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AN EXAMPLE OF HOLOGRAPHIC RADAR USING AT RESTORATION WORKS OF HISTORICAL BUILDING

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Abstract—The former Senate building, Saint-Petersburg, Russia is being refitted for using it by the Constitutional court of Russian Federation. The team of Remote Sensing Laboratory was invited to participate in this work. The case is that the underfloor water heating system had been installed in the Senate building. The arrangement of pipes hasn't been precisely documented. Besides, there are power and communications cables as well as metal mesh under the concrete floor of the building. Workers were afraid of damaging pipes and cables during laying the parquet floor. Main purpose was to investigate the building floor and to define exact position of pipes and cables with the help of subsurface holographic radars developed by Remote Sensing Laboratory.

1. INTRODUCTION

The paper covers a possible use of holographic subsurface radars different from traditional impulse radars [1]. They are distinguished by the type of frequency spectrum. The impulse radar has continuous frequency spectrum while the holographic radar has discrete one. Impulse radars have larger penetration depths because they have variable amplification in the stroboscopic receiver. The signal reflected from deeper objects is amplified more than the signal from shallow objects. This is the main advantage of impulse radars. The holographic radar has the same amplification for all objects. In this case, the penetration depth depends on medium attenuation and its homogeneity at shallow depths. Shallow heterogeneities would shade deeper objects in recorded images.

At shallow depths, the holographic radar has a distinct advantage in resolution over the impulse radar because the radar frequency range can be easily adapted to the demands of a particular task. Another extremely important advantage of this holographic radar technology is the possibility to image, without reverberation, dielectric materials that lie above a metal surface [2]. Such materials cannot be effectively inspected with traditional time-domain impulse radar technology. Reverberation of pulses between the radar antenna and shallow metal objects obscures the actual location and shape of these objects which are seen as multiple reflections (often called ghosts or phantoms) of the transmitted impulse signal on a relatively uniform background [3].

Holographic radars could be easily adapted to the US Federal Communications Commission regulations and demands as the radar can use free frequency bands that don't interfere with other devices. Also, they are cheaper than impulse radars.

2. EXPERIMENTS

The former Senate building, Saint-Petersburg, Russia is being refitted for using it by the Constitutional court of Russian Federation. The building was built by the outstanding architect Rossi in 1829–1834 and has great value for Russian culture.

The team of Remote Sensing Laboratory was invited to participate in this work. The case is that the underfloor water heating system had been installed in the Senate building. In this system, warm water is circulated through pipes that are laid into the floor. The arrangement of pipes hasn't been precisely documented. Besides, there are electricity and communications cables as well as metal mesh under the concrete floor of the building. Workers were afraid of damaging pipes and cables during laying parquet. The main purpose was to investigate the building floor and to define the exact position of pipes and cables with the help of subsurface holographic radars developed by Remote Sensing Laboratory.

The following technology of installation of underfloor heating system is usually used. At first the metal mesh is laid on the subfloor. The spacing of mesh bars is 150 mm. Then the pipes are fastened to the mesh by the plastic clips. Various types of pipes are used including cross-linked polyethylene (PEX), multi-layer (a composite of PEX, aluminum and PEX) and polybutylene (PB): copper pipes aren't used now. The spacing of pipes is 300 mm. The pipes are being covered by the cement screed. The depth of the screed above the pipes is about 3 cm.

There was apprehension that the plastic pipes could be invisible on the background of metal mesh because of plastic has lower reflectivity towards environment (cement screed) then metal. It is worth noticing that an object contrast on holographic radar image depends of its reflectivity and phase shift that is a function of the distance to the object. For extended objects radiation polarization has also great influence on resulting contrast.

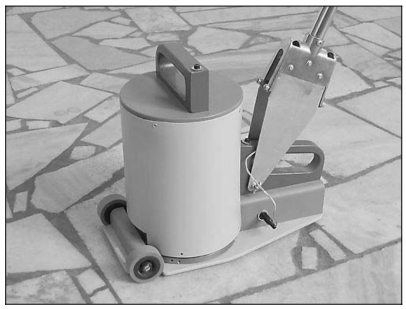

Figure 1. RASCAN-4/2000 radar head.

