SpinTrack: Spinning Infrastructure Nodes for Precise Indoor Localization

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ABSTRACT
We propose SpinTrack, a localization system enabling accurate tracking of both stationary and moving targets in the indoor environments. SpinTrack integrated two complementary methods, SpinLoc (for tracking stationary targets) and dTrack (for tracking moving targets) into one localization system. We propose how to eliminate the transitional overhead between the two methods in order to optimize the overall system performance.

Keywords
Sensor Networks, Spinning Beacons, Doppler Effect, Angulation, Localization

INTRODUCTION

Location is often essential contextual information in UbiComp applications for inferring high-level application semantics from low-level data collected from wireless sensor networks (WSNs). Although GPS is used for tracking in the outdoor environment, it performs poorly and inaccurately in indoor environments due to lack of direct line-of-sight to GPS satellites. Current indoor localization systems employ varying methods to achieve sub-meter positional accuracy such as ultra-wideband (UWB) [5] and ultrasound [4]. However, UWB-based systems such as Ubisense [5] require specialized, expensive hardware to achieve highly accurate, nanosecond time synchronization. Ultrasonic based systems are limited by short propagation range and uninterrupted line-of-sight. Received Signal Strength (RSS) Fingerprinting based systems, such as Ekahau [2], have recently gained popularity due to low deployment cost, but their positional accuracy is in the range of 2-5 meters and does not reach sub-meter range for high accurate indoor localization.

A promising localization system developed by Kusy *et al.* [3], called dTrack afterwards, provides an inexpensive and highly accurate method for highly accurate indoor location tracking. The method is based on a moving target transmitting RF signals, in which the movement of the target produces Doppler shifts observed by the stationary receive-nodes in the infrastructure. The observed Doppler shifts can then be used to estimate the direction of a moving target. However, since the dTrack technique relies on the movement of the target to generate distinguishable Doppler shift, it cannot locate stationary or slow-moving targets. To complement the dTrack technique, the SpinLoc system [1] has been developed that uses spinning beacons, in which the spinning motion produce Doppler shifts to locate stationary or slow-moving indoor targets. Experimental results reveal that the SpinLoc system can achieve a medium error of 39 centimeters and 90% error of 70 centimeters.

We would like to integrate these two complementary methods, SpinLoc and dTrack, into one location system, called "SpinTrack", which enables accurate tracking of both stationary and moving targets in the indoor environments. A key challenge in this integration is to eliminate the transitional overhead and allow for simultaneous execution of both SpinLoc and dTrack methods to track both stationary and moving targets within the same environment. Note that an unacceptable method with a long switching latency would be to attach an accelerometer on a target. When the accelerometer reading indicates high/low motion, the target would trigger the infrastructure location system to switch between SpinLoc and dTrack accordingly. The remote triggering to the infrastructure yields unacceptable delay.

To enable simultaneous execution of both SpinLoc and dTrack, we propose to reverse the signal sender-receiver setting in SpinLoc to match the sender-receiver setting in dTrack, i.e., infrastructure nodes are receivers and targets are senders. Having the same sender-receiver setting eliminates the extra calibration and computational overheads in switching the sender-receiver mode on the nodes, thus reducing the positioning latency. However, reversing the sender-receiver setting requires some algorithm changes in SpinLoc. Therefore, a brief overview of SpinLoc is first described, followed by explanation of our proposed algorithm change to SpinLoc to enable sender-receiver reversal.

SPINLOC OVERVIEW

SpinLoc employs spinning beacons anchored in the infrastructure to produce predictable and distinguishable Doppler signals for high precision localization of stationary or slow-moving indoor targets. Two phases of the SpinLoc method are angulation and localization. The angulation phase measures the Doppler signal from a target and a reference node to a spinning beacon. The difference in observed Doppler shifts reveals the angle between the target and the reference node to the spinning beacon. Such angulation is applied repeatedly to several different spinning beacons. The location of the reference node, the location of the spinning beacon and the estimated angle are then used to determine the probable position of the target. The position of the target can be found by intersecting lines drawn from estimated angles to different spinning beacons in the localization phase. Figure 1 shows the SpinLoc system deployment in a parking garage.

