Millimeter Wave Detection of Landmines

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ABSTRACT

Millimeter wave absorption relative to background soil can be used for detection landmines with little or no metal content. At these frequencies, soil and landmine absorb electromagnetic energy differently. Stepped frequency measurements from 20 GHz to 60 GHz were used to detect buried surrogate landmines in the soil. The targets were 3 cm and 5 cm beneath the soil surface and coherent transmission and reflection was used in the experimental setup. The measurement set-up was mounted on a handheld portable device, and this device was on a rail for accurate displacement such that the rail could move freely along the scan axis. Measurements were performed with network analyzer and scattering data in frequency domain were recorded for processing, namely for inverse Fourier Transform and background subtraction. Background subtraction was performed through a numerical filter to achieve higher contrast ratio. Although the numerical filter used was a simple routine with minimal computational burden, a specific detection method was applied to the background subtracted GPR data, which was based on correlation summation of consecutive A-scan signals in a predefined window length.

Keywords: GPR, landmine detection, millimeter wave imaging

1. INTRODUCTION

Detection of subsurface landmines is an important research area due to their apparent threat to civilian lives, economic and social recovery long after their deployment [1-3]. Especially anti-personnel (AP) plastic mines buried just beneath the surface present a challenging task for their detection and identification. Anti-tank mines, on the other hand, are usually buried much deeper as much as 40 cm beneath the surface. Landmines can take up various shapes and can be composed of many different materials ranging from metals, plastics to rubber. Present detection technologies rely on prodding, electromagnetic metal induction (EMI) sensor [4-7], ground penetrating radar (GPR) [8], ultra-wideband radar, millimeter wave [9-13], acoustic, seismic, and infrared (IR) imaging systems [14-16]. Detection systems based on the contamination of chemical compounds of the explosive materials to air and surroundings include laser induced breakdown spectroscopy, passive electro-optical systems, neutron activation analysis, charged particle detection, nuclear quadrupole resonance, chemical sensors, and terahertz detection sensors [17-20]. The content of the chemical compound is too low, in the order of $10^{-8}$ to $10^{-12}$ M, that handheld spectrophotometer equipment can hardly detect the suspected explosives. EMI is by far the most commonly used technology for detection. However, EMI rely on metal presence and terahertz detection of chemical sensors has not matured to handheld-portable systems yet. With little or no metallic content, landmines can be very difficult to detect. Especially, plastic AP mines buried just underneath 3 to 5 cm of soil surface can be very challenging to detect in the presence of surface clutter such as leaves, rocks, and debris.

Millimeter range of electromagnetic spectrum can offer an alternative in the detection technologies of landmines. Indeed, passive and active millimeter wave detection systems have been shown to hold promise for plastic mine detection. However, calibration of the system, present effective sky temperature, surface roughness, and soil characterization remain major hurdles for practical application of these systems. Moreover, 90-140 GHz band of the electromagnetic spectrum are used in the demonstrations. At these frequencies, the wavelength is so small that the transmitted waveform gets easily affected from surface clutter, and water content in the soil, hence, extreme calibration for soil properties and environment must be carried out.
One of the difficulties in pulsed GPR is that strong surface reflection masks the signature of AP landmine and makes it very difficult to identify unless powerful signal processing algorithms are utilized. For a typical handheld system, power-hungry signal processing algorithms are not practical and rather straightforward processing schemes such as background subtraction with or without moving average are used. Stepped frequency GPR offers an alternative approach because the signal dynamic range and receiver sensitivity are much better than those of pulsed systems. However, the speed and finite number of frequency sample size are major drawbacks of stepped frequency GPR. These drawbacks coupled with low contrast ratio at lower frequencies (1-3 GHz) make the system performance not better than pulsed systems. To increase the contrast ratio, one can use higher frequencies where soil interaction of electromagnetic wave behaves more like a dielectric due to decreased loss tangent. However, dept of penetration is limited using higher frequencies. Millimeter wave frequency range offers such a trade-off for detection of AP mines within 3-6 cm of soil surface.

