A Single Display for RASCAN 5-frequency 2-polarisation Holographic Radar Scans

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Abstract— The RASCAN holographic radar system has been developed by the Remote Sensing Laboratory of Bauman Moscow Technical University. The present design uses five frequencies and two polarisations to give 10 distinct images of scan from buried objects. Because of the sinusoidal phase variation of the interference signals, all displays show a complex picture of dark and light phases which vary in a complicated way between different frequencies and polarizations. This is a preliminary investigation into the optimal presentation of the 10 images as a single composite image. The objective is to display as much as possible of the information present in the original image. The solution presented here is to sum the absolute values of the background-corrected amplitude over both the five frequencies and the two polarizations. The method is justified using an experiment in which nine US pennies, and 9 metal washers, were buried in sand at increasing depths in the range 0 to 56 mm. The method is illustrated by example images from the fields of civil engineering and mine detection.

1. INTRODUCTION

Conventional Ground Penetrating Radar uses echo sounding from a pulsed source to determine the range of buried objects [1]. A quite different radar system was developed by the Remote Sensing Laboratory of Bauman Moscow Technical University [2]. Their RASCAN system uses continuous wave unmodulated signals at several different frequencies. The signal reflected from the subsurface structure is multiplied by the original signal from the antenna to form a hologram. The amplitude and phase of the hologram is sensitive to the depth of any buried object, to its reflectivity and to the properties of the medium. The indication of depth is indicated by the phase change of the radar wave in passing through the material to the buried object. The indication of reflectivity is given by the amplitude of the reflected signal. Generally the antenna and receiver are the same, and placed close to the ground surface. The holographic amplitude and phase may be presented as a function of position (x, y) across the ground surface and scanned manually or automatically to give a holographic image $H(x, y)$ whose amplitude may be plotted as a grey scale image. In the RASCAN system five frequencies are operated simultaneously to give five different holographic images whose amplitude and phase response differs as the phase change caused by the phase difference along the path length alters. The RASCAN system also has two perpendicular polarizations so that the response may be measured both along and perpendicular to the scanning direction. The RASCAN system thus results in 10 different holographic response images. The RASCAN display software allows all 10 images to be displayed either simultaneously, or as a time-sequence set of images. Neither is completely satisfactory for use by unskilled operators and the present paper considers ways in which the 10 individual holograms may be combined into a single composite image.

2. THE CONVENTIONAL DISPLAY FROM A TYPICAL RASCAN IMAGE

As an example image, a floor scan of a concrete floor containing conduits, metal meshes and metal pan decking has been chosen. The scan was made at the Fackenthal Hall at Franklin and Marshall College, Lancaster, USA. Figure 1 shows the floor in question, with the RASCAN being manually pushed along the scan direction (x). The scan length was 500 mm with measurements every 5 mm. The scans were repeated at 20 mm intervals along the direction perpendicular to the scan (y), over 2 m. This gave 100×100 points in total although the images displayed here will only extend over

Figure 1: The floor scan at the Fackenthal Hall in progress. The RASCAN head is being swept along the scan direction. The progress of the scan could be watched on the monitor behind.

