Experimental Investigation of Chirp Spread Spectrum-based Swarm Sensors for Construction Resource Tracking

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ABSTRACT

Emerging wireless sensing technologies hold great promise for improving construction resource tracking operations. Unfortunately, the accuracy and reliability of these sensing technologies as well as their interactions with the dynamics of the construction environment is still not well understood. Existing deployments of these sensing technologies are based on isolated tracking applications rather than adaptive interaction with the construction process. This adaptive interaction can be enhanced using Chirp Spread Spectrum-based swarm sensing systems capable of triggering collective and organized behavior amongst construction resources: a key characteristic of cyber-physical systems. This paper presents an experimental investigation of the performance of a commercially available swarm sensing system on the construction site. This sensing system consists of sensors capable of interacting and communicating with each other without the need for stationary transceivers. A case study is presented to demonstrate the benefits and functionality of the sensing system. The results show that Chirp Spread Spectrum-based swarm sensing systems offer tremendous opportunity for future cyber-physical systems applications in the construction industry.

INTRODUCTION

Tracking the context of construction resources is significant for a number of key project performance management strategies such as safety and productivity analysis. Emerging wireless sensing technologies such as imaged based (cameras and laser scanners) and component based (the ultra-wide band (UWB), radio frequency identification (RFID), and global positioning system (GPS)) holds great promise for providing these context related information. However, the image based techniques can only track resources within their field of view while, the component based tracking devices require pre-installation of receivers/readers around the activity or observation area (Cheng et al. 2011). The receivers are usually positioned in such a way as to ensure maximum signal strength at the nodes or tags. This configuration will likely change as a result of the dynamics of the construction site environment; thus, requiring continuous positioning of the receivers throughout the project.

Chirp Spread Spectrum (CSS) based swarm sensing system is a new radio frequency positioning system which consists of nodes capable of ranging to each other without the need for stationary transceivers. These nodes have integrated transceivers and receivers and unlike the UWB technology, the nodes can be battery powered thus, enhancing their mobility on the jobsite. Each node can be programed to enhance adaptability to specific applications (a key feature of cyber-physical systems). In spite, of the potentials of the (CSS) based swarm sensing system, one of the perceived barriers to the deployment of the system in the construction industry is the lack understanding of its effectiveness and application on construction projects. Therefore, there is need to evaluate the effectiveness of the (CSS) based swarm sensing system on the construction site as this will provide insights into specific application scenarios, limitations and opportunities for enhancing their functionality.

This paper presents preliminary research efforts on evaluating the effectiveness of a commercially available CSS based swarm sensing system for construction application. The paper describes the CSS based swarm sensing system and experimental results illustrating the system performance on the construction site.

BACKGROUND

Over the years, the need for project visibility, improved project productivity and safety record, reduced project delivery time and cost has warranted increased investigations into the use of emerging wireless sensing technologies for construction resource tracking. The choice of a particular sensing technology depends on the calibration requirements, the specific application, line of sight requirements between sensors, the required signal strength and the type of data provided (Cheng et al. 2011). The GPS has been used for variety of construction applications such as vehicle and equipment tracking. It's widely known that GPS application is most suited for the outdoor environment. The RFID technology is majorly categorized as active and passive technologies. Although, the passive tags are limited in range of coverage, they are cheaper than the active tags. Some of the active tags have location sensing capability (also known as RFID-RTLS system) and this makes them suitable for real-time construction resource tracking applications. Compared with the UWB, signal attenuation and multipath intensified by mobile obstacles are the main challenges of using RFID-RTLS systems on construction sites (Lee et al. 2011). Using the RFID-RTLS and UWB technologies, position tracking is achieved by establishing a referenced radio frequency environment, made up of a series of receiver nodes, and by assigning a sensor to each tracked resource. The sensor receives and transmits signals from/to the receiver nodes. Locating a node involves a collection of location information from radio signals traveling between the reference nodes and the tagged resource. The dynamic nature of the construction site makes the deployment of fixed anchor nodes a limitation. For diverse tracking applications, the position of the anchor nodes will have to be changed to meet the signal requirements of the coverage area.

The accuracy of the above described sensing technologies also depends on their localization technique. This techniques can be classified by the Received Signal Strength (RSS), Time of Arrival (ToA), Angle of Arrival (AoA) and Round trip Time of Flight (RToF). The propagation model of the RSS is usually sensitive to disturbances such as diffraction, reflection and multipath effects. The signal strength depends on obstructions, partitions, and moving objects; these makes RSS difficult and sometimes impossible for use in indoor environments. The conventional RFID technology is based on the RSS technique. The AoA uses triangulation to determine the position of objects from fixed anchor nodes. The disadvantage of this AoA is that it requires an expensive antenna configuration for effectively measuring the angle of sensor nodes to the anchor nodes signals. The RToF and ToA determine the range of sensor nodes to anchors by measuring the signal propagation delay. The UWB technology particularly uses the ToA because of its large bandwidth (> 600 MHz) which provides a high ranging accuracy.

