# A Review on Ground Penetrating Radar Technology for the Detection of Buried or Trapped Victims

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***Abstract*—The localization of people buried or trapped under snow or debris is an emerging field of application of ground penetrating radar (GPR). In the last years, technological evolution and many approaches have been developed to improve detection precision, fast localization, and false alarms reduction. Avalanches and collapsed buildings are two scenarios that can be dealt with different methods, e.g. image processing of radargram and detection of the Doppler frequency changes induced by physiological movements of survivors, such as breathing. This work presents and analyses briefly the evolution of research in this field.**

***Keywords- Geo-Information technologies; emergency; disaster management; ground penetrating radar (GPR); sensors.***

## I. INTRODUCTION

The detection and rescue activity of buried or trapped survivors is one of the main emergency to be faced in disasters scenarios, such as avalanches, collapsed buildings and earthquakes. Modern technologies can aid rescue operations, improving precision and speed of localization at the same time. The danger, originated from instability of collapsed structures, forces to adopt noninvasive detection methods. A technological solution of this kind is based on the use of a network of geophones [1], but it needs quiet operational conditions that are hardly met during emergency phase. In a different scenario, e.g. avalanches in mountain environment, transceivers, such as Beacon or Appareil de Recherche de Victimes en Avalanche (ARVA) are usually adopted to detect victims. This technology, based on radio-wave propagation, uses active electronic devices: one transmitter per each buried hiker or skier. A similar principle inspires other technologies aimed at detecting personal electronic devices possibly carried by the victims [2]. However, survivors are normally without of these active devices, so that most used methods are indeed those that consider the detection of passive targets. Among these technologies, ground penetrating radar (GPR) has been tested already in practical scenarios and shows promising improvement margins, so that it could play a significant role in present-day and more again in future applications.

In the basic operation mode, a GPR system transmits electromagnetic (EM) waves into the ground for a propagation in depth. Nonhomogeneous medium characterized by layers of different permittivity and/or electrical conductivity changes EM wavelength and velocity at each homogeneous medium, and EM waves are scattered due to variation in EM properties between two contiguous layers. In particular, variation of permittivity changes the wavelength of EM radiation in the nonmagnetic medium, according to following formula:

$$\lambda = c_{light}/f/\mathrm{sqrt}(\varepsilon_r) \qquad (1)$$

where $\lambda$ is the wavelength, $c_{light}$ is the speed of light in vacuum, f indicates the frequency of EM waves, and $\varepsilon_r$ is the relative dielectric permittivity of the medium. Finally, a reflected fractional amount of energy arrives to the receiving antenna of the GPR allowing generating the relative radargram. For normal incidence, the fractional amount of the energy ($R_E$), which will be reflected at the boundary of two mediums characterized by different values of dielectric permittivity ($\varepsilon_{r1}$, $\varepsilon_{r2}$), and equal permeability ($\mu_1=\mu_2$), is valued by the reflection coefficient:

$$R_E = (\mathrm{sqrt}(\varepsilon_{r1}) - \mathrm{sqrt}(\varepsilon_{r2}))/(\mathrm{sqrt}(\varepsilon_{r1}) + \mathrm{sqrt}(\varepsilon_{r2})) \qquad (2)$$

Main limits of the detection capability of GPR systems are due to the occurrence of multiple reflections and the lowering of the penetration depth that are evident when radio wave must propagate into layers of reinforced concrete slabs or structures mainly made of metallic materials.

Survivors of a disaster that are trapped under rubbles or snow need to be saved in a very short time. The survival time of victims buried under debris is estimated to be approximately 72 hours, depending upon the type of entrapment, climatic conditions and the pulverization of building material. In case of avalanches, the same survival time is dramatically reduced, since the relative probability decreases to 90, 40 and 30 per cent, if the victim is removed from the snow within 15, 30 and 60 minutes, respectively. Consequently, localization method and technology must assure precision and speed. In any case, a more rapid localization is essential for humans buried under the snow. People trapped under rubbles can be free to move, also partially, but some victims can be unconscious and motionless and their localization can be very complicated. The differences between scenarios and the limits of survival time suggest us to split the applicative environment into two subcases. In the first one, victims under avalanche are "seen" as classic targets of GPR surveys: they are assimilated as a perturbation of the backscattered signal due to dielectric discontinuity represented by the human body with respect to the surrounding environment. In the second case, the detection via GPR consists on measurements of vital signs characterizing the trapped victim under rubble, such as heartbeat or breathing, which induce a low frequency perturbation of the backscattered radar signals.