The work of floor inspection was carried out with the aid of the RASCAN-4/2000 holographic subsurface radar. The total area of the scanned surface was 16.7 sq. m. Overall time of work (disregarding the time for equipment installation) was about 5 hours. More than half of that time was consumed by scanning while the rest was spent in plotting the layout of pipes and cables on the floor.

While inspecting the floor a tangle of power and communications cables was found. This badly complicated the interpretation of the radar images.

The surveyed area was divided into fragments with the size of $1.7\,\mathrm{m} \times 2.0\,\mathrm{m}$. After recording a radar image of each fragment, the operator analyzed the image and drew the results by chalk on the floor. The position of heater tubes was presented by blue chalk, and red chalk was used for cables (Figure 2).

As it was assumed before investigation, there was no possibility to distinguish plastic pipes and metal mesh in the parallel polarization radar images. At this polarization background reflections from metal bars suppress signals from plastic pipes that were tied to the bars and parallel to them. In the cross polarization radar images the plastic pipes were clearly visible. An interesting part of the radar image is shown on Figure 3. One can see how heater pipes bent over the cable. Figure 4 presents: a) cross polarization radar image at frequency 2.0 GHz; b) image “a” after numerical filtration (described

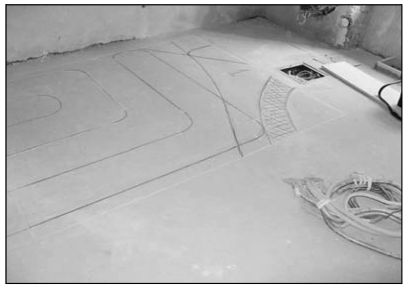

Figure 2. Position of heater tubes was marked by blue chalk, and red chalk was used for cables.

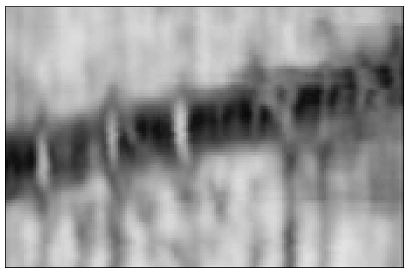

Figure 3. Part of radar image (the image dimensions are $1.70\,\text{m} \times 0.97\,\text{m}$).

below); c) plan of tubes (black lines) and communications (section lines). The observable horizontal lines in image "a" are the mesh grid (cross polarization channel). Vertical elements of the grid can be clearly seen in the parallel polarization channel (not shown). The overall dimensions of the radar image are $1.70\,\text{m} \times 8.04\,\text{m}$ (170×804 pixels).

3. NUMERICAL FILTRATION

To improve quality of radar images by suppressing of background reflections a numerical algorithm was suggested. The horizontal bars visible in Figure 4(a) could be suppressed by filtering in the frequency domain.

Let $f(x, y)$ be an input image, where $x = 0, 1, 2, \ldots, M-1$ and $y = 0, 1, 2, \ldots, N-1$ (in our case $M = 170$, $N = 804$). The 2-D discrete Fourier transform (DFT) $F(u, v)$ of this image is presented