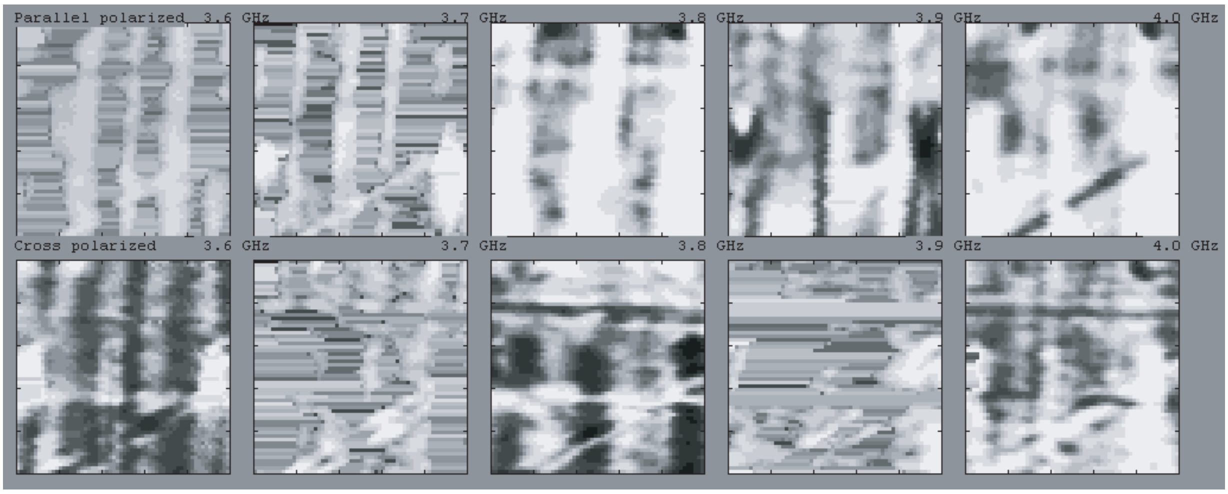

Figure 2: The display from the RASCAN software. The five frequencies from 3.6 to 4.0 GHz are displayed from left to right and the two polarisations are parallel above and cross polarised below.

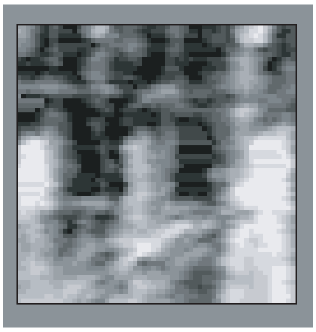

Figure 3: A single image display generated from the RASCAN scan above. The image is sum of the differences from the background level summed over all the ten images shown above. All the featues mentioned above may be seen.

only 60 × 60 points as much of the scan is a repetitive background. Figure 2 shows the display given by the RASCAN software.

Several sets of features are visible in these images. The thin vertical bands sometimes light, sometimes dark, are likely to be the vertical rebars. The broader bands seen at other frequencies are likely to be the corrugations of the pan decking. The thin horizontal bands, more clearly seen on the cross polarization are likely to be the horizontal rebars. At the lower right is clearly seen a diagonal electrical conduit that appears either light or dark in many of the images. This series of images is clearly not straightforward to understand without careful study of all the images. Can this process be simplified without loss of detail?

The RASCAN software package has one such process. An option is to display the images within each polarisation direction in sequence. It helps greatly in the process of assimilating the data together.

An example of our approach is shown in Figure 3. The method has many options and this is just one result. The method will be explored in more detail using images from a much simpler example: a series of buried pennies of different depths.

3. THE METHOD EXPLORED FOR A SIMPLE RASCAN IMAGE

Figure 4 above, shows raw RASCAN data from a scan over 9 US pennies buried in sand at increasing depths from about zero on the left to about 65 mm on the right. Only the parallel polarisation is shown. The scan length and separation were both 1 cm. These experiments are presented in more detail in reference [4] from this meeting. The lower set of circles were some other foreign coins, and are not analysed here. The scans were made along the direction of increasing depth by manually moving the RASCAN head on a glass plate over the sand surface.

An interesting feature is that the background level at each frequency is quite different. In holographic radar there is no specific "main bang" ground reflection from the surface. In this case it is an air-sand interface covered by a thin plastic sheet. Rather the amplitude and phase

