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Optimized UWB Signal to Shallow Buried Object Imaging

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Abstract—The removal of ground surface influence from ground penetrating radar (GPR) signals in shallowly-buried objects is of great importance. The ultra-wideband (UWB) radar is a solution which uses short pulse to distinguish ground surface from shallowly-buried objects. In this paper, a novel method optimizes bandwidth based on designing a Gaussian signal. Experimental results confirm the proposed method efficiency.

1. INTRODUCTION

Ground penetrating radar (GPR) is widely used in military and civil engineering for imaging shallow and deep-buried objects [1]. The distinguishing of shallowly-buried objects from ground surface is a difficult task. The clutter-removing methods have enabled us to solve this problem to a great degree. The new investigations in [1–3] show good results in this regard, but the complete removal of clutter is not possible. In [4], the ultra-wideband (UWB) radar radiated a short-pulse to distinguish ground surface from shallowly-buried objects, e.g., landmines and pipelines. The reflection from surface of the buried object must be separated from ground surface reflection which is controllable by pulse width. The variation of reflected power from the boundary between ground surface and air is almost constant under 20 GHz [4]. Hence, low frequencies have better penetration. The lowest frequency will be determined by the antenna properties. The depth of targets and electromagnetic properties of soil and antenna properties determine radiated signal properties.

In this paper, the frequency bandwidth of a Gaussian signal is optimized according to the deepest buried object. The optimized bandwidth is 2–8 GHz. The results confirm the effectiveness of the proposed method for imaging shallowly-buried objects.

2. SIGNAL DESIGN

2.1. Lowest Frequency

The reflected signal from surface of ground in the frequency domain is almost constant [4]. The lowest frequency depends on antennas gain [5, 6]. In our experiment, the gain of antenna is constant after 2 GHz. Hence, the lowest frequency is set to 2 GHz.

2.2. Highest Frequency

The incident wave is a forth derivation of a Gaussian function in the following form.

$$s(t) = \left(3 - 6\left(\frac{4\pi}{m^2}\right)t^2 + \left(\frac{4\pi}{m^2}\right)^2 t^4\right) \cdot e^{-2\pi\left(\frac{t}{m}\right)^2} \tag{1}$$

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The designed parameter of this signal is "m" which determines the time band of signal. The length of incident wave depends on the minimum depth of target and permittivity of soil. The time band of signal is

$$m = \frac{2R \cdot \sqrt{\varepsilon}}{c} \tag{2}$$

The first step is to determine permittivity. Hence, an experiment is carried out to obtain this parameter. A metallic plate is buried in 5 cm below the ground, and the time interval between ground surface and this plate determines permittivity. The obtained permittivity is 2.9.

The second step is to determine time length. The buried objects' depths are more than 5 cm. Fig. 1 shows the incident wave in time domain. The frequency domain of signal is depicted in Fig. 2 [4, 7].

The results of signal design show that the bandwidth of signal is 6 GHz. Given the lowest frequency, the highest frequency is set to 8 GHz.

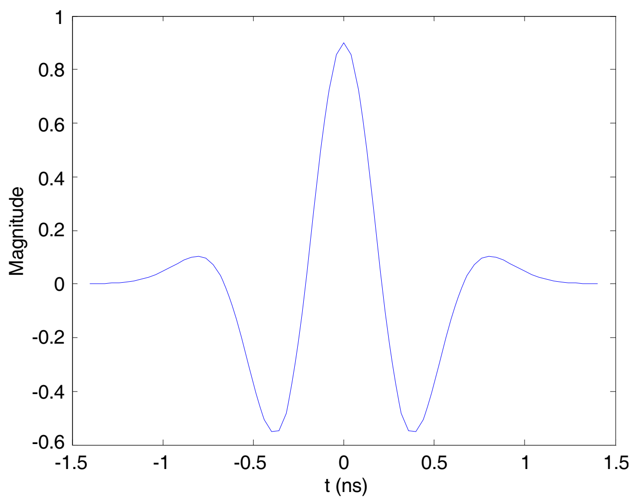


Figure 1. Gaussian signal in time domain.

