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A method for locating multiple intruders with multistatic radars

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ABSTRACT

In this paper, it is presented for the first time a simple and effective methodology for determining the number and positions of various intruders in indoor environments by using a cooperative network of multistatic radars. Several combinations of transceivers and receivers generate various point estimates of the intruders' positions. It is proposed in this work a statistical procedure that processes the overall cloud of point estimates towards the generation of *spheres of estimates*, which define regions with high probability of containing the intruders. This is accomplished by defining a volumetric discrete probability density function of estimates. The efficiency of the methodology was evaluated by means of FDTD numerical simulations and the intruders were detected and properly located for most of the studied cases.

1. Introduction

In last decades, violence has been increasingly affecting society, causing financial losses for industries, corporations and, in a domestic scale, residences. In order to protect goods, many kinds of security solutions have been developed, such as radar systems for monitoring indoor environments [1].

A widely used technique is based on microwave sensors, which act as radars based on Doppler Effect [1]. However, these devices do not present satisfactory range resolution, given the narrowband signals involved. Thus, these equipment require the areas to be free of objects and foliage [1]. On the other hand, ultra-wideband (UWB) systems are appropriate tools for this task because signals present good resolution, reasonable capability of penetrating objects and improved immunity to frequency filtering (a natural characteristic of radio channels) [1–4]. In [4], it was presented a technique for locating a single intruder by using a single UWB multistatic radar in 2D. In [5], this problem is treated in 3D and a network of multistatic radars, as proposed in [6], is used for improved precision.

This way, the main contribution of this work is to present a technique that estimates multiple intruders' positioning by using a network of UWB multistatic radars. This is accomplished by defining a discrete volumetric density function proportional to a probability density function (PDF) [7] for finding intruders, which is built from the multiple point estimates generated by the multistatic radar system. From the volumetric discrete PDF, computer algorithms are described for finding the regions with higher probabilities of containing the intruder(s).

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2. Basic theoretical analysis and the proposal

2.1. Background theory and the single intruder problem

The electromagnetic wave phenomena are fully described by Maxwell's equations, which are solved numerically in this work by using the Finite-Difference Time-Domain (FDTD) method [8]. All physical aspects are considered, such as wave reflections, diffractions, refractions, delays and the associated media parameters. This way, a pulse transmitted by an antenna is usually received with several additional oscillations (distortions) due to the multiple occurrences of the foregoing effects on the scatterers present in the environment (walls, ground, ceiling and men). If a man moves and a new pulse is transmitted, distortions registered by a receiver are altered from specific time instant on, which is associated to the new relative position of the man to the transceivers and receivers.

This way, by transmitting two pulses (say, 100 ms apart) and then subtracting the pair of signals registered by a given antenna – that is, removing the influence of all static objects – the radar system is able to detect the presence of a man who moved meanwhile.

The instants from which differences are observed (for each receiver and for the transceiver signals) are used to build the radar geometry such as illustrated in Fig. 1 [4–6]. For a 2D case, consider a multistatic radar consisting of one transceiver TX/RX_1 and two receivers RX_1 and RX_2, as depicted in Fig. 1(a). Once the target moves, a new pulse is transmitted and the transient electric field signal measured by the transceiver becomes different from its reference, which is obtained with the target in its original position (Fig. 2). The instant t_o at which this difference is first detected can be used to estimate the distance between the transceiver antenna and the intruder. Physically, the wavefront associated to this difference reaches the target at its second position and is reflected back to the transceiver, which detects the difference in transient signal at time t_o. Therefore, considering that the electromagnetic wave transmitted by TX/RX_1 always propagates at the speed of light (there are no obstacles between the antenna and intruder), the first difference at t_o indicates that the target is at a distance $R = c_o \frac{t_o}{2}$ from the transceiver, where c_o is the speed of light in free space. The locus of all possible intruder's positions that meets this condition is a circumference C centered at the transceiver and of radius R (Fig. 1(a)).

Likewise, the signal registered by receiver 1 differs from its reference signal as of a time instant t_1. After being emitted by the transceiver, the signal propagates through the environment, reaches the target which just moved and is reflected to receiver 1. The signal reflected on the intruder reaches receiver 1 at time t_1. The time instant t_1 is used to build an ellipse E_1, of which foci lie at TX/RX_1 and at RX_1 (Fig. 1(a)). Since C and E_1 intersect at points P_1 and P_2, it is necessary to build a second ellipse E_2 to eliminate this ambiguity (an additional receiver is necessary) [4]. When there are scatterers in the environment (walls, doors, furniture etc), these geometric elements do not intersect at a single point, rather, they bound a region S (Fig. 1) that contains all the possible locations of the target [6]. This region, related to the uncertainty of the problem, arises from the fact that the reduction of the wave's velocity of propagation on its way through obstacles is not taken into account by the process of composition of the geometric elements of Fig. 1, since the obstacles around the surveilled area are not known beforehand. The solution considered for the point estimate is the centroid of region S (Fig. 1), obtained in 2D by means of the Particle Swarm Optimization method [6]. When various antennas are employed (multistatic network), each combination of one transceiver TX/RX_i and two receivers RX_{i1} and RX_{i2} forms a multistatic radar, generating one point estimate.

For 3D problems, the multistatic radar geometric elements – which are one sphere and two ellipsoids (Fig. 1(b)) [5] – and the point estimate (still located at the centroid of region S) are obtained by using the method reviewed in Section 2.2 [5]. A point estimate is calculated for a given transceiver and a pair of receivers. Then, each transceiver is associated to a sphere of estimates, defined in [5] as a spherical region in space with higher probability of containing the intruder for a given transceiver working with each possible pair of receivers. The average and standard deviation of point estimates' positions obtained for a given transceiver are, respectively, equal to the center and radius of its associated sphere of estimates.

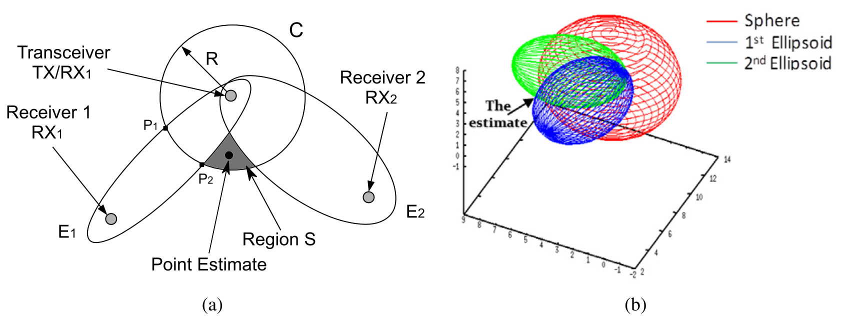

Fig. 1. Multistatic radar composed of one transceiver and two receivers and the point estimate of the target's position at the centroid of region S [6]. The geometric elements generated to find the point estimate are (a) one circumference and two ellipses for the 2D case [4] and (b) one sphere and two ellipsoids for the 3D case [5].