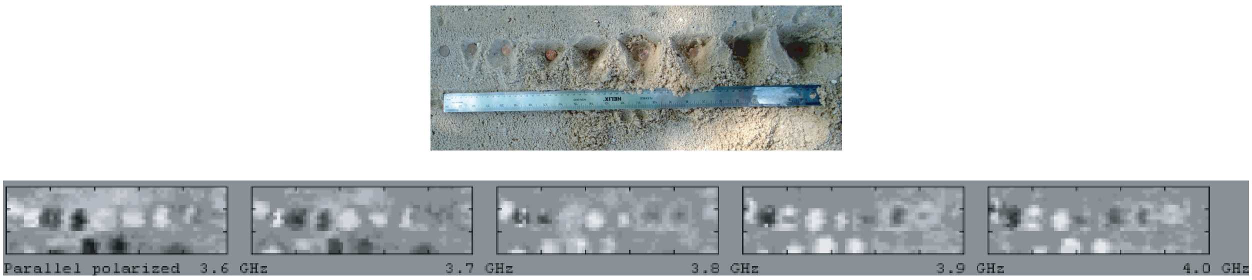

Figure 4: A set of nine US pennies buried in sand at different depths and is set of RASCAN images in the parallel polarisation.

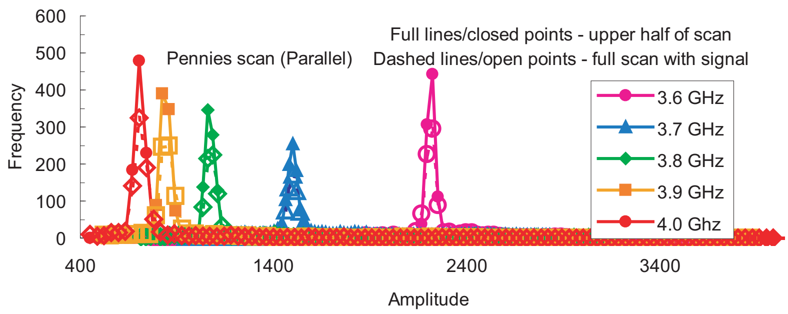

Figure 5: The histogram of signal amplitudes over the raw data from a scan over 9 US pennies buried in sand. The scan showed a larger region of background than is shown in Figure 3. Note the change in amplitude with frequency.

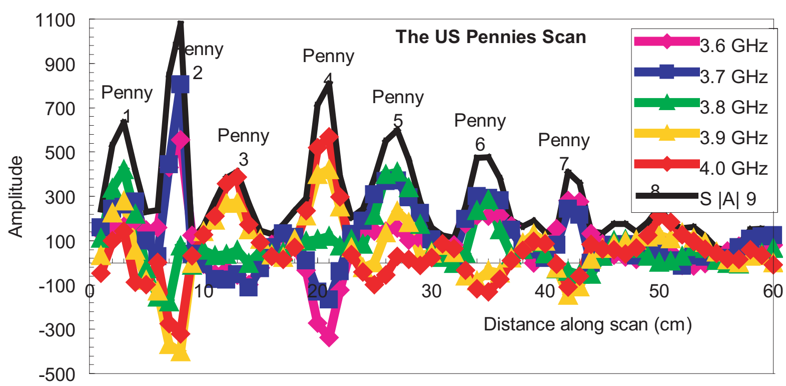

Figure 6: The amplitude along the scan of pennies for the five frequencies (coloured) and for the summed absolute amplitude (black).

of the reflected wave from the surface interferes with the incident wave to give a characteristic background signal level. In this example, there was a wide region of sand without pennies that could be analysed to give the background level. Figure 5 shows the histogram of the amplitudes for each of the frequencies. There is width to the peak in amplitude at each frequency and a small almost invisible "tail" to the distribution from the much larger amplitude variations present in the portion of the scan representing the pennies. This background level is important in since it enables "contrast", or deviation from background, to be identified. Positive and negative phases have at last a clear meaning. In the pennies scan that particular scan giving the largest amplitude across each penny was identified, (almost always one particular scan) and the coloured lines in Figure 6 shows this scan for each of the five frequencies. It is seen that for penny 1 all the frequencies show a positive peak. For penny 2 the 3.7 GHz peak has the largest positive amplitude and the 3.9 GHz the largest negative peak. For penny 4 the 4.0 GHz peak has the largest positive amplitude and the 3.6 GHz the largest negative amplitude. By penny 6 this situation is almost reversed. The full line in Figure 6 shows the sum of the five frequencies of the modulus of the amplitude

$$\boldsymbol{F} = \boldsymbol{\Sigma}_f |A_f(x) - B_f|$$

where the summation is over frequencies f, $A_f(x)$ is a the amplitude at frequency f and position$x$, and B_f is the background.

