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An artificial neural network approach to the problem of wireless sensors network localization

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A B S T R A C T

One of the imperative problems in the realm of wireless sensor networks is the problem of wireless sensors localization. Despite the fact that much research has been conducted in this area, many of the proposed approaches produce unsatisfactory results when exposed to the harsh, uncertain, noisy conditions of a manufacturing environment. In this study, we develop an artificial neural network approach to moderate the effect of the miscellaneous noise sources and harsh factory conditions on the localization of the wireless sensors. Special attention is given to investigate the effect of blockage and ambient conditions on the accuracy of mobile node localization. A simulator, simulating the noisy and dynamic shop conditions of manufacturing environments, is employed to examine the neural network proposed. The neural network performance is also validated through some actual experiments in real-world environment prone to different sources of noise and signal attenuation. The simulation and experimental results demonstrate the effectiveness and accuracy of the proposed methodology.

1. Introduction

Localization of wireless mobile nodes in wireless sensor networks (WSN) has been widely used in different applications including but not limited to tracking AGVs (automated guided vehicle), robot navigating and large scale metrology [1] among others. Besides the direct applications of localization in wireless mobile sensors, they play a crucial role in the fundamental protocols of wireless sensor networks such as sensor network quality of coverage using the location of active nodes, controlling wireless network topology based on geometric techniques, geographic routing of messages among wireless sensor nodes based on the location of the current node, its neighbor nodes, and the destination node and location information of certain events captured by wireless sensors [2]. Localization refers to the problem of determining the location or position of wireless sensors in the wireless sensor network filed [3].

In this study, we attempt to find the location of mobile sensor nodes in the harsh, uncertain, dynamic, and noisy conditions of manufacturing environments using some beacon nodes called simply beacons or anchor nodes. The locations of the anchor nodes, with respect to a global frame of reference, are known a priori. Among all factors which appear to have significant impact on the performance of the wireless sensor nodes localization in manufacturing environments, we take into consideration noise sources, physical obstructions and ambient conditions for further investigation.

Signal attenuation constitutes numerous phenomena, each of which impact strength of signals in a way. The distance between transducers, the misalignment angle between transmitter and receiver transducer (in case of ultrasonic signals), ambient conditions (especially for acoustic signals), and multipath are among the phenomena that impact the signal attenuation. Path loss model is also affected by the environment. The presence of a plethora of obstacles in indoor environments in general, and manufacturing environments in particular, makes the signal propagation model and path loss model different from open field environments. Obstacles can reflect and diffract signals toward a different direction or even worse scatter them in many directions. The aforementioned phenomena can have both a destructive and a constructive effect on the propagation of the signals. They can cause interference – hence having deteriorative effect – or they can propagate the signals toward areas where there is no clear line of sight. Moreover, the destructive effect of noise sources in a manufacturing environment, including but not limited to vibration sources and diverse electrical and electronic systems, can deteriorate the signal attenuation to an even higher extent. These noise sources eventually beget some measurement errors when the localization of wireless sensor nodes is undertaken.

As discussed, one group of factors which affect the performance of the wireless sensor nodes localization are the ambient

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conditions. The level of humidity, temperature and the medium pressure are three main factors that are particularly important when it comes to sonic and ultrasonic waves.

Finally, among all aforementioned factors, perhaps the most destructive impact on the performance of wireless sensor networks belongs to obstruction. In a typical manufacturing environment, there exist tens or hundreds of machines, workers, conveyors, vehicles and forklift trucks among other solid bodies each of which can be accounted as an obstruction for the carrier waves. The carrier waves which encounter a solid body either go through the new medium and become refracted and attenuated, or return to the originated medium and become deflected, diffracted, and scattered; finally, they propagate in the medium in different directions. In either case, the signal waves may become so much attenuated that they may no longer be perceived by any other wireless sensor nodes.

The novelty of this study lies in investigating the impact of different interfering factors on the localization of wireless sensor networks in indoor environments in general and in manufacturing environments in particular. Subsequently, we present a neural based technique to reduce the impact of the interfering factors on the localization of wireless sensor networks. A simulation study following with statistical analysis is devised to examine the proposed technique's performance in comparison with a conventional trilateration technique. Finally, actual experiments are conducted to validate the performance of the proposed technique in indoor environments. The commonly used cricket devices developed by MIT and produced by Crossbow [4] are employed to perform the experiments.

