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A Novel Distance Measurement Approach Using Shape Matching in Narrow-Band Ultrasonic System

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Abstract: Nowadays, a large number of novel technologies and systems are invented in order to solve the problems of Indoor Positioning Systems (IPS). One of the most well-known and common positioning technology is ultrasound. The zero rooms' leakage, low cost, scalability, reliability, and less complexity in hardware and computing are the main advantages of ultrasonic systems. However, existing ultrasonic systems are hampered by many problems such as uncertainty and reduced robustness. This paper contributes an approach with the intention of improving distance measurement for indoor robot positioning by using an ultrasonic sensor. In the proposed method, start point of received signal will be determined more precisely.

Keywords: Ultrasonic system, correlation, lateration, accuracy, indoor positioning.

1. INTRODUCTION

Positioning refers to the process with the aim of tracking and provide the location of humans or objects in a determined area by a system. In other words, it is a distance with the direction. Positioning systems are divided into two categories: 1) an outdoor positioning system which is used for global coverage with meter accuracy, and 2) an indoor positioning system that is applied inside a limited region such as a room or building. Satellite-based Global Positioning System (GPS) which is the most well-known outdoor positioning system provides good accuracy (3 meters horizontal accuracy) in outdoor applications as stated by Ijaz et al. (2013). Required accuracy of positioning is variable, depending on demands and applications. So, this technology is inaccurate in indoor applications, calling for new methods of measuring indoor positioning. In the last decade, the need for indoor positioning has rapidly increased, therefore indoor localization systems and techniques fall under researchers' observation. In field of robotic, positioning and localization is a fundamental topic on account of safe movement, near-miss detection, collision, as well as costs.

There are not any certain and reliable procedures for finding the position inside of a building due to multiple factors, including non-line of sight, singularity, influence of temperature, moving objects, and reflection of walls and objects. According to Kitanov et al. (2007), Aitenbichler and Muhlhauser (2003), Zhang and Ghosh (2000), Hallberg et al. (2003), Caruso (2000), as well as Mandal et al. (2005), current technologies used for indoor positioning systems include visual techniques which are based on measuring the image coordinates, infrared that is available in board of most of systems, laser which generates light through a process of optical amplification, radio frequency with wide range of utilization, magnetic systems used for device heading, and Sound divided into Audible and Ultrasound. As expected, these technologies have various applications, measuring principles, coverage areas, costs, and accuracy.

Among the mentioned indoor positioning systems, the ultrasonic system has some advantages which make it more interesting such as cost effective means, reliability, scalability, and low power consumption. In systems trying to find the robot position using lateration, having accurately measured distance between the robot and some fixed beacons is crucial to produce meaningful position values. Previous approaches by ultrasonic systems failed to localize the first point of a signal generated through the transceiver in order to minimize localization error for a robot. Usually, they apply to assume the first point of signal or to define a threshold that did not cover it. To meet the aforementioned problem, a method will be introduced to indicate the first point of signal in the receiver. The remainder of the article is organized as follows: the previous ultrasonic positioning systems are first investigated. Then our measurement improvement method, objectives and problems will be presented. The results of our experimental results are illustrated in section V and final section covers the conclusions.

2. PREVIOUS WORKS

There is a huge number of positioning systems. In general, the positioning system architecture/ configuration can be divided into three main sections. The first sec-

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tion is Positioning algorithms and methods referred to as processes or mathematical algorithms used in order to obtain the reliable or usable information from raw data. Some methods used by previous systems are dead reckoning (divided into odometry and inertial navigation), centroid, pattern matching (divided into scene analysis and map matching), land mark navigation, polar point, proximity detection, and lateration. The second section is methods which are applied for measuring the physical quantity of signals and are known as measuring methods. There are several measuring methods such as Angle of arrival (AoA), Doppler ranging, Near-Field Electromagnetic Ranging (NFER), Phase of Arrival (PoA), Received Signal Strength (RSS), Round-Trip Time (RTT), Time of Flight (ToF)/ Time of Arrival (ToA), as well as Time Difference of Arrival (TDoA). The third section is hardware and positioning technologies that is based on a specific device and technologies. The devices generate the signals like US, RF, etc. Each signal contains the specific information transmitted from transmitter to receiver. In this article, ultrasonic system has been focused.