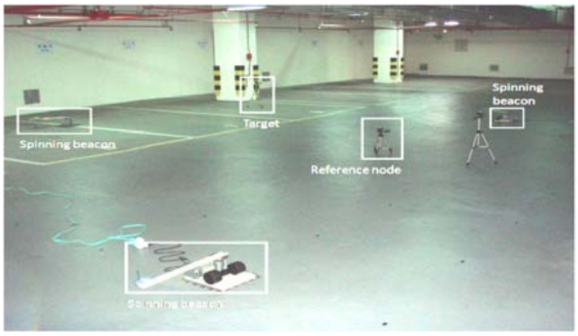

Figure 1. SpinLoc system deployment in a garage.

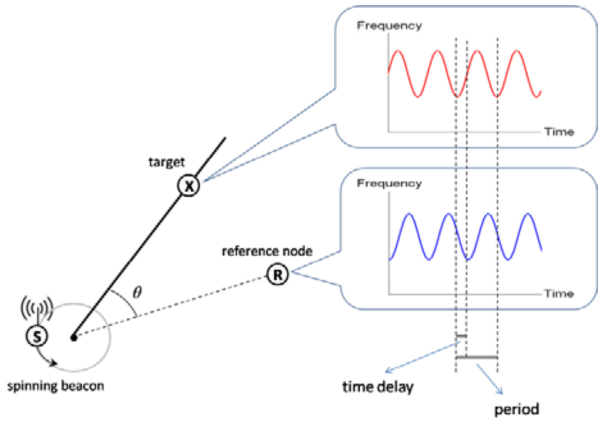

Figure 2. SpinLoc angulation phase.

Figure 2 depicts SpinLoc angulation phase. While the spinning beacon *S* is transmitting Doppler signal, the target *X* and the reference node *R* simultaneously observe the signal frequency. The angle between *X* and *R*, i.e., θ, is derived from the period and the time delay between two frequency waveforms as follows.

$$\theta = \frac{time\ delay}{period} \cdot 2\pi \qquad (1)$$

A line indicating the position of *X*, called *orientation line*, can thus be drawn from *S* based on the know locations of *S* and *R*.

PROPOSED APPROACH: SPINTRACK

The main difference between SpinTrack and SpinLoc is the angulation phase. All spinning nodes, i.e., the spinning receivers, measure the Doppler signal to the target and to the reference beacon. To some spinning node, the difference in observed Doppler shifts reveals the angle between the target and the reference beacon to the spinning node. The position of the target can be found from intersecting orientation lines to different spinning nodes in the localization phase.

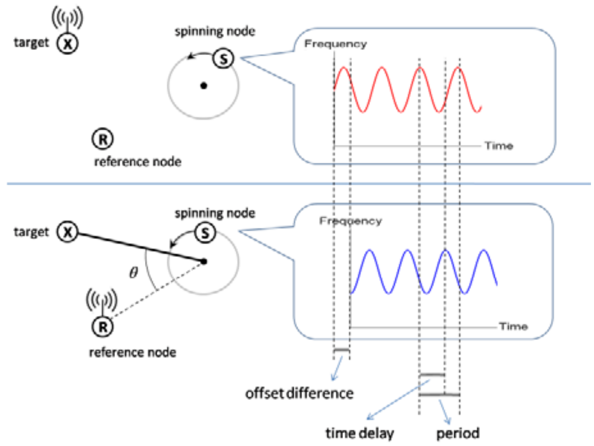

Figure 3. SpinTrack angulation phase.

Figure 3 depicts SpinTrack angulation phase. The target *X* and the reference beacon *R* transmit signals at different times. Then the spinning node *S* observes their signal frequencies to obtain two frequency waveforms. Due to different rotational offsets, these two frequency waveforms have an offset difference, which contributes to the time delay between two frequency waveforms. The derivation of the angle between *X* and *R*, i.e., θ, is thus modified with an extra term *offset difference* as follows.

$$\theta = \frac{time\ delay - offset\ difference}{period} \cdot 2\pi \qquad (2)$$

In order to measure offset difference, *S* additionally records the timestamp at the beginning of frequency observation each time. The offset difference is the remainder of the elapsed time between transmission of *R* and *X* divided by the period. With the angle between *R* and *X* to each spinning node, the position of *X* can be found from intersecting all orientation lines.

FUTURE WORK

We will prototype the integrated system and conduct evaluation in a real-world environment.

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