Chapter 1. Introduction

Ground Penetrating Radar (GPR) is considered as being one of the most promising technologies for close detection and identification of buried Anti Personnel (AP) Landmines, due to its ability of detecting non-metallic objects in the sub-surface.

Ground Penetrating Radar is the name for the family of radar systems that image the sub-surface. Some authors prefer to speak of Surface Penetrating Radar (SPR) instead of Ground Penetrating Radar, but there is no essential difference between those two terms. Nowadays, Ground Penetrating Radar is a wide used technique and the number of its applications is still growing. Locating pipes and cables, civil engineering (bridge inspection, finding voids), security, archaeology investigation, geophysical survey and ice mapping are a few examples of its use.

The operating principle of Ground Penetrating Radar is straightforward. A GPR couples EM waves in the ground and samples the backscattered echoes. The EM wave will be backscattered on any electrical parameters contrasts in the ground. The special property of GPR is that it can detect echoes from all three types of electrical parameters contrasts, *i.e.* e_r, m_r and s . This means that a GPR system has potential for locating and identifying both metallic and non-metallic buried targets on the echo characteristics. The relative permittivity e_r of a medium describes the behaviour for electric field propagation; the relative permeability m_r describes the behaviour for magnetic field propagation and s defines the conductivity. All these three macroscopic parameters are in general function of frequency.

Fig. 1-1 shows a block diagram of a generic GPR system. The antennas are normally scanned over the surface in close proximity to the ground. An EM wave sent into the ground will backscatter on any electrical parameter discontinuity. The backscattered echoes that reach the receiving antenna are sampled and processed by a receiver. GPR systems always use different antennas for transmit and receive functions. The difficulty of using a single antenna arises because there are no sufficiently fast switches available to protect the receiver from the transmitted power.

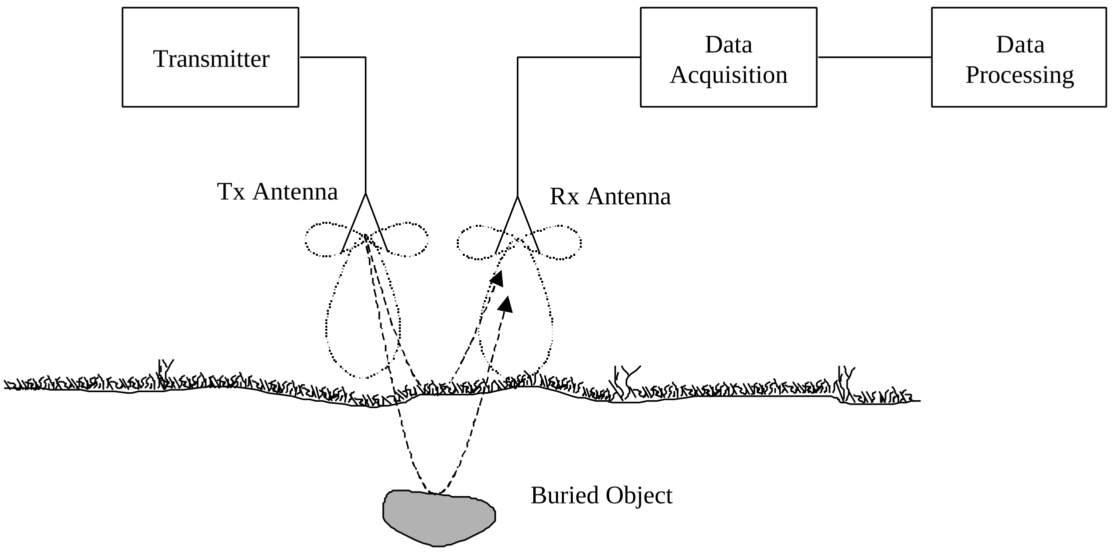

Fig. 1-1 : Ground Penetrating Radar block diagram

Fig. 1-2 shows a typical time representation of a signal, received by the GPR at a given fixed position. The first and normally the largest echo is due to the air-ground interface. Other echoes, appearing later in time are reflections on target or clutter present in the subsurface. Two or three-dimensional images can be produced by moving the antennas on a line or a two dimensional grid.