Furthermore, the CSS is a new radio frequency for positioning systems by using IEEE 802.15.4a in a wireless personal area network (WPAN) and is enriched by the 802.14CSS constraints. CSS has advantages over previous methods based on radio signals. Other localization systems that are based on Received Signal Strength Indicator (RSSI) (Bahl and Padmanabhan 2000; Swangmuang and Krishnamurthy 2008) have issues such as high initialization cost, measurement errors, and security issues, which are not present in CSS. CSS offers a speed of about 2 Mb⁄s and fast data transmission available on 2.45 GHz; that makes it possible to merge with other wireless systems for providing location awareness. The signal transmission distance is about 0.621371 mi, and power consumption is low (1 W to 100 mW) (Lee et al. 2011). Another key feature of the CSS is that it compromises the weaknesses of traditional ranging techniques using time of flight for signal between two devices, distance estimation error from hardware clock drift, and signal interference by Symmetrical Double-Sided Two-Way Ranging (SDS-TWR). In comparison with the UWB and RFID technologies, the CSS based sensors have a higher robustness against multipath effects and environmentally caused distortions (Bastani 2009). These specifications inspire the potential of employing the CSS based sensor in the construction field for location awareness.

CHIRP-SPREAD SPECTRUM BASED SWARM SYSTEM

Node Specification. The CSS based swarm sensing system developed by Nanotron Technologies, consist of wireless swarm nodes (Figure 1) which are able to communicate and determine their distance to one another without the need for fixed anchor nodes. The distance between two swarm nodes is determined using the SDS-TWR. SDS-TWR estimates the distance using RToF symmetrically from both nodes. Both the ranging methodology and wireless communication are integrated on a single chip in each node and operates at 2.5 GHz frequency. Each node has a dimension of 83 x 75 x 18 mm and weighs 37 grams. The range of the tags can be up to 500m. The nodes have the option of being battery powered using a 2.5-5V rechargeable battery or through a USB connected to the computer.

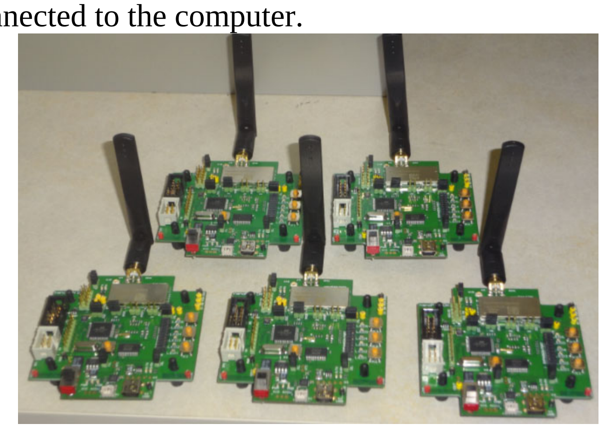

Figure 1. Nanotron swarm nodes (swarm of 5 nodes)