## II. DETECTION BURIED PEOPLE UNDER AVALANCHES

### A. Research progression

Since about 1980, radar has been considered for detecting avalanche victims. First examples are concerned with the use of radiometers in S band [3] and multi-frequency radars [4]. At the end of the 80s of the last century, the first applications of GPR in snow measurements were published [5]. Since 1994, the GPR has been considered for searching persons buried under snow [6], relying on the fact that avalanche snow is a quite favorable medium for radio-wave penetration and that the body of the buried person reacts as a "strong" scattering target hosted within an almost homogeneous medium. For these reasons, the technological solutions typically exploit standard UHF GPR systems, operating in the 0.4-2 GHz band. In the past 10 years, some researcher groups have investigated for improving detection reliability and the organization of an effective research operation [7][8]. Experimental observations have been extended beyond the limits of survival time, using a slaughtered pig like body mass equivalent (BME) that simulates a human, to verify how the detection of GPR signals at 450 and 900 MHz deteriorates in the time [9]. Furthermore, they demonstrated that the BME has a different radar signature as compared to other objects buried under snow (rock, log, dirt clod, tree and so on) [9][10]. All the previous studies have used radar at direct contact with the snow surface. However, moving these radar systems on a mountain slope run over by avalanche is particularly complicated, due to the presence of bulky slabs of ice mixed with snow. On the other hand, for a systematic search of avalanche victims and for examining whole area, contiguous strips should overlap. Therefore, this search technique is time-consuming and it is not fast enough for using it during emergency. In order to exploit potential advantages of GPR technology, since 2005 researchers have considered GPR system mounted on an aerial vehicle [11].

### B. Airborne GPR

Recently, feasibility study of radar mounted on an aerial vehicle has been examined, highlighting the specific quality that must show application of airborne GPR systems [12]. In particular, Heilig et al. have investigated three fundamental topics: 1) the influence of the snow properties on the radar signal; 2) the maximum horizontal distance of a victim from the flight direction; and 3) the influence of the orientation of the victim with respect to the flight direction. In addition, they have introduced a post processing able to provide automatic location procedure. Following the last approach, that considers how a manual real-time detection is impossible to solve, in the next period the same researcher group proposed improved automatic algorithms to detect avalanche victims using airborne GPR [13]. Experiments that are described in [12] and [13] simulate the flight of an aerial vehicle by means of an equivalent aerial tramway system or chairlift 6-12 m above the snow surface, and use an IDS (Ingegneria dei Sistemi, Pisa, Italy) RIS system, equipped with properly designed processing tools. In the same experiments, control unit manages 400 MHz signals of both mono-static and bi-static antennas. In mono-static mode, both antennas transmit and receive radar signals separately and consecutively; in bi-static mode, one antenna alternatively transmits and receives, in complementary mode the other antenna receives and transmits.

In the case of radar at direct contact with the snowy surface, data recording consists of at least two layers: snow and underlying layer (ice, soil, rock and so on). Airborne radar acquires data of at least three layers: air, snow and underlying layer. When radar moves along a direction at constant velocity, the boundaries of the materials result as continuous lines in the radargram. Objects buried under snow, of finite geometrical dimension, and characterized by different permittivity and/or electrical conductivity are shown in the radargram as diffraction hyperbola [10] [13] [14]. Little debris could confuse the data interpretation, and in any case, signature identification of a human could be complicated to distinguish from a different object buried under snow. Moreover, victims roll and float when they are run over by avalanche, creating more layer interfaces at the end: snow/body, snow/air/body, ice/body and so on. Therefore, buried persons that lie in different positions generate hyperbola of modified characteristics. Only an automatic procedure can solve the detection of victims more quickly and with precision. Interesting algorithm proposed by Fruehauf et al [13] is based on two steps approach. The first and more important one is a method for automatic extraction of snowpack. The second one is a matched filter algorithm for enhancing the diffraction hyperbola. Air holes in the snowpack are not detectable. However, snowpack extraction allows that detection of avalanche victims to be independent of the underground material (rock, ice, and talus), and altogether minimizes the computing time, decreasing the application area of second step. The success of such an algorithm depends from a suitable choice of some parameters that are function of velocity, height of GPR system, and so on. For this reason, in such a framework is also of interest to consider the adoption of tomographic imaging techniques, such as [15] [16], that cast the imaging problem in terms of an inverse scattering one and therefore allow for robust (i.e., more easily interpretable) imaging results.

