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Swarm nodes for automated steel installation tracking: A case study

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ABSTRACT

Monitoring the installation of building components offers great opportunities for enhancing not only the productivity but the performance of construction operations. Existing approaches and technologies still suffer from low level automation and lack of adaptability to material installation processes. This paper examines the feasibility of automatically tracking the installation of building components using proximity data obtained from swarm nodes. Proximity data were collected from tagged steel components during the installation process and compared with that obtained from the design model. Experiments were conducted to determine the accuracy of the swarm nodes. The error obtained from the experiments was used to set a buffer or tolerance around the components for accurately capturing the installation status in the developed system. This result has demonstrated that the application of swarm nodes has the potential to automatically track the installation of building components.

1. Introduction

Effective tracking of material installations can bring about immediate awareness of potential issues relating to project performance and productivity. This provides project participants (e.g. owners, contractors and subcontractors) with the information they need to easily and quickly make project control decisions. This is particularly important in large projects involving lots of materials, where certain materials can only be installed in specific locations and interchanging the installation locations will result in rework, thus delaying the project.

Recent advances in information technology have triggered investigations into efficient and innovative approaches for capturing material installations. This involves the use of semi-automated and automated technologies such as component – Conventional radio frequency identification (RFID) system [6,28], real-time location sensing systems (RTLS) [1] and image based sensing systems – Cameras [11] and laser scanners [39]. In spite of the benefit of these technologies, construction personnel will still spend significant amount of time using the technologies to track material installations. For example, in order to use the RFID system to track the installation of tagged materials, once the tagged materials are installed, the status of the material will need to be written to the tags. Such data are usually incomplete due to the reluctance and inherent human limitations of the workers to record all needed data correctly and as required. Since the data collection is an added task, the workers may require motivation such as financial incentives. Also, with large size projects, it will be time consuming and sometimes impractical to manually scan and record the installation status of every tagged material. Although, the installation status data obtained from image based sensing systems have been identified as being reliable, significant data collection and processing is required prior to acquiring progress information, thus delaying timely decision making. Structures are typically designed such that the materials or components are spatially distributed and within defined distances or ranges from one another. The design model, therefore serves as a reference for contractors during construction. Opportunities exist for leveraging the spatial distribution data present in design models for tracking when components have been placed and if they are placed in their rightful or as-planned locations. Proximity sensing systems have the potential for providing the range or distance between components. The concept of proximity sensing have been successfully employed in a number of applications, such as tracking human-robot interactions [29,30], collision avoidance between autonomous vehicles [16], food consumption to reduce obesity [3] and seat occupancy [9]. Similar proximity sensing concepts have previously been applied to safety management [38] and locating materials on the construction site [35,36] and the storage yard [7].

In this research, the swarm node proximity sensing system is applied to steel installation tracking. The motivating context for implementing the swarm nodes in this research is to reduce or possibly eliminate the time spent documenting installed steel components, thus enhancing access to quick decision making. Structural steel work in high-rise

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building construction projects, could consist of thousands of steel components. This work forms a high proportion of the total cost of the project. Ensuring that the components are installed on time and in the right place is critical for the successful completion of the project. Over the years, efforts towards tracking steel installation have involved manual and automated approaches. Although, the automated approaches reduce the data collection time, some manual effort is still required to capture and sometimes process progress information. Thus, the objective of this research is to assist the construction industry in monitoring the progress of installation of building components. The purpose of the research is to test and demonstrate the feasibility of automatically tracking the status of installed steel components using swarm nodes.

2. Background

Various efforts have been made to automate the tracking of material installation in the construction industry. These efforts involve the integration of component and image based technologies with virtual models. These have proven to be reliable for obtaining information necessary for controlling construction projects such as cost and schedule. Some of the image based approaches efforts includes the following: Turkan et al. [39] developed a four dimensional (4D) progress-tracking system that updates the construction schedule (of materials installed) through a three dimensional (3D) CAD model and point clouds data acquired from laser-scanning. Bosché et al. [5] used 3D laser scanning point cloud models and building information models (BIM) for monitoring Mechanical/Electrical/Plumbing (MEP) installments. Fard and Peña-Mora [8,12,13], examined the use of unsorted daily photographs and 4D simulation for estimating the progress of work. The developed system was able to portray the amount of material installed. Other researchers have also explored the role of image processing techniques for recognizing installed materials: concrete [19,40,41] and dry wall [22]. These image based techniques do not provide real-time information as significant data capture and image processing is required before material installation data can be obtained. Furthermore, since they require line of sight, the images will need to be captured from multiple positions before data processing commences. However, their benefits can still be leveraged for materials that cannot be tagged or may not be worth tracking with the swarm node.

