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A new measurement method for through-the-wall detection and tracking of moving targets

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ABSTRACT

The paper deals with a new measurement method for through-the-wall detection and tracking of hidden targets (e.g. human bodies in rescue missions) in two-dimensional scenes, by using radiofrequency signals. In particular, the method is based on a multisensor system and exploits an advanced imaging technique, which takes advantages from a regularized linear inversion scheme.

Several numerical tests are conducted to assess the performance and capabilities of the method; satisfying values of the difference between estimated and nominal target position are experienced for different investigation domains, number of targets and signal-to-noise ratios. Moreover, experiments in actual measurement conditions and involving a prototype of the multisensor system (based on eleven antennas operating both as transmitting and receiving elements) are also presented, which show the reliability of the method as well as the effectiveness of the implemented measurement strategies.

1. Introduction

In recent years, the demand for security applications has lead to improvements in the effectiveness of safety operations in dangerous situations and to the development of methods for obtaining information about the internal features of rooms or structures, as well as the location of any people present therein [1]. Methods for monitoring and surveillance of borders and perimeters can, in fact, maximize the likelihood of successfully detecting possible intrusions and minimize the number of needed employers. Furthermore, battlefield search, rescue and triage assessments must always be conducted in a manner that minimizes human losses.

Radiofrequency imaging can prove effective in detecting and monitoring the presence of human subjects from a distance and through barriers, such as walls [2–7]. To this aim, two main conditions have to be satisfied. Depending on the electromagnetic properties of the wall, a suitable trade-off between the desired resolution of hidden objects and the permeability of the structure to the used electromagnetic radiation has to be found out. Moreover, the adopted reconstruction algorithms, designed to provide an image of the scene including any moving target of interest, have to operate on the acquired data in a reasonable computational time, which is a fundamental prerequisite to succeed in real-time tracking the position of the targets.

In recent years, several works concerning through-the-wall detection of targets have been presented [8–16]. Even

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though they certainly meet the first considered condition, some of them shows results, either numerical or experimental, based only on nonreal-time measurements methods and achieved in very controlled environments. As an example, the method proposed in [8] takes about 4 h on a personal computer operating at a clock frequency of 2.4 GHz to generate each data frame in simulated experiments, thus preventing its use for real-time security applications. Besides traditional synthetic aperture radars, several examples of fixed-aperture imaging systems have also been proposed. Such systems are, however, heavy, large and expensive, and their operations are based on Vivaldi or horn type antennas (i.e. not easily portable), thus making their use in limited spaces, such as a room or a building very difficult [9].

Ultra Wideband (UWB) is a promising technology for high resolution radars, collision detectors, high data rate communication systems and geolocation devices. The narrow pulse width allows the use of UWB signals in accurate positioning and high-resolution imaging applications [10]. As a consequence, they are usually proposed and adopted in sensors for subsurface imaging applications, due to their capability of penetrating sand providing good measurement resolution [11].

Thanks to the availability of UWB technology, time-modulated UWB (TM-UWB) radars have become even more adopted for through-the-wall imaging applications [12]. It is worth noting that, due to the presence of spurious spectral lines, conventional TM-UWB radars fail to achieve the ideal resolution and detection performance [13]. Recently, some research activities have been focused on noise UWB radars [14], since they achieve better resolution performance than previous TM-UWB radars and grant robust detection in several operating conditions. However, as for all the devices based on a radar approach, they suffer from a stringent requirement in terms of coherent reception at the receiver; assuring coherence over a wide bandwidth results to be not only challenging but also impossible when the transmitter and receiver are physically separated by a distance [15]. Moreover, bi-static and multistatic configurations (usually adopted to improve the coverage performance and assure a distortion free synchronization) become difficult to put in practice for through-the-wall imaging applications. Finally, a problem always associated with through-the-wall systems operating in the frequency range from 1 GHz to 10 GHz is the ubiquitous presence of room reverberations. Their origin relies on multiple reflections of the transmitted signal by the walls, causing numerous false alarms associated with weak targets (i.e. targets whose backscattered signals exhibit low amplitude).

In [16], a compact UWB radar system for indoor and through-the-wall ranging and tracking of moving objects has been built up by using the compact self-grounded Bow-Tie antennas and the low-cost Novelda transceiver. Robust and accurate algorithms for ranging and tracking have been developed. The most attractive aspect of the system is its low-cost and compact size. However, due to its small size, the dynamic range is relatively low, and therefore, only short-range applications are feasible.

Recently, a new framework for simultaneous sensing and compression, referred to as compressive sensing (CS), has received considerable attention and has been successfully applied in many fields, such as signal/image processing, communications, geophysics, remote sensing and radar imaging [17–19]. In [17], through-the-wall imaging by means of impulse radar has been faced within the framework of compressive sensing. Rather than sampling the time-domain signal at or above the Nyquist rate, the random modulation preintegration (RMPI) architecture has been employed for CS projection measurement, and has led to significant data reduction. Target space sparsity has been exploited to solve the TWRI problem using sparse constraint optimization. Numerical imaging results of point-like and spatially extended targets have clearly shown the advantages of using CS in urban sensing applications.

In [18], a compressive-sensing-based through-the-wall imaging algorithm has been presented. Preliminary numerical results have been given regarding relevant issues such as required number of measurements for a given sparsity level, measurement strategy to subsample in the frequency and space domains and imaging performance for different noise levels. Simulations with off-the-grid targets and unknown parameters have been performed, and it has been observed that for small grid sizes or errors in the unknown parameters, the imaging performance is not severely affected, whilst large grid sizes or errors degrade the reconstructed image.

In [19], a sparse tomographic inverse scattering approach for fast data acquisition and 3-D scene reconstruction in TWRI applications has been dealt with. While a combined 2-D sliced approach has been used for 3-D scene representation, the number of degrees of freedom (NDOF) of the scattered field has been exploited in order to choose the number of needed nonredundant spatial measurements. The performance of the proposed scheme has been assessed using experimental data collected from 3-D scattering scenes in a semi-controlled environment. The results have shown that use of a limited number of measurement aperture points, as predicted by the NDOF analysis, reduces the data acquisition time and permits to achieve an image quality comparable with that obtained by using a finer grid of spatial measurements.

In this paper the authors present an innovative method for through-the-wall detection and tracking of the target position in real-time. The proposed method could be a viable alternative to UWB radar, overcoming the related problems due to synchronization and multipath. It requires a multisensor system (i.e. a set of identical transmitting and receiving antennas arranged on one or two lines with uniform spacing), exploits a new linear inverse scattering algorithm, referred hereinafter to as measurement algorithm, and takes advantages of an original tracking algorithm.

The key idea underlying the method is to face the two-dimensional tracking problem in terms of an inverse scattering one. The adopted scattering model (referred to as target-based model, TB-model), in particular, is capable of taking fully into account the complex electromagnetic phenomena related to actual scenes with a reduced