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Landmine Detection Using Impluse Ground Penetrating Radar

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Abstract: This paper presents a novel system to obtain images from the underground based on ground penetrating radar (GPR). Landmines are a persistent threat to human life and socioeconomic development, with millions of undetected and unexploded landmines buried in former conflict zones worldwide. Impulse ground-penetrating radar (GPR) technology has emerged as a promising technique for detecting buried landmines, offering a non-invasive, fast, and effective means of detecting subsurface objects. Impulse GPR technology works by sending short electromagnetic pulses into the ground and measuring the reflections from different materials and structures, allowing it to distinguish between different objects, including landmines. However, the technique has several challenges and limitations, including soil conditions, moisture content, and the size and depth of the buried object. In this paper, we review the principles of impulse GPR technology and its application in landmine detection..

I. INTRODUCTION

Landmines are a significant threat to human lives and pose a considerable challenge to post-conflict reconstruction efforts. One approach to locating landmines is using impulse ground-penetrating radar (GPR), which provides a non-invasive, fast, and effective means of detecting buried landmines. Impulse GPR technology sends short electromagnetic pulses into the ground and measures the reflections from different materials and structures, allowing it to detect the presence of buried objects, including landmines. The technique has been shown to be effective in a variety of soil and terrain types, making it a valuable tool for demining operations worldwide. Landmines are a deadly legacy of conflict, with millions of undetected and unexploded landmines buried in former conflict zones worldwide.

The presence of landmines not only poses a significant threat to human life but also impedes economic and social development, hindering the return of refugees, the reconstruction of infrastructure, and the use of land for agriculture and other productive activities. Impulse GPR technology offers a promising solution to the landmine problem. It has the potential to detect buried landmines quickly and accurately, allowing for their safe removal and clearance. Impulse GPR technology works by sending electromagnetic pulses into the ground and measuring the reflections from different materials and structures. This allows it to distinguish between different objects, including landmines, and to create a high-resolution image of the subsurface. However, landmine detection using impulse GPR is not without its challenges and limitations. The performance of the technology is affected by soil conditions, moisture content, and the size and depth of the buried object. The presence of metallic debris or other clutter can also cause false alarms, reducing the effectiveness of the technique. In this paper, we will explore the application of impulse GPR technology in landmine detection. We will discuss review the current state of research and development in this field and consider potential future directions for improving the effectiveness and efficiency of landmine detection using impulse GPR.

II. METHODOLOGY

Before beginning the detection process, the survey area must be prepared by removing any surface debris, vegetation, or other obstructions that could interfere with the GPR signal.Impulse GPR technology sends short electromagnetic pulses into the ground and measures the reflections from different materials and structures, creating a high-resolution image of the subsurface. The data is collected by moving the GPR device over the survey area in a systematic grid pattern, typically with a spacing of several centimeters between each measurement point.The collected GPR data is processed using specialized software that filters, enhances, and analyzes the signals to identify buried objects, including landmines.

i). Electromagnetic induction: based on inducing an electric current in the concealed metallic objects One of the scenarios of interest is landmine using a transmitting coil. The induced current reradiates an electric field which is detected by a receiving coil. The main advantage of this system is its low cost and simplicity. However, it suffers froma high false-alarm rate when several metallic objects are alsoin the scenario under test (shrapnel, bolts, etc.).

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ii). Nuclear Quadrupole Resonance (NQR): based on the detection of the radiofrequency signals emitted by certain substances that are backscattered power is directed towards the radar (although it also depends on the geometry of the buried target). In this kind of systems, the challenge is to achieve normal incidence while keeping the security distance of 3-5 m. One solution is based on small lightweight unmanned autonomous robots, capable of performing detection with a minimum landmine detonation risk [25], [26].

iii). Thermal imaging: infrared sensors are capable of detecting the different thermal behavior of landmines with respect to the surrounding medium. In particular, thermal image time series acquisition is proposed in [17], using thermal response analysis in the time domain to detect landmines. The main weakness of this methodology is the dependence with weather conditions that affect soil thermal conductivity, and thus the thermal contrast between soil and buried land- mines.

In these systems, transmitting and receiv- ing antennas are placed in the air-soil interface at different positions separated half wavelength, so that the coherent combination of the received signal at each position resultsin a bi-dimensional radar image (in range or depth,

iv). Ground Penetrating Radar (GPR): it has been consid- ered as one of the best techniques for underground imaging thanks to the capability of creating images of the soil and the objects buried in it [13]. In consequence, GPR has been widely used for landmine detection [18]–[21]. GPR is based on emitting electromagnetic waves to the soil, whose reflec- tion at the soil and at potential concealed objects allows to recover a radar image where these concealed objects can be identified. It must be remarked that GPR is quite sensitive to the soil composition and the air-soil interface roughness, requiring additional signal processing techniques for image artifacts and clutter removal. Regardless the operating principle, the application of non-invasive techniques for landmine detection requires the scanning system to be placed at a safety distance with respectto the potential placement of the landmine, typically 3-5 m, to avoid the accidental detonation of the landmine by the scanning device. To achieve this

v) Forward-looking radar systems, where the transmitting antenna illuminates the soil under an angle of incidence suchas the injected power in the soil is maximized [22], [23].In this case, due to the angle between the radar and the soil, only part of the reflected energy is backscattered towards the radar, thus requiring higher dynamic range in the receiver todetect the buried targets. ii) Downward-looking systems, where the incident wave direction is perpendicular to the soil surface [22], [24]. In this case, the fact that the transmitted power is not maximized is partially compensated thanks to the shorter distance between the radar and the soil; and also the backscattered power is directed towards the radar (although it also depends on the geometry of the . In this kind of systems, the challenge is to achieve normal incidence while keeping the security distance of 3-5 m. One solution is based on small lightweight unmanned autonomous robot

