An Adaptive Automated Monitoring of Construction Activities using Swarm Nodes

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Abstract –

Effective progress monitoring of construction activities is always of great value to project stakeholders. It is increasingly being recognized that the success of any project is hinged on the level of awareness of the project status. Although, automated technologies have shown to potentially offer real-time information for quick decision making, there is still resistance to their adoption because of the amount of effort required in obtaining progress data. This calls for investigations into approaches and technologies for creating an adaptive and automated monitoring method. Thus, to address this need, this paper introduces an approach for automatically tracking the status of installed steel components using swarm nodes. The swarm nodes are attached to prefabricated steel components and automatically range to each other in real-time during the steel installation process. In this way, the installation of each steel component and the correctness of the installation are automatically identified and verified in real-time. Particle swarm optimization is used to support an automated arrangement of the swarm nodes for adapting to any steel components configuration. The method of using swarm nodes for data collection, preliminary experiments and results are presented. The potential of the developed method for performance monitoring is also discussed.

Keywords –

Swarm; Monitoring; Adaptive; Optimization

1 Introduction

Recent advances in information technology have triggered investigations into efficient and innovative approaches for automating construction activities. In-spite of these efforts, construction personnel still spend significant amount of time manually tracking and recording project status. Data collected using manual methods are usually incomplete due to the reluctance and inherent human limitations of the workers to record all needed data constantly. Efficient and effective construction progress tracking is crucial for management of construction activities. Although there has been significant improvement to existing progress tracking approaches through the isolated use of radio frequency identification (RFID) tags to the use of integrated approaches such as the integration of RFID tags and virtual models, these approaches still involve manually embedding status information into the tags. As such construction personnel would typically need to spend significant amount of time learning about and using the technology to gather data in addition to accomplishing their required task. For example, in the use of RFID tags for progress tracking by [1] and [2], construction crew need to manually scan installed tagged steel or precast concrete components in order to record their status. For these approaches to be adopted by the industry, construction workers will need to be motivated to collect and record progress or status data, thus reducing the reliability and access to real-time information. Furthermore, the use of information technologies in construction operations is to greatly simplify the complexity and burden associated with existing practices and not to contribute to it [8]. Hence, there is a need for investigations into adaptive and more automated approaches for tracking the status of construction projects.

Thus, this paper introduces an approach that adapts computational resources to the physical construction activities such as to automatically track the status of installed components. We collect component positioning data using swarm nodes. The swarm nodes are arranged on steel components (according to their roles) using particle swarm optimization. The accuracy of the swarm nodes in providing proximity data is presented.

2 Background

Over the years, a number of reasons have necessitated the need to track the progress of construction projects, including tighter schedules, shrinking budgets, environmental influence and increasing competition.

There have been a number of effort developing approaches to tracking construction progress using automated technologies. Among these efforts are the integration of data acquisition technologies (both image and component based technologies) with virtual models. The image based approaches involve the integration of virtual models with laser scanners and digital cameras [3,4]. While these approaches were capable of identifying discrepancies between as-built and as-planned construction models, further processing of the captured data is required before progress data can be attained. Component based approaches involve the integration of RFID tags with the virtual models, [2,5,6] investigated the integration of passive RFID tags and 4D CAD for supply chain and steel management. A higher level of automation in tracking components was illustrated by [5] using active RFID tags. Although, the active RFID tags enables access and update of tag information from distant locations, status information is still updated manually.

3 Research Objective

The research objective is to assist the construction industry in monitoring the progress of construction activities. The purpose of the research is to demonstrate an approach that leverages swarm nodes for automatically tracking the status of installed building components.

4 Swarm Nodes

A swarm node (shown in Figure 1) consists of a swarm bee radio and a microcontroller, both connected using a USB to serial connector.