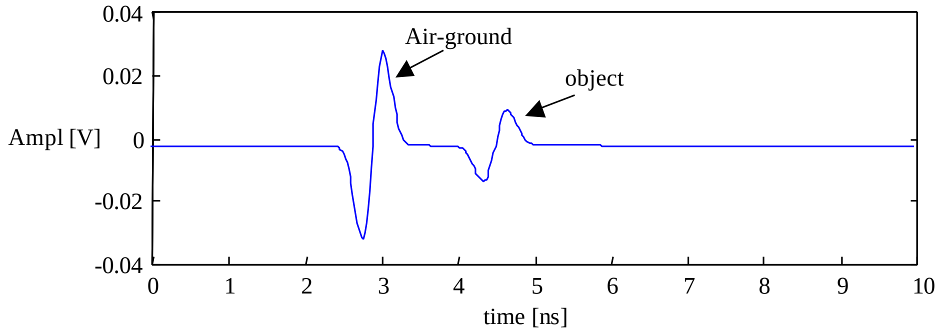

Fig. 1-2 : Typical signal, received by the GPR

The potential of detecting non-metallic targets makes the GPR complementary to a metal detector in the application of AP landmine detection. The additional information on location and other target features could drastically reduce the number of false alarms and thereby speed up the mine clearance. In spite of this promising potential, the use of GPR in real demining operations for the moment is negligible. This is mainly due to four reasons or drawbacks:

1. The first drawback is the limited range resolution. The range resolution of a radar system is defined as " the ability to distinguish between two targets solely by the measurement of their ranges (distance from the radar); usually expressed in terms of the minimum distance by which two targets of equal strength at the same azimuth and elevation angles must be spaced to be separately distinguishable" (IEEE Std 686-1990). The range resolution (in this case depth resolution) of a GPR is just like in any other radar system directly related to the bandwidth of the system (B) and the propagation velocity v by

$$\Delta R = \frac{v}{2B} \qquad \textbf{(1. 1)}$$

In most of the conventional GPR systems, the bandwidth is inferior to 1 GHz. Using the quantitative definition (1.1) the depth resolution is limited, depending on the permittivity of the ground, to 9.4 cm for dry soil ($e_r = 2.55$) and to 3.4 cm for very wet soil ($e_r = 20$). The depth resolution problem is also illustrated on fig. 1-2. Trace (a), (b) and (c) represent the response of three impulses on one layer. Trace (d), (e) and (f) represent the total response of the same impulses on a two layered structure, with equal reflection amplitude on both layers. In case (d) the pulse duration is short compared with the two-way travel time between the layers. In case (e) the pulse duration is about equal to the two-way travel time between the layers, which means that the separation Δd between the two layers equals the depth resolution ΔR as defined in (1.1). In case (f) the pulse duration is longer than the two-way travel time, and the two layers can not be distinguished in the response.

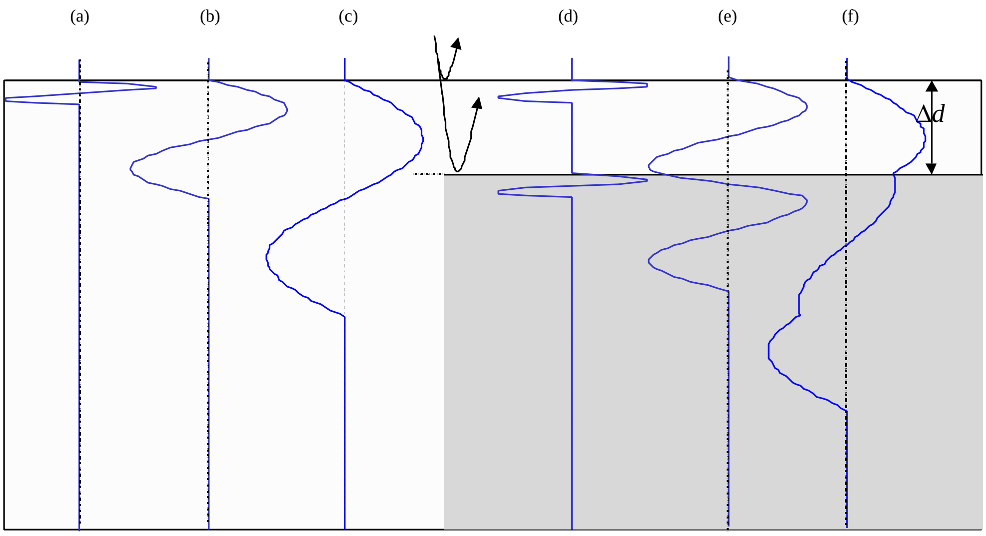

Fig. 1-3 : Illustration of the depth resolution problem

As anti personnel landmines are often laid shallow, conventional GPR can have difficulties discriminating the target echoes from the air-ground interface. If the air-ground interface is smooth and flat, simple image processing techniques can enhance the depth resolution. Post-conflict areas however have often a rough surface and are covered with a lot of vegetation. In this case, the performance of these simple image-processing techniques will be insufficient and just more depth resolution is needed, which means larger bandwidth. The choice of the lower and the upper cut-off frequencies of the frequency band is not straightforward. Using an ultra wide-band involves the use of higher frequencies, which are strongly attenuated by the lossy soil. Low frequencies (< 1GHz) on the other hand have a good penetration in the ground, but a poor resolution. So when mines are buried too deep and the frequency band is chosen too high, it is possible that we don't detect anything at all because of the dramatically increased attenuation of the soil with frequency.