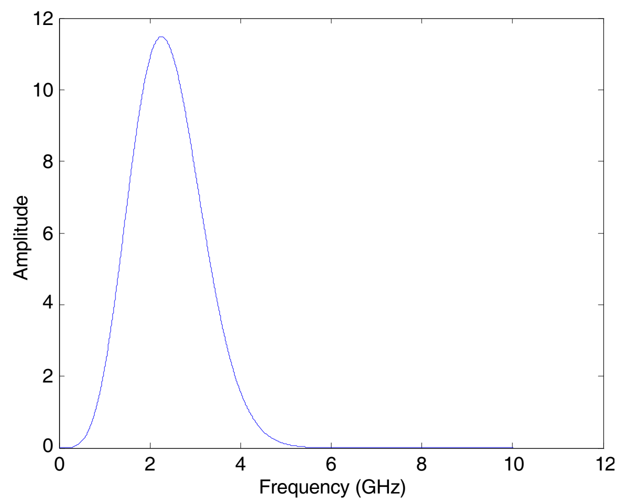
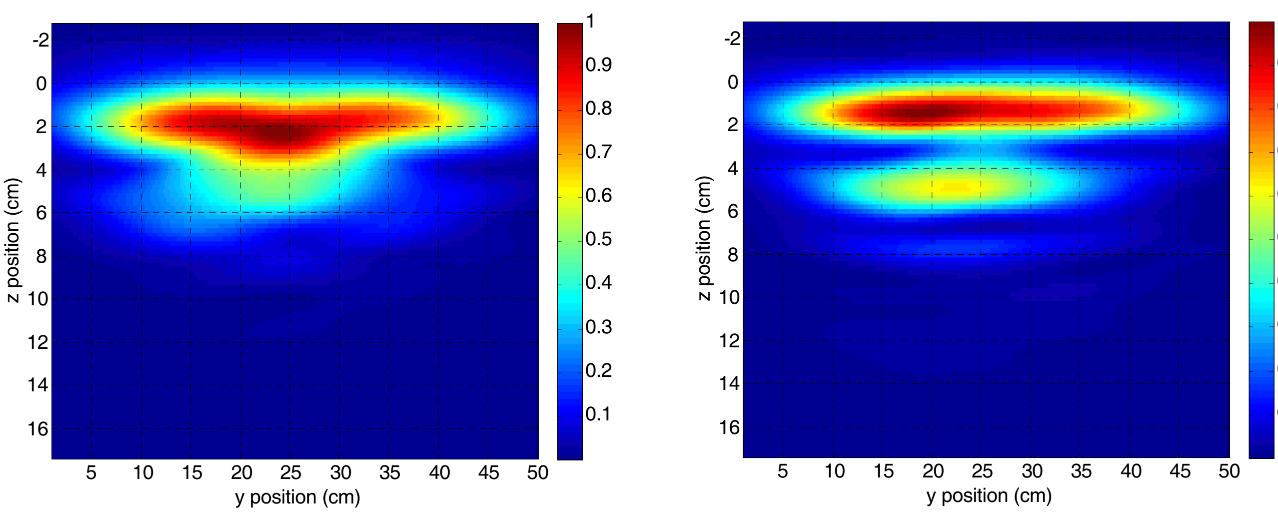
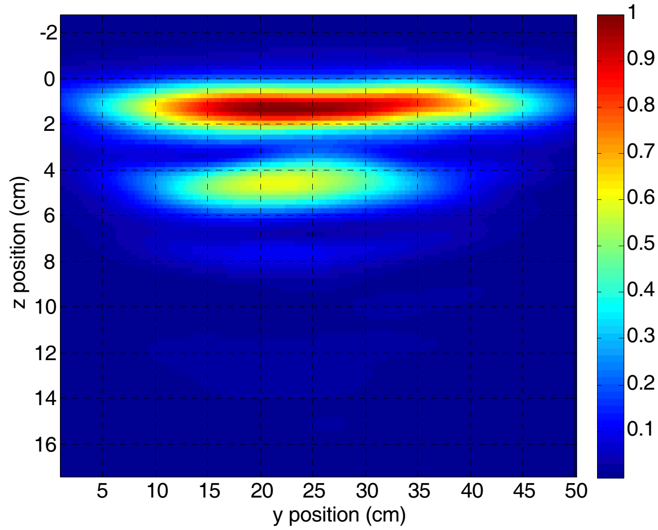


Figure 2. Designed Gaussian signal in frequency domain.



(a) (b)



(c)

Figure 3. Results of BP algorithm in the imaging near buried objects: (a) 2–6 GHz bandwidth of Gaussian signal, (b) 2–8 GHz bandwidth of Gaussian signal, (c) 2–10 GHz bandwidth of Gaussian signal.

