Scalable, Low-Cost Indoor Localization System using TDoA and UWB

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ABSTRACT

We use a network of commercial ultrawideband radios with highly accurate message timestamping as the basis for our real-time indoor localization system. The fixed anchors are wirelessly synchronized to within a nanosecond in order to report the arrival time of tag transmissions in a common timebase. A centralized location engine uses time-difference of arrival in order to calculate the position of tags with a precision of 20 cm 1σ. The system has been designed to support a large number of mobile tags while keeping capital costs and operating costs low.

Keywords

RTLS, UWB, TDoA, wireless synchronization

1. INTRODUCTION

We have developed a real-time location system (RTLS) to track the positions of a large number of objects inside large industrial buildings. Physical deployment of this system involves affixing battery-powered tags to mobile targets and mains-powered anchors to fixed infrastructure. Capital costs of installation are minimized by employing semi-automated self-calibration and wireless time synchronization among anchors. Commercial off-the-shelf (COTS) microcontrollers and ultrawideband (UWB) transceivers keep scaling costs low while providing sufficiently high position accuracy. A centralized time-difference of arrival (TDoA) algorithm achieves good scalability and minimizes power requirements, allowing for long battery life and thus low operating costs.

2. SYSTEM ARCHITECTURE

Our system uses a set of fixed anchor nodes whose positions are determined during installation and whose clocks are regularly and wirelessly synchronized during operation. New installations run through a self-calibration procedure in which the 3D positions of anchors are calculated using a semi-automated algorithm aided by a requisite number of ground truth references. During RTLS operation, the tags periodically transmit blinks that are received by a varying number of anchors. The time of arrival (ToA) of these blinks are reported in real-time to a common anchor (that we call a "collector") and in a common timebase. The collector reports all ToAs to a centralized location engine, which uses TDoA to convert the set of timestamps recorded by the anchors at various known locations into the 3D positions of the originating tag.

2.1 Hardware

We use a COTS microcontroller to communicate with the DWM1000 from Decawave over a dedicated SPI bus operating at 20 MHz. A custom PCB joins the two surface-mount modules and various passive components while supplying a regulated voltage. The entire system consumes <1 W when operating at full power. The anchors can be battery powered but are generally mains powered. Anchors have no other wired connections with the exception of one serving as a gateway for accessing the location engine, which may be local or remote. The tags are battery powered and enter a low-power sleep state between blink transmissions.

2.2 Software

2.2.1 Wireless Medium Access

Anchors have the ability to communicate with any other anchor, so time division multiple access (TDMA) is employed to effectively eliminate packet collisions among anchors. Tags are power optimized to transmit blinks periodically with a slight randomization but without consideration for current medium traffic, an approach known as pure ALOHA.

2.2.2 Anchor Self Calibration

Before running real-time TDoA, the positions of each anchor must be determined accurately in 3D. This is sometimes performed in industry using automated or manual laser-based systems. Our approach uses a calibration procedure in which every anchor discovers and subsequently performs two-way ranging (TWR) with every other visible anchor on a round-robin schedule. A few ground-truth references must be supplied to define the origin and orientation of a local coordinate system. These degree-of-freedom constraints are combined with the inter-anchor ranges in a nonlinear optimization process to solve for the unknown anchor coordinates.

2.3 Real-Time Localization

At the core of the TDoA system is the synchronization of anchor clocks to report tag blinks in a common timebase, as any variability in the clocks introduces a bias in the calculated position. The anchors distribute synchronization messages to estimate the relative clock offsets and achieve a 1σ relative error of 0.2 ns with the standard 30-ppm clock of the DWM1000. This process runs regularly to account for the clock drift and frequency drift, that vary mainly with temperature, but also with voltage and time to a lesser extent. The location engine uses a nonlinear optimization algorithm to perform the TDoA multilateration and achieves a 1σ precision of 20 cm.

3. SCALABILITY

Since the transceivers share a common radio frequency for sending and receiving, system scalability is determined largely by the total transmission time required to calculate a single 3D position. Localization systems based on two-way ranging (TWR) require many message exchanges for each position, limiting scalability and battery life. Furthermore, multiple ranges are collected over a finite duration, degrading accuracy with increasing velocity. Our solution uses time-difference of arrival (TDoA) in which 3D positions can be generated from a single tag transmission, keeping the channel open for more transmissions, and supporting all practical tag velocities (up to perhaps 1 km/s) with no effect on accuracy.

Our submission to the 2017 Microsoft Indoor Localization Competition uses up to 10 anchors and requires only 1 tag. Since the system was designed for scalability, these same 10 anchors could support 20 blinks/s, which could be 1 tag at 20 Hz, 20 tags at 1 Hz, and so on. While currently unproven, we believe that the system can be further tuned to support on order of 100 blinks/s or more with some modification to the anchors.

4. CONCLUSIONS

Our localization system was designed to track the location of many objects using mobile battery-powered tags and fixed mains-powered anchors with a sufficiently high position accuracy for typical use within industrial buildings. Wireless communications among installed infrastructure coupled with a self-calibration procedure reduces capital expenses while power-efficient and low-cost hardware keep operating expenses low.