2. MEASUREMENT SETUP

The measurement setup is illustrated in Fig. 1. Measurements were performed from 20 to 60 GHz with a network analyzer (IFBW= 1 KHz, $P_{in}= +3$ dBm, number of calibration points= $10^5$). Wideband conical and standard gain horn antennas were used for transmission and reception. The antennas were rated from 23 to 40 GHz and 40 to 60 GHz. The landmine under study was buried in soil pool with 3 cm and 5 cm depths from the surface. The antennas were kept at 5 cm away from the soil surface. The measurement set-up was mounted on a handheld portable device, and this device was mounted on a rail for accurate displacement as shown in Fig. 2. The rail could move freely along the scan axis and measurement data were taken with 1 cm intervals. $S_{21}$ data were recorded for inverse Fourier Transform and background subtraction.

Fig. 1 Measurement setup a) 40-60 GHz, b) 20-40 GHz.
3. SIGNAL PROCESSING

Raw data contains $N$ position specific frequency measurement results. At each spatial scan point, there are $M$ frequency response data. If the clutter distribution is assumed to be invariant with position, then the following operation can be performed on these ensembles in a moving background calculation window size $W$:

$$\tilde{A}_j(t) = A_j(t) - \frac{1}{P} \sum_{i=1}^{P} A_i(t)$$

where $P$ is the number of A-scans to be averaged, $A_j(t)$ is the position dependent A-scan, and $\tilde{A}_j(t)$ represents the background subtracted A-scan data. Median filtering can also be used instead of averaging. More complicated and better background subtraction tools exist but we are constrained with minimal computational burden for real-time hand-held use.

Measured data were in the form of transmission spectra of the medium including landmines. This is directly related to the absorption spectra because all measurements were referenced to input power by the nature of $S$-parameter measurement set. Of course, we assume that the antennas were perfectly matched within the measurement band and reflections from antenna input ports were minimal. With background subtraction, signals from soil-air interface and soil only background can be averaged out against signals those that originate from landmine. Additionally, the detection method given in [21] has been applied to the background subtracted GPR data, which is based on correlation summation of consecutive A-scan signals in a predefined window $C$.

4. RESULTS

In the millimeter wave band of the electromagnetic spectrum, soil has low reflectivity and relatively high absorption, whereas metal has low absorption and strong reflectivity [22-23]. Such contrast differences can be utilized for subsurface imaging. At higher frequencies (above 40 GHz) water content of the soil greatly affects the reflectivity and absorption of the soil (less absorptive), hence making the detection more difficult. Lower frequencies are required for greater penetration into the soil at the expense of decreased spatial resolution. Thus, 20 to 60 GHz range seems to be a good compromise for reflectivity, penetration to soil, and spatial resolution.

First we considered metal disc (10 cm diameter and 2 cm thickness) buried 3cm beneath the surface. A-scan data were collected with 1 cm increments. The data were post-processed and resulting images of background subtracted data and detection function are displayed in Fig. 3. Clearly, metal disc can be detected from these images. Number of A-scan signals used to construct background A-scan signal was selected as $P=5$, moving background calculation window size is selected as $W=5$, correlation summation window size is selected as $C=5$ for the detection results of all targets.
Next, TS-50 mine was buried at 3 cm depth from soil surface. The maximum lateral dimension of the AP mine is 56 mm. The AP mine was buried at 25 cm away from the scan axis. B-scan image and detection function are shown in Fig 4.
5. Conclusions

Millimeter frequency band starting from 20 GHz to 60 GHz measurements were used as a stepped frequency GPR to detect anti-personnel landmines. Specific landmines were M14 and TS50. Background subtracted images reveal that landmines can be clearly detected. Identification of these mines require different signal processing techniques which will be further studied.

Unlike conventional pulsed GPR, stepped frequency radar can be a good resource in detection and identification of buried landmines with little to no metal content. Presence of clutter and rough surface will also be studied to further develop advantages and disadvantages of this frequency band.

REFERENCES


Fig. 4 Millimeter wave imaging of TS-50 mine, a) S11, b) S21, c) background subtracted data.