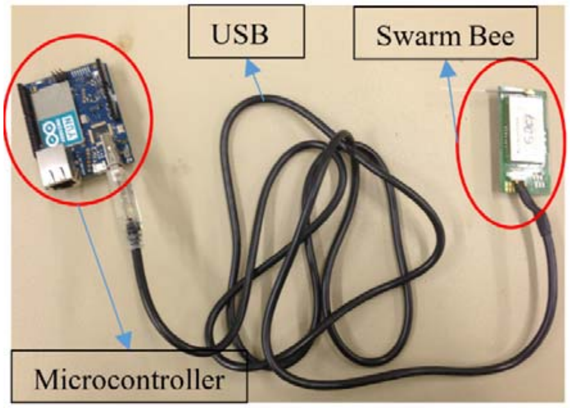

Figure 1. Swarm node

The swarm bee radios developed by Nanotron Technologies, each, has a dimension of 65 x 35 x 12 mm and a weight of 15 grams. The swarm radios have unique ID which distinguishes each node from one another. The swarm bee was powered using the Arduino Yun microcontroller. The microcontroller has a dimension of 73mm and 53mm and a weight of 38 grams. Communication between the swarm bee and the microcontroller is established through a USB to serial connector. The swarm nodes communicate and determine their distance to one another without the need for fixed anchor nodes. The distance between the swarm nodes is determined using the Symmetric Double Sided Two Way Ranging (or SDS-TWR). SDS-TWR estimates the distance using time of flight (ToF) symmetrically from both radios. The ranging methodology and wireless communication are integrated on a single chip in each radio and operates at 2.5 GHz frequency. The range data is extracted from the swarm nodes using a host node. Figure 2 shows interaction between three swarm nodes and a host node.

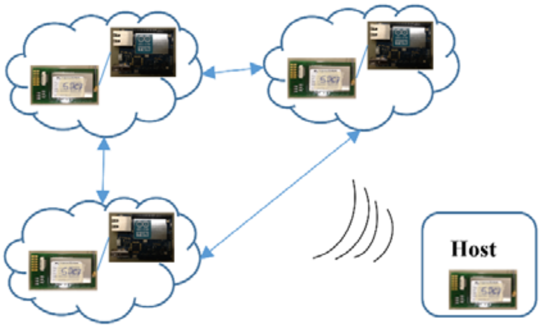

Figure 2. Interaction between swarm nodes

5 Adaptive Automated Steel Installation Monitoring

5.1 Key Considerations

An adaptive automated approach to monitoring the installation of steel members needs to consider the following:

- Steel members/components typically vary in sizes. Installing each member in the right location is important to prevent rework.
- Steel components are erected in specific sequences such as to enable stability of the frames. As such, the proposed approach needs to allow for dependencies between steel members during steel erection.

5.2 Framework

In order to demonstrate the functionality of the swarm nodes, an application was developed for tracking installation of steel components. The framework (Figure 3) is described as follows:

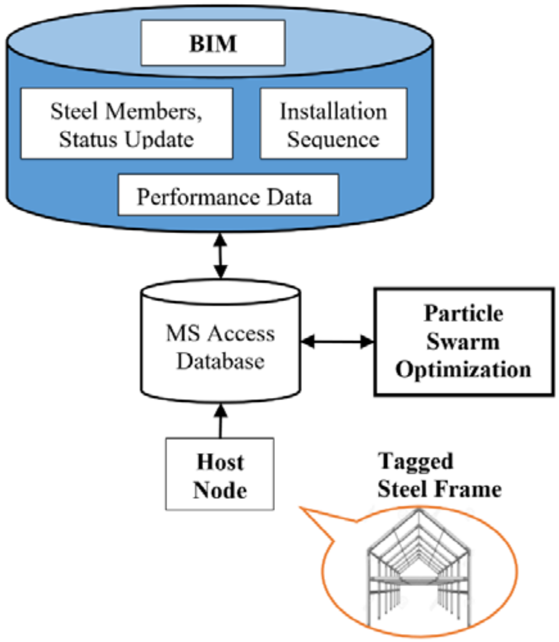

Figure 3. Framework for adaptive automated monitoring system for tracking steel installation

The overview of the information flow among the various applications in the proposed framework is shown in Figure 4. The stages of the model are described below:

5.2.1 Stage 1: BIM Module: Define Steel Members and Properties

At this stage, the steel members are defined and the erection sequence of each member is also defined. This erection sequence is embedded in each member. This erection sequence indicates the dependencies between the steel members (i.e. which members need to be installed before others). This essence of the erection sequence is to avoid the problems that can occur when a member is in line for installation before the supporting members have been erected. The model contains dimensions and proximity data of each steel component, alongside the ID of each component. This is extracted and exported to the database. BIM tools provide a platform for defining and embedding properties of building components. In Autodesk Navisworks, when building elements are defined, erection sequence can also be defined as part of the element properties.