Figure 7 shows this representation for the pennies scan. The first seven pennies are clearly delineated with positive signals and there are suggestions of the remaining two deeper pennies.

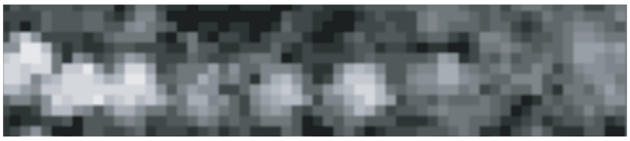

Figure 7: The mean modulus of the amplitude for the pennies scan.

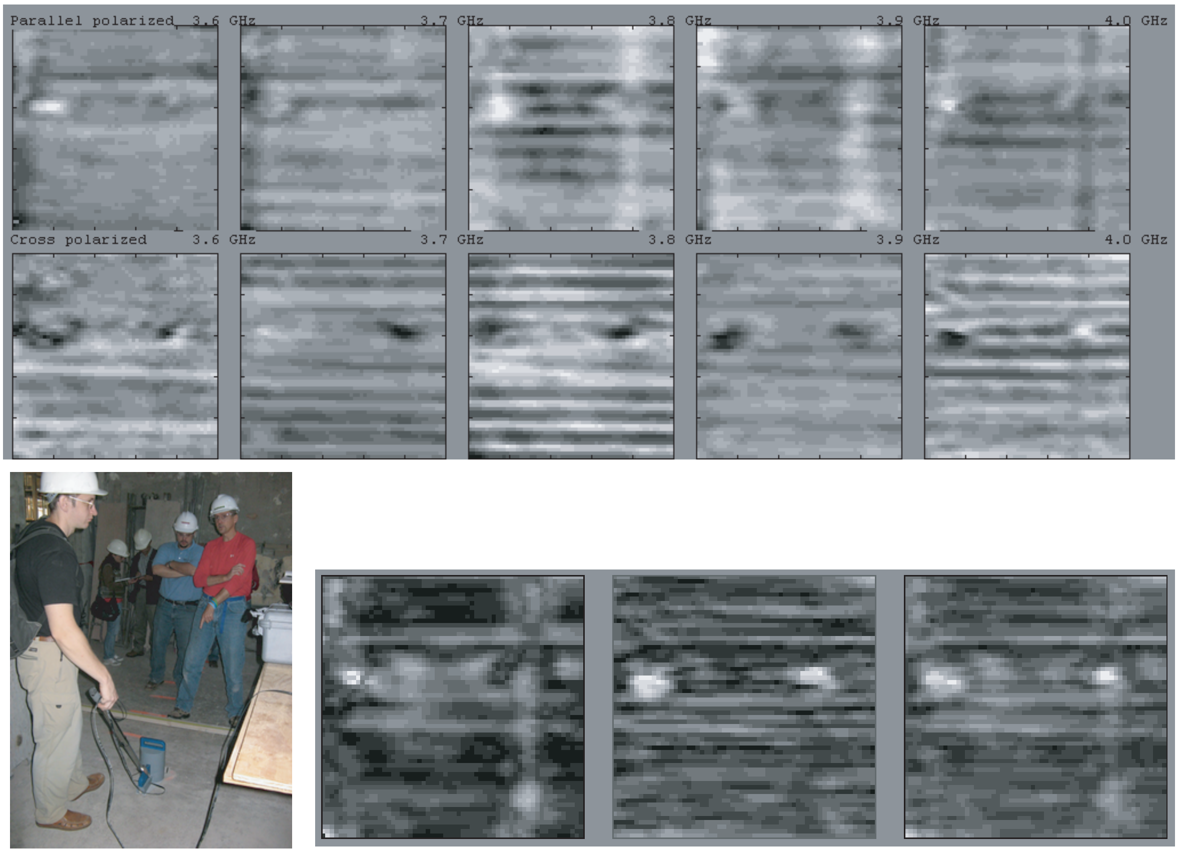

Figure 8: Above, a second RASCAN at the Fackenthal Hall over an area containing two holes and several unknown signals. On the left is shown the scene and below is shown the composite image from parallel perpendicular and combined polarisations.

4. SOME EXAMPLES OF THE COMBINED IMAGE FOR OTHER RASCAN IMAGES

Returning to the Fackenthal Hall location a second image was taken of an interesting location which showed two holes 16 cm diameter separated by 36 cm. The scans are again parallel to the corrugations. A portion of the RASCAN data collected are shown in Figure 8 with the same presentation as with the scan of Figure 2. Much is seen in this image: in particular the two holes appear with varying phases. Some scans show clear vertical lines which are probably from electrical conduit which approach the holes in both directions.

In the lower part of Figure 8 the two polarisations, parallel and perpendicular to the scan direction (left to right) are shown separately. In this case they are appreciably different with the corrugations being much clearer in the parallel direction.