III.UNMANNED AERIAL SYSTEMS FOR LANDMINE DETECTION

Improvements in UAV technology have made possible the development of UAV-assisted landmine detection systems, as they exhibit disruptive advantages such as: i) higher scan- ning speed compared to existing solutions in the market based on autonomous robots; ii) possibility of inspection of remoteareas, unaccessible with other systems; and iii) higher safety throughout the scanning process, especially when looking for explosives, since contact with soil is avoided. A prototype consisting of a metal detector onboard a UAV that also includes a robotic arm capable of placing a remotely controlled detonator to blow out the landmine is described in [27]. This system provides contactless (and thus safe) and fast scanning capabilities. However, metal detectors cannot distinguish between different kinds of metallic

Latest advances for landmine detection are based on placing a GPR on board a UAV [28]–[32]. The implemented prototypes are mostly based on a compact GPRunit that forwards geo-referred measurements to a groundstation for post-processing and results displaying. Again,cross-range (horizontal) resolution is limited by position-ing and geo-referring accuracy, mostly relying on GNSSreceivers integrated within the UAV controller. In consequence, these state-of-the-art systems have been proved to beeffective for detecting buried targets larger than 25-30 cm,and/or exhibiting significant contrast with the medium (e.g. metallic targets buried in clay or sand). However, existing UAV-based GPR systems do not providehigh resolution subsurface images as they do not support SAR imaging capabilities, that is, GPR measurements collected at each position of the flying objects.

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IV.AIM AND SCOPE OF THIS CONTRIBUTION

Aiming to overcome the limitations in terms of detection capabilities of current UAV-based GPR imaging system, this contribution introduces a system and method for high accuracy underground SAR imaging, conceptually depicted in Fig. 1. The developed technology allows the UAV to autonomously explore a particular area using GNSS coordinates, while transmitting and receiving radio signals using a radar module. The collected data includes timestamps to enable synchronization and is sent in real time to a computer, where it is processed to generate SAR images of the subsurface with a resolution of centimetres. In addition, algorithms for proper characterization of the soil and clutter removal have been implemented. FIGURE 1. Concept of the UAV-based GPR system for underground SARimaging. The main innovation of this contribution is the capability of using SAR-based techniques for subsurface imaging withrange and cross-range resolution of a few cm, overcoming the limitation of current UAV-based GPR systems where coher- ent combination of measurements taken at different positions (i.e. creating a synthetic aperture) is not possible.

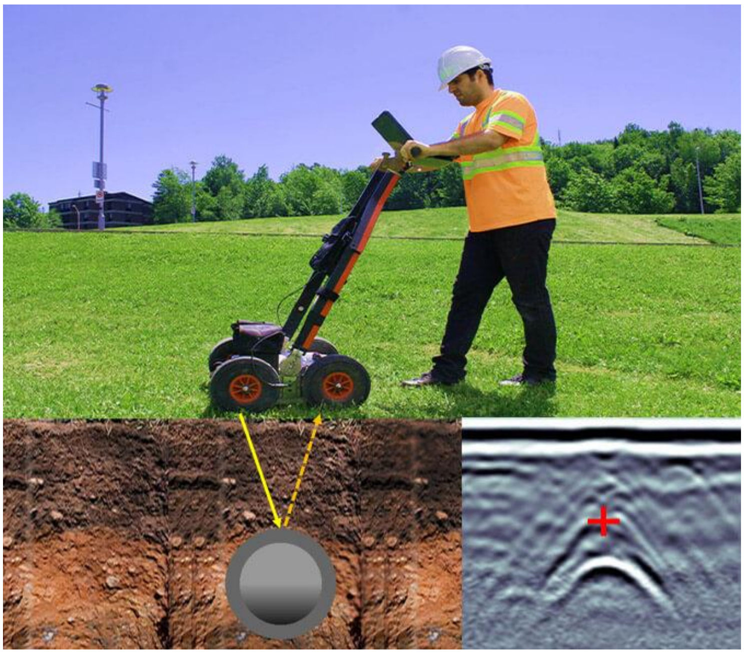

Figure. Impulse Ground Penetrating Radar Techniqu

V. CONCLUSIONS

A UAV-based underground SAR imaging system for the detection of buried objects has been presented. It aims pri- marily at detecting explosives such as antipersonnel land- mines, but it can also be used for any other application where detection and identification of hidden objects is necessary.

Results presented in this contribution have proved: i) that the radar range and cross-range resolution are Δr 7.5 cm and Δl 2 2.5 cm, respectively, ii) the capability of detecting buried non-metallic objects, and iii) the repeatabil- ity and reproducibility of the measurements for SAR imaging. A 3 min video summarizing the features of the system (operating principle and description of the architecture) and a briefapplication example, can be watched at The prototype and developed algorithms could be of inter- est in sectors where the detection of buried objects is essen-tial, as the aforementioned detection of landmines, pipeline inspection, or archaeology work.

The system can also be used in the detection of infrastructure defects, walls, roofs and road inspection. The added value, when compared with similar systems for nondestructive testing, comes from the fact that the GPR is mounted on a UAV, which prevents physical con- tact with the ground during scanning. With respect to similar airborne GPR prototypes, this system is capable of creating SAR images with a few cm resolution, enabling detection of small metallic and dielectric objects buried in the ground.

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