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REGULAR PAPER

Mitigation of the ground reflection effect in real-time locating systems based on wireless sensor networks by using artificial neural networks

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Abstract Wireless sensor networks (WSNs) have become much more relevant in recent years, mainly because they can be used in a wide diversity of applications. Real-time locating systems (RTLSs) are one of the most promising applications based on WSNs and represent a currently growing market. Specifically, WSNs are an ideal alternative to develop RTLSs aimed at indoor environments where existing global navigation satellite systems, such as the global positioning system, do not work correctly due to the blockage of the satellite signals. However, accuracy in indoor RTLSs is still a problem requiring novel solutions. One of the main challenges is to deal with the problems that arise from the effects of the propagation of radiofrequency waves, such as attenuation, diffraction, reflection and scattering. These effects can lead to other undesired problems, such as multipath. When the ground is responsible for wave reflections, multipath can be modeled as the ground reflection effect. This paper presents an innovative mathematical model for improving the accuracy of RTLSs, focusing on the mitigation of the ground reflection effect by using multilayer perceptron artificial neural networks.

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1 Introduction

Wireless sensor networks (WSNs) [4] allow us to obtain information about the environment and act on this, expanding users' capabilities and automating daily actions. Some of the most interesting applications for WSNs are real-time locating systems (RTLSs). The most important factors in the locating process are the kinds of sensors used and the techniques applied to calculate the position based on the information recovered by these sensors. Although global positioning system (GPS) has provided outdoor locating services for almost two decades, and similar systems such as Galileo [27] are currently under development, indoor locating still needs much more development, especially with respect to accuracy, and low-cost and efficient infrastructures [25,33]. There is a need to develop RTLSs that perform efficient indoor locating in terms of precision and resource optimization. This resource optimization includes the reduction in the costs and size of the sensor infrastructure involved in the locating system. In this sense, the use of optimized locating techniques obtains more accurate locations using even fewer sensors and computational requirements [25].

There are several wireless technologies used by indoor RTLSs, such as RadioFrequency IDentification (RFID), wireless fidelity (Wi-Fi), ultra-wide band (UWB), Bluetooth and ZigBee [20]. However, independently of the technology used, it is necessary to establish mathematical models that determine the position of a person or object based on the signals recovered by the sensor infrastructure. The position can be calculated by means of several locating techniques, such as *signpost*, *fingerprinting*, *triangulation*, *trilateration* and *multilateration* [11,20]. However, each of these must deal with important problems when trying to develop a precise locating system that uses WSNs in its infrastructure, especially for indoor environments.

The electromagnetic waves transmitted and received by the wireless sensor infrastructure used by these systems are affected by some propagation effects, such as reflection, scattering, attenuation and diffraction [9]. Due to these effects, the energy of the transmitted electromagnetic waves is substantially modified between transmitter and receiver antennas in these systems. With the attenuation effect, it is possible to estimate the distance covered by a wave between a transmitter and a receiver antenna [2]. This is very useful for building RTLSs based on these distances or based on trilateration [20]. However, reflection, diffraction and scattering effects lead to other problems such as *multipath*, where the expected distance covered by a wave is decreased or even increased due to the sum of the waves reflected off the walls or the objects placed throughout the environment [2]. Indoor locating systems based on the measurement of distances between the sensors and the objects to be located are especially affected by the *ground reflection effect* [9], a kind of multipath propagation effect. Therefore, it is necessary to define new models and techniques that improve the accuracy of these kinds of systems. This paper proposes a new mathematical model aimed at improving the precision of RTLSs based on WSNs, especially with indoor environments. This model uses artificial neural networks (ANNs) as the main component to mitigate the ground reflection effect and calculate the position of the elements. This way, the new model proposes the use of two multilayer perceptron (MLP) ANNs [26,37] to improve the precision of RTLSs. The first MLP can mitigate the ground reflection effect when estimating distances from power signal levels used to calculate the positions of users and objects by different locating techniques. The second MLP then calculates the final positions of users and objects in the environment,