Ultrasound is the sound with frequency from 20 kHz to several GHz that is out of human hearing range. In this system, distance is calculated by knowing the time and acoustic velocity. However, environmental conditions such as temperature, humidity, etc. can influence the velocity which directly causes errors in calculation of distance as identified by Leighton (2007). According to works in Zungeru (2013) and Wehn and Belanger (1997), there are some advantages offered by ultrasonic in comparison to the other techniques. The ultrasonic response time is fast (a few milliseconds). In addition, the system is very sensitive to any movement and can detect displacement more quickly. In order to discover the objects, contiguity is not needed. Moreover, the ultrasound wave is reliable and due to its nature, inaudibility and invisibility, it is user friendly.

The narrow-band ultrasound systems can be divided into three categories according to their structures. 1) Passive system, 2) Active system, and 3) Echolocation. In passive system, emitters are fixed in certain places on the wall or ceiling and receivers are integrated with the moving objects like in Bat system. The active system's structure is reverse such as cricket system. According to demands, numbers of receivers are installed in known locations and transmitters which are located on the robot are sending the waves. In the system based on Echolocation, transmitter sends sound pulses and uses the returned echoes for locating objects. Therefore, beacons are not needed anymore which has been noted by Mautz (2012). Reijniers and Peremans (2007) and Wan and Paul (2010) deployed mentioned system in their proposed methods. Some well knwon narrow-band positioning systems are Bat system, Cricket system, Buzz system, and DOLPHIN which are compared in table 1.

The method in order to improve the Cricket system introduced by Piontek et al. (2007). In the cricket system, there are two disadvantages which are addressed by this method. First one is due to limited bandwidth of ultrasound transducer, finding the exact edge of signal is hard. The other one refers to cricket update rate which causes low accuracy in finding the position. In order to solve the first one, a technique for compaction of impulse is recommended although transmitting a short pulse may cause mis-detections. As a solution two methods are introduced: 1) Making a high power pulse and 2) providing weaker and longer pulse. For improving update rate, time division multiple access (TDMA) is implemented in order to synchronization of beacons.

Marantos et al. (2008) proposed a system similar to cricket, in which ultrasonic and RF signals are simultaneously transmitted by a robot. Therefore, wireless sensor nodes, which are equipped with ultrasound receiver, receive these signals and after computing distance, data is send to a robot. In this case, robot estimates its position according to the clustering technique. The results of practical study show an error of 5%.

In Kitanov et al. (2009), position and orientation of the robot are detected by using combination of RF ultrasound transceiver system with the dead reckoning method. The benefit of system is that just one listener is required at time in order to determine robot position. In experiments, positioning accuracy of 1±2.5 cm and orientation accuracy of 1±2 degree are obtained.

A novel motion capture system is suggested by Sato et al. (2011). The distance between device and the moving item is measured via introduced method called Extended Phase Accordance Method (EPAM). In order to achieve a better result, system is implemented in a Field Programmable Gate Array (FPGA). Nevertheless, two experiments are performed and an error of 55 mm and standard deviation of 42 mm are announced for the body motion.

Localization of Sensor Nodes by Ultrasound (LOSNUS) system is introduced by Schweinzer and Syafrudin (2010) that is planned for static device localization. The accuracy of 10 mm with 10 cycles/sec locating rate is reported. In this system, time differences of arrival is applied for calculating the location of the device especially in a Wireless Sensor Network.

Ruiz et al. (2013) applied merging of odometer sensor information and ultrasonic beacons positioning data in order to obtain the localization with regard to H-Infinite filter. The mentioned ultrasonic beacons build an Ultrasonic Local Positioning System (ULPS) and a group of them form the vast ULPS, so all parts of experimental region can be covered. UlPS consists of five beacons which send ultrasound concurrently. A receiver is mounted on the mobile robot and receives these waves. With regard to avoid the collision, Direct Sequence Code Division Multiple Access (AD-CDMA) methods is implemented. Accordingly, odometer errors which are stored during the pass are adjusted via ULPS. According to recommended codification techniques, a mean error of around 3 cm with 4 mm deviation is reported.

In Yazici et al. (2011), a system for indoor robot applications is applied. The system which is called ultrasonic based positioning system (SESKON) is just based on the ultrasound signal. The method of Time Difference of Arrival (TDOA) for calculating the position is employed, so clock synchronization and start time of transmission are not needed. The time of 70 ms is considered between broadcast waves. In the mentioned system, three trans-