey on other nearby areas will finalize the interpretation about the nature of these two features that are likely to be reinforcing bars.

3. CONCLUSIONS

In this paper we present a robotic scanner for high resolution imaging with holographic radar. The high-spatial resolution allows use of the robotic scanner at high frequencies (> 2 GHz) that require a sampling tighter than at most a quarter of the wavelength in the soil or material under investigation.

The robotic scanner is currently used in different applications: Detection of low dielectric contrast objects like plastic landmines, for rapid scan of floors after an earthquake or other natural disaster, investigation of historical structures, or for searching for hidden dinosaur tracks in the rocks of paleontological sites. Moreover, for these applications a light-weight robotic scanner (less than 6 kg) is suitable to avoid loading of sensitive surfaces with the weight of a human operator.

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