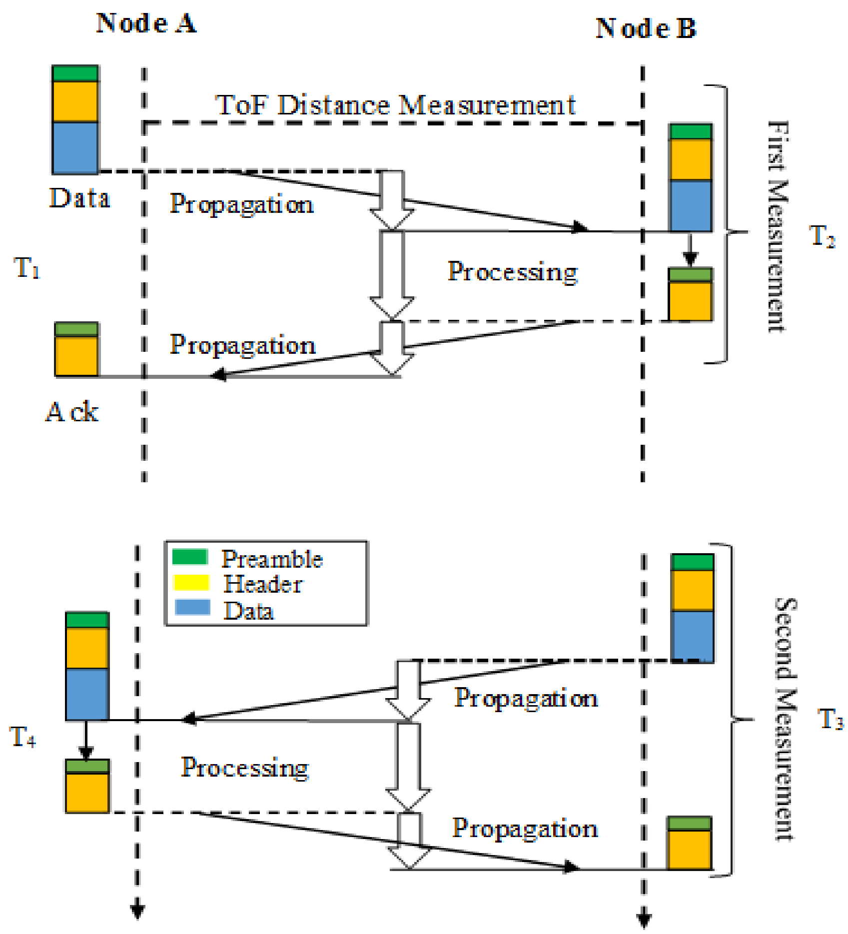

Figure 2. Symmetrical double-sided two way ranging (Röhrig et al. 2012)

Symmetrical Double-Sided Two Way Ranging. The SDS-TWR technique uses two delays which usually occurs in signal transmission to determine the distance or range between two nodes (Figure 2). The SDS-TWR technique estimates the round trip time and avoids the need to synchronize the clocks. To start time measurement, Node A initially sends a package to Node B. Node B commences its measurement when it receives the packet from Node A and ends, when it sends it back to Node A. As soon as Node A receives and acknowledges the packet from Node A, the accumulated time values from both nodes are used to estimate their range. In order to prevent the issue of the clock drift, the range measurement is computed twice and symmetrically.

Swarm Interaction. The nodes can exhibit three different types of behavior: active, passive and sniffer (shown in Figure 3). The active radios initiate ranging requests and are able to communicate with one another. The passive nodes listen for ranging requests from the active nodes and respond. They do not initiate requests. The sniffer nodes collect information or activities from the swarm and sends these to the host. The swarm nodes are controlled through an application programming interface (API) by a host controller. The API enables ranging between any of the nodes in a swarm. On making the ranging request, the API is programmed to return an error code which indicates the success or failure of the node in executing the request.

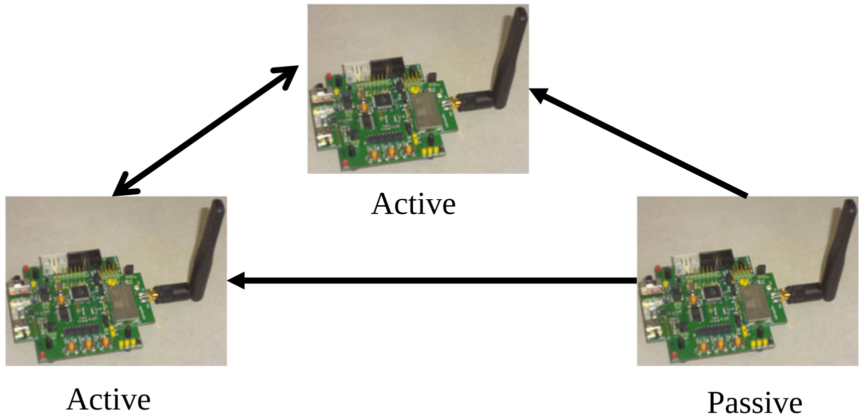

Figure 3. Overview of swarm system interaction

RESEARCH OBJECTIVE

The research objective is to evaluate the effectiveness of a commercially available CSS based swarm sensing system in providing the range between swarm nodes attached to construction resources by examining a number of application scenarios. One of such applications includes the use of CSS based swarm sensing system in collision avoidance between equipment and construction personnel.

EXPERIMENTAL SETUP

The experiment was designed to evaluate the performance of the CSS based swarm sensing system in both the outdoor and indoor construction environments. Prior to commencing the experiments, the nodes had to be activated in order to function effectively in the swarm. This activation only needs to be performed once. The nodes were activated using a swarm ranging demo application (from Nanotron technologies). Two nodes was utilized for the experiments. Using the swarm ranging application, each node was assigned an identity (ID) number in order to distinguish between the nodes. Each node was also assigned other attributes shown in Table 1.

Table 1. Swarm Node Settings.

Commands	**Node 1**	**Node 2**
SetNodeID	000000000001	000000000002
SetNodeType	Active	Passive
RangeTo	000000000002	None
SendDataTo	N/A	000000000001
SetBroadcastNodeID	N/A	Yes

Node 1 was connected to a computer via a USB cable. Since Node 1 exhibits an active behavior, it is expected to range to node 2 and transfer the range data to the computer via the USB.