Component based approaches involve the integration of RFID and RTLS systems with virtual models. Chin et al. [6] investigated the integration of passive RFID tags and 4D CAD for tracking the installation of steel components. Ghanem and AbdelRazig [10] presented a model that uses RFID for tracking material installation. Hu [17] also integrated passive RFID tags and 4D CAD for tracking the installation of steel components. In their approach, once the components are installed, construction personnel use a Personal Digital Assistant with an embedded RFID reader to manually input the installation status of tagged components. Ko et al. [21] also advocated tracking material installations using RFID by manually updating and storing the status data in the cloud. There have also being attempts by the industry to integrate BIM and passive RFID tags for tracking the installation of precast concrete [26]. Since the passive RFID system was used in these cases, users will need to be in close proximity to the tag in-order to embed status information. It will be labor intensive to walk-through the job site in-order to manually scan all the installed components. The limitation of these integration approaches is that access to status or progress information is dependent on when the construction personnel embeds information into the tags. Thus, opportunities exist for an automated approach to capturing status information of tagged components without manually embedding status information in the tags. Hammad [15] also proposed the integration of active RFID tags with BIM for lifecycle tracking of building components. Although, the active RFID tags enables updating of tag information from a longer distance, manual entry of status information is still required. A higher level of automation in tracking components was illustrated by Akanmu et al. [1]. The authors proposed tracking the installation of laboratory scale building components using RFID-RTLS system. RTLS systems require the placement of anchors or sensors around the area of observation or activity. The anchors will need to be constantly repositioned in order to track activities in different locations. Also, the anchors are typically connected with timing cables which tends to obstruct the flow or movement of resources on the construction site, thus making this approach impractical.

Swarm bee radio is a commercially available transceiver, developed by Nanotron Technologies, capable of ranging and communicating with other similar transceivers without the need for a support infrastructure (stationary transceivers). The swarm bee radios transmit and receive chirp spread spectrum (CSS) signals at 2.4 GHz. CSS is a wireless network technology that utilizes IEEE 802.15.4.a [2,20]. CSS have also been identified as being able to operate at a distance of about 1000 m and transmit data at the rate of 2 Mb/s [23,24]. A key advantage of CSS is its' ability to compromise the weaknesses of traditional ranging techniques by using time of flight (ToF) 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 other RTLS based technologies (such as ultra-wide band and RFID), CSS based sensors have a higher robustness against multipath effects and environmentally caused distortions [4,31,32,37]. This makes the resulting range data more accurate. These benefits inspire the need to explore the potential of swarm bee radio for tracking material installation on the construction site.

3. Swarm nodes

3.1. Specification

A swarm node (see Fig. 1) consists of a swarm bee radio, a microcontroller and a power-bank. The swarm bee radio and microcontroller communicate with each other using a universal serial bus (USB) to serial connector and the microcontroller is powered by the power-bank. Swarm bee radios require line of sight and each swarm bee radio can be distinguished from one another through their unique IDs. The swarm bee radios have a dimension of 40 × 24 × 3.5 mm and a weight of 7 g. Each bee radio has an in-built application whose functions are to query other bee radios, determine their ranges using the ranging method, SDS-TWR (described in Section 3.2) and communicate the range data to any data collection interface or platform. In order to power the swarm bee radio, each swarm bee radio is attached to a microcontroller using a USB to serial connector. The connector also transfers the raw data collected by each swarm bee radio to the microcontroller. The microcontroller processes the raw data using the in-built application. The

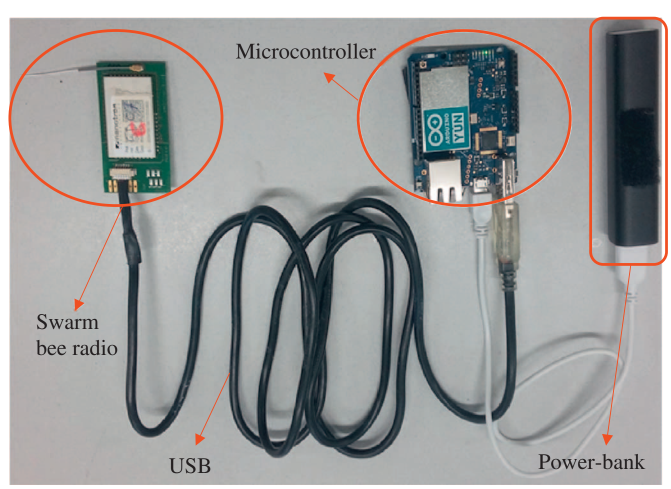

Fig. 1. Swarm node.