The remainder of the paper is organized as follows. Section 2 presents some background and literature review on wireless sensor networks in general, localization of wireless sensor nodes, and some industrial applications of wireless sensor nodes localization. The third section sheds light on the problem at hand in more detail. Section 4 elucidates the undertaken approaches and methodologies. Subsequently, the fifth and sixth sections illustrate the simulation study and experimental results respectively. Finally, the last section presents our conclusions and future work.

2. Background

2.1. Wireless sensor networks

The wireless sensors in wireless sensor networks can be categorized based on their ability to move. With this regard, a wireless sensor can be mobile, hence having the capability of changing its position from time to time and as needs arises, or it can be static, thus having always the same location through its life-cycle in the network [2].

In the former scenario, the necessity of localization of wireless sensors is self-evident. The mobile wireless sensors move from place to place collecting data and interacting with the physical environment, and whenever they are within the range of other mobile or static nodes (sink nods for instance) they can communicate the collected data. In general, mobile wireless sensors have all the abilities of a static one, such as sensing and monitoring, communication, and processing, yet they are equipped with the extra potential for changing position. A mobile wireless sensor can either be self-propelled and be in control of its trajectory such as AGVs (automated guided vehicles) or mobile robots, or it can monitor the physical property of interest while being mounted on mobile vehicles or even animals, hence not having any control on the path it is on. In either case, localization plays an imperative role on many wireless sensor network applications and protocols. As a case in point, once an event is monitored by a mobile wireless sensor, the location of the reported event can become of paramount importance.

However, the localization can be even of the same importance in case of static wireless sensor networks. In some application of static wireless sensor networks – especially in large scale outdoor applications such as environment monitoring – the wireless sensor may be deployed on an ad hoc fashion: for instance, they can be spread out in the environment on a random basis without any prior knowledge about their employed locations. In this case, although static, the location of the wireless nodes becomes also important.

2.2. Sensor node localization

Global positioning system (GPS) has been long used for positioning especially in outdoor environments. However, when it comes to indoor applications or outdoor applications with large-scale obstructions, such as dense foliage areas or metropolitan areas with high-rise structures, the GPS system reaches its limits [3,5]. Ref. [2] extensively studies different positioning systems designed particularly for wireless sensor networks. According to the WSN localization technique taxonomy introduced by Ref. [2], the localization techniques are either range-based or range-free. In case of range-based localization methods, the precise distance from the wireless sensor node of interest to other wireless sensor nodes in general and to reference nodes in particular is estimated and then employed to find the location of the wireless sensor node of interest. The reference nodes whose locations are known a priori and have the capacity to send/receive beacon messages to/from other nodes are referred as anchor nodes or sometimes beacons. On the other hand, in the range-free methods, only a coarse approximation of the distance between nodes is used to estimate the whereabouts of a wireless sensor node. The latter techniques are usually more cost efficient and require less complex hardware [2].

The range-based techniques can be further classified into two categories, namely methods with anchor nodes and methods without anchor nodes. The former, refers to the methods employing anchor nodes, the position of which is known a priori, and are able to find the absolute location of the wireless sensors with respect to a global frame of reference. On the contrary, in the latter approach, the anchor nodes are not used. Thus, the relative locations of the wireless sensors with respect to a local frame of reference are of interest. For further information about range-based techniques, one may refer to reference [2].

The range-free techniques can be also categorized into two main classes: hop-count-based methods and area-based methods. It is noteworthy that methods in this category can estimate a rough approximation of location of wireless sensors. The former technique is especially suitable for multiple-hops networks. That is, if the network field is too large for the wireless sensors to communicate directly with the anchor nodes, some other sensors can relay the messages from the wireless sensor in the origin to the anchor nodes. The hop-count-based techniques count the number of hops it takes to relay the message from a wireless sensor to an anchor node and then multiply it by the average size of one hop to the anchor node (in terms of distance) to calculate the approximate distance from a particular wireless sensor to an anchor bode. Although producing approximate location of the wireless sensor nodes, this class of techniques is cost efficient and does not require complex hardware [2].

The second class of range-free techniques is area-based methods. In this class of methods, instead of providing the location coordinates of a wireless sensor, the area/region in which the wireless sensor is deployed is given. The logic behind these techniques is that in many applications, there is no need to determine the exact coordinates of a wireless sensor, instead only the area that the wireless sensor node