For the outdoor experiment, Node 1 was attached to a pay loader while Node 2 was attached to the helmet of a construction worker as shown in Figure 4. On executing the swarm demo application, the range of Node 2 from Node 1 was collected in an excel file in the computer. The swarm application was programmed to collect range data every 500ms. The construction worker was assigned to four different positions around the pay loader and for each position, the range data was documented.

In the indoor environment, the position of a Wacker Neuson wheel loader in relation to a construction worker was measured (Figure 5). Node 1 was attached to the wheel loader and Node 2 was attached to the helmet of the construction worker. The construction worker was also assigned to four different positions around the wheel loader and for each position, the range data was documented.

Alongside the measurements taken with the CSS based swarm system, a Total Station was utilized to record the ground truths of each swarm node for both the outdoor and indoor experiments. A 360^0 mini prism was attached to the construction worker's helmet (beside the Node). The Total Station measurements was taken, in order to understand the amount of error associated with the CSS based swarm system measurements.

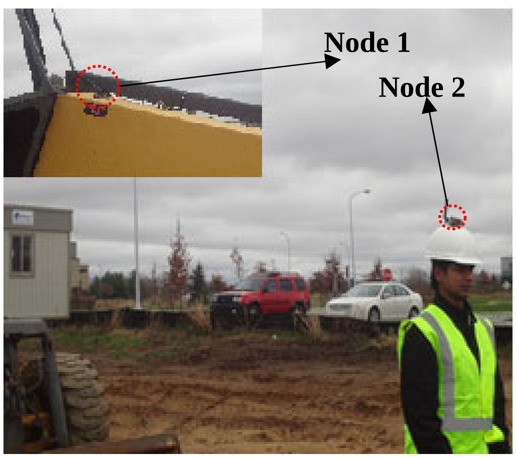

Figure 4. Outdoor environment

Figure 5. Indoor environment

EXPERIMENTAL RESULTS

The results of the outdoor and indoor experiments are discussed in the following paragraphs:

For each range data, 285 results was collected in order to fully understand the consistency or inconsistency in the generated range data. Table 1 and 2 presents a summary of the data collected for different placement positions of Node 2 for both the outdoor and indoor experiments. The average of the range results for each position of Node 2 is represented in column 3 of both tables. The standard deviation of each sets of range data for each position of Node 2 is represented in column 4 of the tables. The error of the swarm range data ($E_{Swarm\ node}$) is determined by computing the absolute difference between the average swarm range data ($R_{Swarm\ node}$) and the range from the (calculated from) Total Station data ($R_{Total\ Station}$). This is represented in column 5 of both tables.

$$E_{Swarm\ node} = |R_{Swarm\ node} - R_{Total\ Station}|$$

Table 2. Outdoor Results

Node 2 Position (1)	Total Station Range (m) (2)	Average Range (m) (3)	Std. dev. (Range) (m) (4)	Swarm Error (m) (5)
1	4.95	4.88	0.32	0.07
2	5.72	5.68	0.40	0.04
3	5.52	5.24	0.23	0.28
4	6.88	5.75	0.28	0.13

Table 3. Indoor Results

Swarm Node Position (1)	Total Station Range (m) (2)	Average Range (m) (3)	Std. dev. (Range) (m) (4)	Swarm Error (m) (5)
1	2.95	2.90	0.50	0.05
2	2.70	2.24	0.62	0.46
3	3.50	2.73	0.74	0.77
4	3.36	2.84	0.32	0.52

From Table 1, it can be observed that the error range of the CSS based swarm sensing system for all four positions is 0.07-0.28m. When compared to the UWB which has an accuracy of 0.1m in an outdoor environment (Cho et al. 2010), the CSS based swarm system has a slightly higher accuracy. The standard deviation of the 285 range data collected, is between 0.28-0.4m. This implies that the range values produced by the CSS based swarm sensing system are fairly consistent. Furthermore, for the indoor test, the error range of the CSS based swarm sensing system was less than 1m while the standard deviation of the range values indicate significant variation.

CONCLUSION AND FUTURE WORK

This paper presents preliminary results on an ongoing research involving the performance evaluation of a CSS based swarm sensing system for construction applications. The effectiveness of CSS based swarm nodes in providing the range between tagged construction resources for collision avoidance in both outdoor and indoor environments of a construction site is determined. The range data obtained from the CSS based swarm nodes in both (the indoor and outdoor environments) is compared with the ground truth obtained from the Total Station. The results indicate that the CSS based swarm system has an improved accuracy when compared with other similar technologies such as the UWB. Future work includes the following:

- Investigating strategies for capturing and documenting near misses and close calls, resources involved and frequency of occurrence. This is necessary for providing context specific training to construction workers;

- Investigating the performance of the CSS based swarm sensing system under non-line of sight (NLOS) scenarios. This will also include error modeling of the swarm sensing system for a number of application scenarios.

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