

## A RESCUE RADAR SYSTEM FOR THE DETECTION OF VICTIMS TRAPPED UNDER RUBBLE BASED ON THE INDEPENDENT COMPONENT ANALYSIS ALGORITHM

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**Abstract**—This work presents a light-weight microwave system for search and rescue of victims trapped under the rubble of collapsed building during an earthquake or other disasters. The proposed system based on a continuous wave X-band radar is able to detect respiratory and heart fluctuations: the information are extracted from the backscattered electromagnetic field exploiting independent component analysis (ICA) algorithm which provides an efficient noise and clutter cleaning. The proposed rescue radar is enough compact to be mounted onboard of a small unmanned aerial vehicle (UAV) in order to reach inaccessible or dangerous areas. The obtained experimental results show that the proposed detection method is able to successfully locate trapped victims with a reasonable degree of accuracy.

### 1. INTRODUCTION

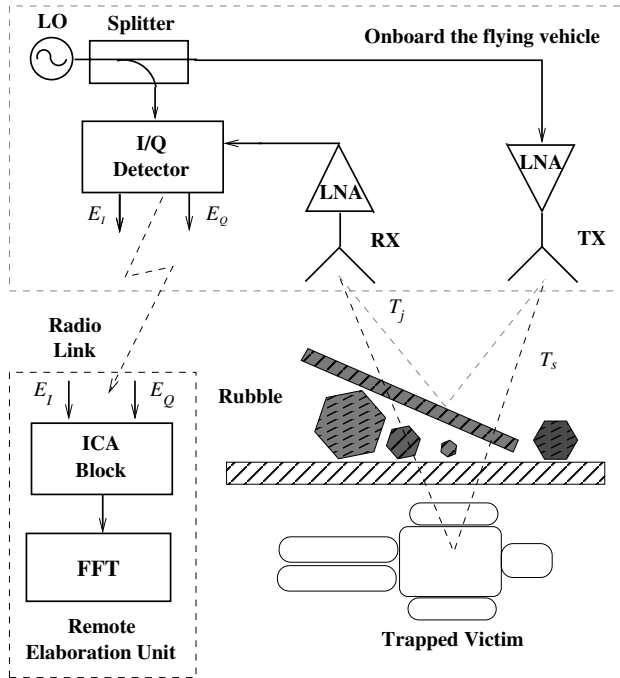
Most of the victims of earthquakes, avalanches or other natural disasters in various parts of the world, including the 2011 earthquake and tsunami in Japan, are people trapped under rubble of collapsed buildings. An early detection of survivors can potentially reduce the mortality rate, so the development of survivors detection systems is desirable. Optical and acoustical life detectors are widely used in search and rescue missions. Optical systems present a limited number of degrees of freedom, require expert operators and cannot be used in inaccessible area. Acoustical detectors such as geophones, are simple to use but they require quiet working environments, a condition

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*Received 12 June 2011.*

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difficult to reach especially in critical situations. Recently, microwave life-detection systems has been developed to remotely detect vital life signals for rescue missions [1–6]. Such kind of problems have been efficiently solved considering continuous wave or ultrawideband radars [7] which offer good localization and spatial accuracy. In rescue mission and also in some surveillance operations there is not only the need of detect life signals but also the identification of people in a given area, to facilitate rescue team operations in case of emergencies. This task can be complied with through the wall surveillance techniques [5, 8–11]. This techniques could be effectively used with efficacy for medical applications like the monitoring of the breathing and heartbeat of critical patients in a clinic. All the cited methods consider the backscattered modulated wave generated when an human body is illumined by an electromagnetic wave. The extraction of information associated to breath and heartbeat signals is possible with an appropriate processing of the backscattered wave [6, 7]. The aim of this work is the design and development of a light-weight microwave detection system based on a compact X-band radar to detect victims trapped under rubble and other obstacles. The life signals are extracted from the modulated backscattered wave by the independent component analysis (ICA) algorithm [12–14], a powerful processing technique successfully adopted to analyze mixed signals and adopted recently in order to analyze brain signals and in particular electroencephalographic (EEG) data [15]. The preliminary experimental results, obtained considering a realistic scenario, are quite promising. The main innovation introduced in this work is the post processing of the data with the ICA algorithm, according to the best knowledge of the author it has never be used before for these kind of applications. The use of the ICA permits to clearly identify life signals despite the low power of the system and the presence of interfering signal sources. Moreover the proposed rescue system make use of a remote elaboration unit for the data post processing, to reduce the complexity of the radio frequency sub-system, the power consumption and consequently to obtain a very light and compact radar. The letter is organized as follows. The procedural schema of the system and the description of the application of the ICA algorithm is reported in Section 2. The description of the system prototype, of the experimental setup and of the preliminary experimental result is described in Section 3. Finally in Section 4, conclusions are drawn and areas of future work are examined.