3. EXPERIMENTAL RESULTS

The GPR data are collected from a scene of 50 cm length. The scene is filled with homogeneous dry soil. The GPR system consists of two antennas, a vector network analyzer and a positioner. The transmitted and received antennas are two similar horn antennas, with the first antenna transmitting a short time Gaussian signal and the second one receiving the reflected signal. The GPR system is scanned over the surface of ground in a constant height. The height of antenna is 20 cm. The scanning step is 1 cm. The network analyzer measures 16001 time samples with a frequency bandwidth of 2–8 GHz and bistatic responses.

The experimental scenario consists of a metallic plate with 10 cm $*$ 5 cm dimensions buried 5 cm

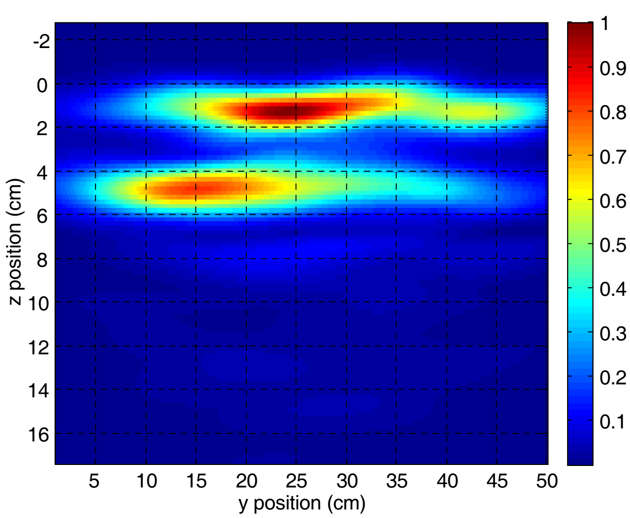


Figure 4. Results of mean subtraction method for clutter cancelation in 2–8 GHz bandwidth of Gaussian signal.

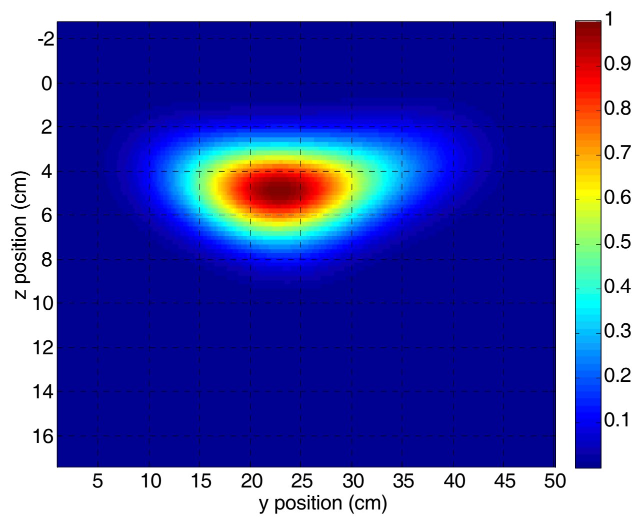


Figure 5. Results of near buried objects by 2–8 GHz Gaussian signal.

below the ground surface. The back projection (BP) algorithm which is implemented in [8, 9] is used to reconstruct images. Mean subtraction and time gating results are depicted in Fig. 3 and Fig. 4. The discrimination surfaces of ground from buried plate in different bandwidths are depicted in Fig. 3. In Fig. 3, the first red line is the ground surface reflections, and the second one is a buried object. Mean subtraction method in Fig. 4 shows that disability in clutter cancelation causes error in determining the precise location of the buried object. Mean subtraction method is suitable when the length of the scan is much greater than the length of the buried object. In this paper, the scan points is very few, and mean subtraction is not suitable. The results show that a bandwidth of 2–8 GHz separates buried plate from ground surface better than the bandwidth of 2–6 GHz, and the image of 2–10 GHz is almost the same as that of 2–8 GHz.

The plate buried 3 cm below the surface of ground is depicted in Fig. 5 which shows that it is detectable without being distinguished from ground surface in Fig. 3. It is because the incident wave is not attenuated considerably in soil [4].

4. CONCLUSION

The Gaussian signal design for distinguishing the ground surface from the buried plate is optimized according to time domain response. The short time Gaussian signal has wide frequency response. However, increasing frequency above optimized bandwidth do not result in distinguishing improvement. The optimized signal cannot distinguish the buried objects nearer than 5 cm from ground surface, but these objects are detectable without clutter cancelation methods due to their strong reflection.

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