A third example is RASCAN image of simulated mines and is from the published literature [3]. In Figure 9 above is shown on the left the four simulated mines. Two of the simulants were made of metal and they are easily picked up by the metal detector scan shown in the centre of the figure. On the right is shown the amplitude composite image. This is presented on a logarithmic scale and shows some noise background. However the two metal mines are also seen very clearly, as is a length of metal wire which was placed beneath the sand surface. The two plastic simulants are seen on the lower left and right. The rather conspicuous object in the lower centre of the figure is a "knee print" from one of the operators.

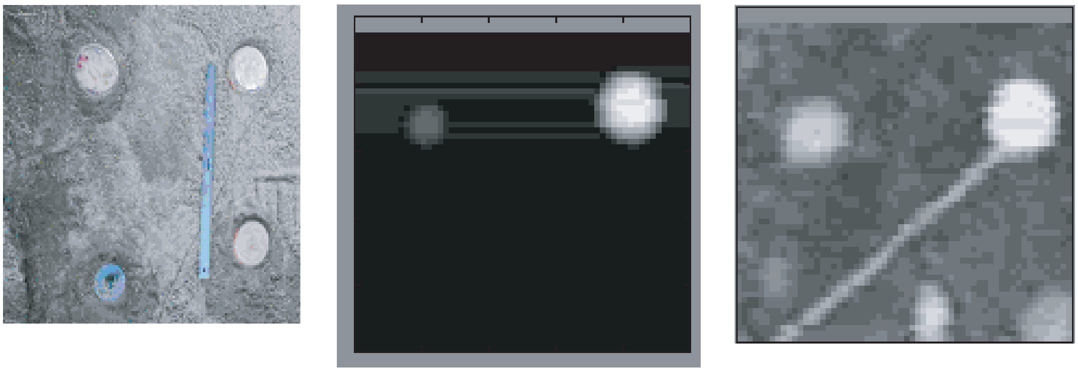

Figure 9: A scan from the garden in the University of Florence previously reported [1]. The mine simulant objects are shown on the left, the metal detector image in the centre and the composity single image on the right.

5. CONCLUSIONS

A method for combining the ten images given by the RASCAN system is proposed based on a sum of the modulus of the background-corrected amplitudes, without affecting the spatial resolution.

In the pennies experiment the summed images showed all pennies distinctly. In the Fackenthal Hall experiment the summed images showed all the expected features, including the conduit, the metal mesh and the deeper metal pan decking.

In the test bed of the University of Florence experiment with simulated mines, all four mines, two metal and two plastic were all seen satisfactorily.

The precise form of the average over background corrected amplitudes does not seem critical.

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