**Figure 1.** Diagram of the microwave life detection system.

## 2. MATHEMATICAL FORMULATION

Let us consider the schema of the system shown in Figure 1. The main components is a bi-static continuous wave (CW) radar consisting of a local oscillator which produces a sinusoidal signal of 10.45 GHz, a low noise amplifier, and a two patches array as transmitting antenna. The radar irradiates an electromagnetic wave and collect the reflected signal that contains the breathing and the heartbeat information coming from a human detected target. The backscattered signal is received by a two patches antenna, amplified and led to an I/Q detector. The orthogonal detector is mandatory because the ICA [12] requires a number of observation points equal to the number of the original signals and we exploit I/Q signals as two independent sources of information. Then the output I/Q signals are given as input to a remote elaboration system by means of a low frequency wireless channel. As stated previously the amplitude and the phase of the received backscattered wave are modulated in accordance with the movement of breathing and heartbeat. The information associated to amplitude is generally negligible [6] and only the phase variation is considered. The signal

at the receiving antenna can be expressed considering the following relation [4].

$$E_{rx}(t) = A_x \cos\left(\omega_0 \left(t - \frac{2R_s(t)}{v}\right)\right) + \sum_{j=1}^J A_j \cos\left(\omega_0 \left(t - \frac{2R_j}{v}\right)\right) \quad (1)$$

where  $\omega_0$  is the angular frequency and  $v$  is the propagation velocity of the radio waves,  $A_x$ ,  $A_j$  are the amplitudes associated to life signals and rubble respectively.  $R_s(t)$  and  $R_j$  are the round trip distance of the survivor and rubble from the radar system. The second term describes the constant contributes due to the rubble and it can be easily removed with a simple filtering procedure while the first term contains informations related to life-signals. The small movement of the survivor body caused by breathing and heartbeat can be seen as a fluctuation around a mean distance  $R_s$  and modeled at the output of the orthogonal phase detector as  $\varphi_x(t) = (\frac{\omega_0}{v}(R_s + A_b \cos(\omega_b t) + A_h \cos(\omega_h t)))$ , where  $\omega_b$  and  $\omega_h$  are the frequencies due to the breathing and the heartbeat respectively.  $A_b$ ,  $A_h$  are the amplitudes due to the movement of the chest and heart respectively. The weak received backscattered field, which is a mixture of vital signals, noise and clutter contribute, is amplified down-converted with an orthogonal detector, and processed with an analog-to-digital converter. The I/Q signals at the output of the orthogonal detector are led to a remote elaboration unit by means of a low frequency transmission module. The received signals must be post-processed to separate the life signals from the noise and the clutter contribute. ICA algorithm has been chosen to accomplished this task. The ICA is a method for separating mixed data (such as MRI images [13], biomedical data [15], sounds, telecommunication channels or signals) into underlying informational components. The ICA belongs to a class of methods called blind sources separation (BSS). The classical example is two person speak at the same time in a room. Two microphones, placed in different points inside the room collect a mixture of the two voice signals. From these two signal mixtures, ICA can recover the two original source signals. One of the most important fact about standard BSS methods like ICA is that the number of independent source of information (i.e., the receivers) must be greater than the number of overlapped source signals. For the problem at hands this implies that there must be at least two probes to detect the life signals and for this reason we use an orthogonal detector generating  $E_I$  and  $E_Q$  these two signal mixtures collected at the output of the orthogonal phase detector and sent to the remote elaboration system for the post-processing could be expressed