Another issue important in this framework is the characterization of snow properties, as snow density, and snow wetness, determine dielectric permittivity and conductivity of the medium. The radar signature of the snow should be measured in the whole area. In order to evaluate snow properties in a time consuming reasonable, researchers proposed measurements by using of radar on board of aerial vehicles [17]. In any case, observation of snow structure, measured by means of GPR [18] [19] or by other measurement systems, should allow to archive data for using them for the occasion of emergency.

### C. Detection of survivors

All previous GPR systems can detect avalanche victims. Nevertheless, they do not verify if people are survivors or not. Whereas, e.g. the active device ARVA, equipped with sensors of vital signs are designed at present. A study that detects vital signs of people buried in snow by using GPR is [20]. In the experimental setup, a human is behind a barrier of snow or inside of an igloo. Different from real situations, for the presence of relevant layer of air, the study is a special case, adapted to snowy environment, of through the wall (TTW) life detection and monitoring. However, it shows how continuous-wave (CW) microwave transceiver working at 2.4 GHz is able to detect breathing and heartbeat through a snow barrier, at least in the considered simplified conditions. Moreover, the vice the overall procedure is time consuming its application in emergency situations is actually limited.

## III. Detection buried people under debris

Processing tools routinely adopted in GPR surveys are not applicable for detecting survivors buried under a collapsed building, in consequence of earthquake or accident as gas explosion, structural implosion, and so on. As a matter of fact, they are valid procedures only in the case of homogeneous, or reliably approximated as homogeneous, media in which survivors are trapped. Collapsed building creates stratified slabs of heavy rubble at different inclinations; a very inhomogeneous environment that makes it impossible to exploit the retrieval of the dielectric contrast features as the only means for detection. In addition, the irregular surface of debris and the danger of next collapses, due to the instable structures, cannot allow traditional linear scans, thus making further difficult the correct localization of the possibly detected target on the GPR image. Although the same processing tools should detect trapped people able to move or to be partially free to move: radargram of fixed GPR stands out in consecutive recordings the presence of no-static subjects; they are ineffective to detect unconscious or motionless victims. Consequently, alternative methods need to be explored.

### A. CW signals

In the last years, several researchers exploited capability and performance of radars to monitoring vital signs as breathing or heartbeat [21]. In the field of biomedical engineering, the usage of radar is an example of noncontact measurement method. This one allows several advantages on the examined human subjects (e.g. no inhibitions, no discomfort and it avoids electrodes applied to the skin). In the case of unmodulated radiofrequency signal, the working principle is the following: a CW signal is transmitted towards the human subject; physiological movements such as heartbeat and breathing modulate the phase of signal (Doppler shift) that is reflected back to the receiver; vital signs are extracted by demodulating received signal. Frequency of physiological movements is very low: 12 to 50 times per minute (1-2 Hz, approximately) for typical breathing, with width of chest breath between 2-5 cm, and 50-130 times per minute for heartbeats. The Doppler shift due to breathing is approximately 0.3 Hz, whereas that one due to heartbeat around one Hertz. In biomedical studies, absence of obstacles between antenna and target subject allows measurement at Ka (27-40 GHz) [22] and X (8-12 GHz) [23] [24] bands radars with higher resolution. However, in the last years, most of experiments operate at lower frequency, in the Instrumental Scientific Medical (ISM) band (around 2.4 GHz that has the additional advantage of does not needing a specific license).

CW radars operating in the ISM band have been first considered for both people buried under debris [25] and snow [20]. CW-radar assumes that the subject is within the beam of the antenna and cannot give any information about the distance between antenna and target location. Moreover, if different targets must be detected simultaneously in the area, this measurement system needs multiple antenna CW radars and more sophisticated digital signal processing [26]. In practical applications, this kind of radar shows null detection points and co-frequency interference. To overcome these problems, many demodulation methods have been developed and different architectures have been proposed, such as: double-sideband transmission [27], complex signal demodulation [28], arctangent demodulation with DC offset compensation [29], and I/Q receiver [20]. Resorting to frequency-modulated continuous-wave (FMCW) radars and ultra wide-band (UWB) pulse radars can overcome some of the limitations of CW systems.

### B. FMCW and UWB

FMCW radars allow to measuring the distance of the detected subject: pulse radars transmit a sequence of short RF pulses, and evaluate the range position of the target by measuring the time delay of the returning pulses.