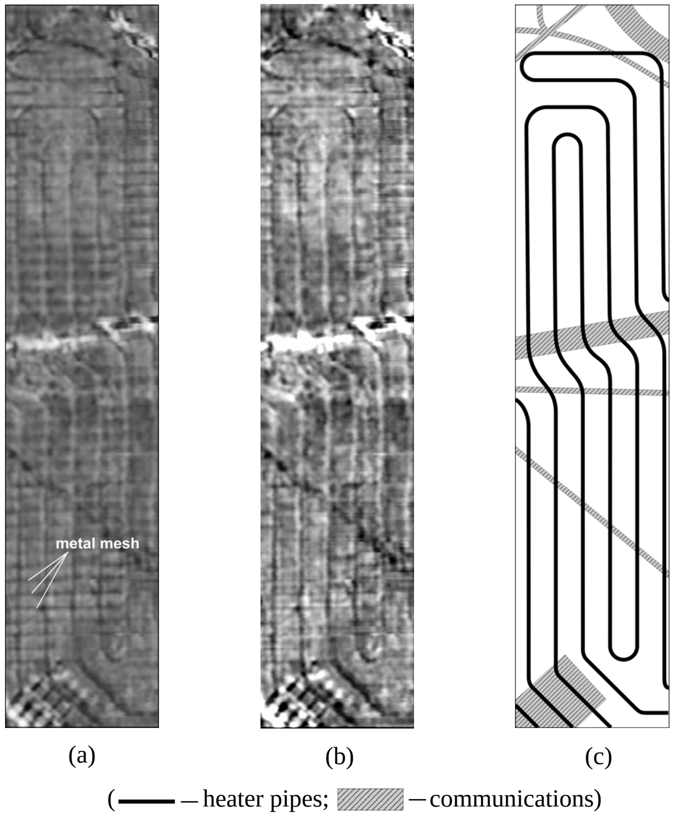

Figure 4. Interpretation of the radar image. (a) Raw radar image at frequency of 2.0 GHz (cross polarization); (b) Image "a" after numerical filtration; (c) Layout of pipes and communications. The overall dimensions of the radar image are 1.70 m × 8.04 m.

by the expression

$$F(u, v) = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x, y) e^{-j2\pi(ux/M+vy/N)} \tag{1}$$

where $u = 0, 1, 2, \ldots, M-1$ and $v = 0, 1, 2, \ldots, N-1$.

The basic idea of filtering:

1) Apply the Fourier transform to the initial image.
2) Manipulate the spectrum by suppressing periodical mesh of 15 cm.
3) Take the inverse Fourier transform to obtain a "better" image with decreased reflections from metal mesh.

More in details [4]:

1) Multiply the image by $(-1)^{x+y}$ to prepare for a centered FT.
2) Compute $F(u, v)$, the DFT of (step 1).
3) Multiply $F(u, v)$ by a filter function $H(u, v)$.
4) Compute the inverse DFT of (step 3).
5) Obtain the real part of (step 4).
6) Multiply (step 5) by $(-1)^{x+y}$.

The bar spacing in the metal mesh is 15 cm. The radar image resulting from horizontal bars reflections can be approximated as

$$r(x, y) = \sin^4(\pi x/15 + \triangle s) \tag{2}$$

where $\triangle s$ is vertical distance from first bar to image border; $x = 0, 1, 2, \ldots, 170 - 1$; $y = 0, 1, 2, \ldots, 804 - 1$.

The absolute value of centered DFT of $r(x, y)$ gets the largest extremum in the points with coordinates $(86, 349)$ and $(86, 457)$. So, a filter function should suppress the spectrum of input image at these points. Considering approximation of $r(x, y)$, a filter function has to go to zero not only at these points, but also in some intervals d stretched along axis v. A filter function can be expressed by

$$H(u,v) = \begin{cases} 0-\text{at} \quad u=86 \quad \text{and} \quad (v \in (349-d,\ 349+d) \quad \text{or} \quad v \in (457-d,\ 457+d)) \\ 1-\text{at} \quad u \neq 86 \quad \text{or} \quad v \notin (349-d,\ 349+d) \quad \text{or} \quad v \notin (457-d,\ 457+d) \end{cases} \tag{3}$$

where $d = 10$ (found by fitting).

The result of filtering was obtained as follows: the inverse discrete Fourier transform of $F(u, v) \cdot H(u, v)$ was calculated, the obtained result was contrast enhanced and is shown in Figure 4(b).

4. CONCLUSIONS

The experiments have shown that the choice of correct polarization of antenna allows increasing contrast of objects under investigation in relation to background reflections that are in current case plastic pipes and metal mesh accordingly.

Comparison of the RASCAN-4/2000 radar with RASCAN-4/4000 that has approximately twofold operational frequency indicates that former radar has better efficiency and records higher quality microwave images at concrete floor investigation. The choice of radar operational frequency range has to take into account the property of surveying medium and frequency-dependent attenuation.

Among possible applications of holographic subsurface radars is the inspection of shallow buried objects in flat construction details. In this field, holographic radars have advantage over impulse radars in terms of resolution and quality of recorded images.

ACKNOWLEDGMENT

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