2. A second problem with the GPR systems is the ability of discriminating between a mine and a mine-like target. This problem is like the first one related to the frequencies used by the GPR system. The wavelengths radiated by the GPR have the same order of magnitude as the size of the landmines. As a consequence, the backscattering on the mine is very complex and the backscattered signal is a combination of different backscattering mechanisms.

   Many authors suggest that there is a lot of information in the late-time response (resonant part) of buried objects to short EM impulses. Looking to the buried mine as a linear system, the larger the bandwidth at the input of the system, the more information one can get on the system. This additional information can be very useful for clutter reduction and/or classification of targets. So again a UWB approach imposes itself.

3. The third drawback concerns the antennas used in commercially available GPR systems. Antennas are a critical point in a GPR system. Most of the GPR systems are designed for applications other than the demining application and the antennas do not meet the specific requirements as needed for this application. The most apparent example is the element antenna. Element antennas, like dipoles, are widely used in GPR systems. Unfortunately they have a low directivity and therefore perform best when they are in contact with the ground, to couple as much energy as possible into the ground. For safety reasons, deminers do not want to use a sensor that is in direct contact with the ground. Further, minefields have often a very rough surface and are covered with a lot of vegetation. So the mobility and hence the dimensions and weight of the antenna become an issue. In the demining application, antennas that can be used off-ground are needed.

4. The last drawback is a more practical one. The output of a GPR is usually an image representing a vertical slice in the subsurface. These images are sometimes difficult to analyse and expert knowledge of the system and the physics behind the operating principle of the system is needed for correct interpretation of the results. In demining operations the deminers are usually not highly educated and they are anyway under too much stress to perform such a complex interpretation.

In this research we want to investigate the feasibility of possible solutions for all of these four drawbacks. It is not our intention to present an enhanced demining tool nor to build a field usable system. The research will not be limited to some hardware aspects of the system nor just to the development of new image processing algorithms, but a more overall system approach is searched for. In this research we will also try to demonstrate that the complete knowledge of the hardware system, which is in fact an *a priori* knowledge, can be used to enhance or tune image processing algorithms. The latter is probably one of the most original parts of the work.

The outline of the work is as follows. In Chapter 2 we will give a general description of the conventional GPR. The history of the GPR, possible applications and the physics behind the operation principle are described. In a second part of the chapter the state of the art in demining applications and field trials with commercially available systems are presented and conclusions are drawn.

In Chapter 3 the development of antennas adapted for the demining application is described. After a short introduction and an overview of existing GPR antennas, we will discuss some design goals for the antennas we need in this application. The design goals are mainly a product of field trials. Further in this chapter the step by step development of TEM horn antennas for UWB GPR will be treated. We will show that the dielectric-filled TEM horn antenna is capable of radiating and receiving very short, but still clean pulses. We also study a model for prediction of antenna impedance and radiated far-field for air-filled and dielectric filled TEM horns.

In Chapter 4 we present a method for characterising the antennas by considering the antenna as a convolution operator. It is always important to select a domain that presents a solution in the easiest and most compact manner. For UWB antennas this domain is the time domain. In this chapter we show how the antennas can be characterised by their normalised impulse response and how this impulse response can be measured. Further we show that this compact way of describing the antennas can be used for simulations and comparing performances of different time domain antennas.

In Chapter 5 we model the whole radar system as a cascade of linear responses, which gives a lot of advantages and possible applications. The study results in an equivalent time domain expression of the radar range equation. The model will also be the basis of the link between the system and the image processing.

At the start of the HUDEM project in 1996, there was no UWB GPR system commercially available. Therefore we decided to develop an indoor laboratory version of an impulse UWB GPR to investigate the feasibility of enhancing the depth resolution and classification rate of UWB systems. In Chapter 6, a detailed description of the UWB GPR is given together with a study of its range performance, using the time domain model from the previous chapter.

In Chapter 7 we give an overview of some possible UWB signal processing techniques and investigate to which extent they can enhance the classification capability of an UWB GPR. Further we investigate some migration techniques. In this chapter we present a novel 3D migration method that takes into account the complete time domain model of the system. We will show that the migration method is able to reconstruct the 3D shape of small targets, in some cases even with the correct dimensions.

Finally some conclusions are drawn and possible future work is suggested.