UWB electromagnetic wave sources, used in more recent systems, generate short pulses that spread their energy over a broad frequency range. These UWB systems then employ the difference of the time-of-arrival of the backreflected wave due to the movement of the chest of the person to extract the desired features. The UWB radar approach has no null-point problem. Zaikov and Sachs designed a prototype UWB radar that allow non-stationary clutter removal, and signal to clutter separation with principal component analysis [30]. Another work of the same authors [31] examines the effects of different sources of noise faced in UWB detection of buried victims. The work lists many noise sources, such as: stationary clutter, non-stationary clutter, internal noise, narrowband jamming, and random jitter. The contribution of the noises changes depending on the type of radar used: pulse, pseudo-noise, stepped frequency, and random noise. Furthermore, authors developed a model for a pseudo-random radar, which is similar to GPS, trilateration included.

Loschonsky et al. [32] have introduced a different approach for the detection of buried persons exploiting signal-processing algorithms such as fast Fourier transform (FFT) and continuous wavelet transform (CWT) for detecting RF devices that many people carry with themselves. More recently, in order to remove the direct wave, reduce noise and extract the sought features; Li et al. [33] have proposed the use of a processing chain made out of several blocks: curvelet transform, singular value decomposition, and Hilbert-Huang transform. Whereas, Grazzini et al. [34] have proposed the interesting adoption of a Continuous Wave Stepped Frequency radar (CW-SF) for overcoming the poor time stability of UWB impulse radar, which the jitter causes in the pulse triggering process. In addition, thanks to the enhancement in the dynamic range, this class of radar improves the capability of detecting low frequency movements. Moreover, from the point of view of the system, Akiyama et al. [35] have proposed and tested an alternative to UWB radars, mono-static or bi-static: a radar arranged in a moving UWB array to detect breathing.

### *C. Questions*

Researchers have solved many problems in the last years, but several other questions are still open and worth of further investigations.

The increase of sensitivity improves the probability of detection, but also results in the occurrence of a larger number of false alarms. Recent works [36][37] have introduced a novel method of life detection, based on constant false alarm ratio (CFAR) and clustering, improving greatly the signal to noise and clutter ratio (SNCR), and removing effectively the nonstatic clutter.

Radio sources and cell phones, unavoidably present in the operative scenario of emergency, create interferences, similar to other sources of random noises (device internal noise, narrowband jamming, and so on) [31]. This interference has to be accounted for by some kind of integrated background noise monitor in order not to impair the GPR survey. Moreover, nonstationary clutter, like motion of objects located near the sensor, rescue engines, etc., appear to be the main source of false alarms.

Clambering over debris is more time consuming than performing data acquisition itself, so that suitable, no-canonical, acquisition strategies (and the relevant processing tools) have to be devised.

The Doppler radar cross section associated with breathing is usually greater than that of heartbeat-induced movements. Consequently, vital signs associated to heartbeat can be appraised only in relatively simple situations, such as a subject buried under snow, but cannot provide a useful signature to detect victims trapped under debris.

## IV. CONCLUSION

Development of GPR technology can aid rescue operations, thanks to noninvasive detection methods and lower time consuming of the detection activity, but some important issues must be solved or should be improved present-day solutions. Results achieved in other applications, such as bioradiolocalization and TTW radars, can produce novel methods that overcome present-day limits of procedures. In particular, TTW radars aim to detecting moving or static human beings hidden behind an obstacle, although in simpler conditions than collapsed building. An interesting solution has been proposed by Wang et al. [38]: the self-injection-locked (SIL) method; in which the signal partially reflected from a distant target is injected in the same oscillator that produced the transmitted wave. This technique improves the sensitivity of demodulation and allows the radar system to achieving higher signal-to-noise ratios (SNR). Tiny body movements of subjects that stay still can be monitored, and at same time position of different individuals concealed behind the wall can be located. Again, such a technique has been tested in a simpler scenario than the one dealt with in rescue operation, but it is nevertheless an interesting possibility.

In addition, detection of victims buried under snow or rubble can take advantage from preventive data acquisition, such as snow properties, and building materials, allowing the decrease of time-consuming during the real-time working. In fact, in the case of emergency and crisis management, only collaborative information systems can generate effective solutions. The architecture of a detection system, together with specific technologies and appropriate algorithms can decrease delay of rescue intervention and mitigate disaster effects.

Finally, it is worth to recall that European COST Action TU1208 “Civil Engineering Applications of Ground Penetrating Radar” [39] has included a specific project on “Advanced application of GPR to the localization and vital signs detection of buried and trapped people” [40], in order to support actions and foster cooperation among researchers, representatives of manufacturers, and of Governmental agencies in charge. Hopefully such a collaborative environment will provide an effective framework to address the questions that have still to be tackled for an effective deployment of GPR technology in rescuing victims from avalanches and collapsed buildings.

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