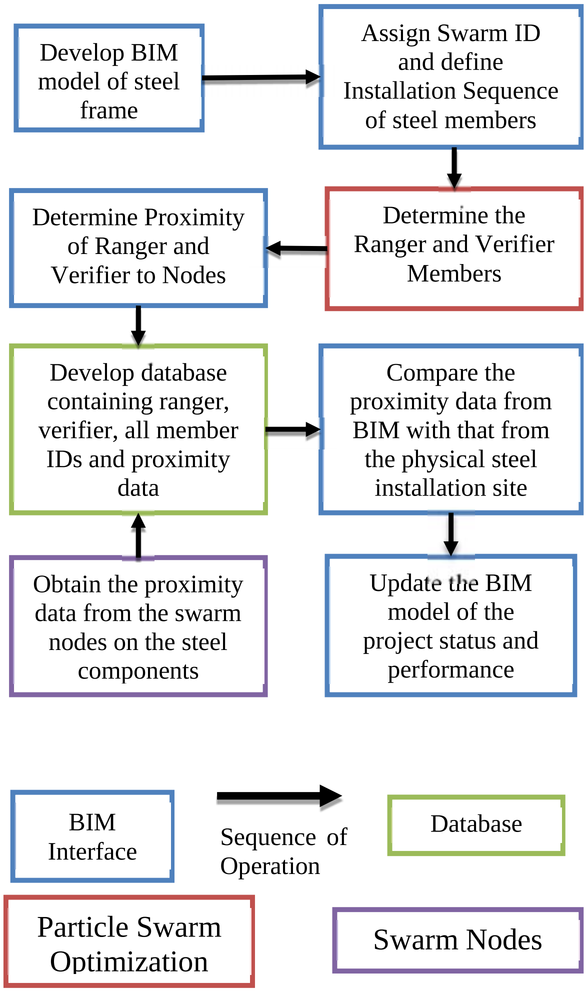

Figure 4. Information Flow for Developed System

5.2.2 Stage 2: Particle Swarm Optimization Module

Swarm nodes range to each other and determine their proximity. To determine the position of a swarm node, it is important to range two fixed swarm nodes to the node with unknown location. These two fixed swarm nodes are assigned the roles of a ranger and a verifier, respectively. The ranger and verifier both range to the unknown swarm node (Figure 5). The minimum number of swarm nodes that can range or have line of sight to the maximum number of nodes are assigned the roles of rangers and verifiers. The rangers and verifiers are determined using the particle swarm optimization (PSO).

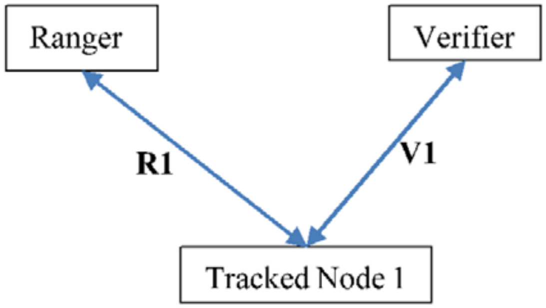

Figure 5. Triangulation to Determine Node Location

PSO is a metaheuristic that makes little or no assumptions regarding the problem being optimized. PSO can also search very large spaces of candidate solutions; this makes it suitable for this research problem. PSO has been widely used for combinatorial optimization and continuous parameter optimization problems. The PSO algorithm can be considered as a swarm intelligence-based multi-agent search method with solutions coded as particles [7]. Each particle keeps track of its location or coordinates in the problem space until the best solution is achieved, at which stage the fitness value is stored. At each step, the PSO involves changing velocity of each particle at its best fitness and global location.

If $X_i = (x_{i1,} x_{i2,} \dots \dots, x_{id})$ is the position of the i th particle in the B-dimension, (5)

$V_i = (v_{i1,} v_{i2,} \dots \dots, v_{id})$ is the velocity representing the search direction, (6)

During the iteration process, each particle keeps the best position that it finds $(pbest)$ and knows the best position searched by the group of particles and changes the velocity based on the two best positions. The standard PSO formula is given below [8]:

$$v_{id}^{k+1} = wv_{id}^{k} + c_1 r_1 \left(p_{id} - x_{id}^{k}\right) + c_2 r_2 \left(p_{gd} - x_{id}^{k}\right) \tag{7}$$

$$x_{id}^{k+1} = x_{id}^{k} + v_{id}^{k} \tag{8}$$

Where

$i = 1,2, \dots \dots, N$

$N =$ Population of the group particles

$d = 1,2, \dots \dots, D$

$k =$ Maximum number of iteration

$r_1, r_2 =$ Random values between [0, 1] used to keep the diversity of the group particles

$c_1, c_2 =$ Acceleration coefficients

$v_{id}^{k} =$ Velocity of particle i in k-th iterating for the d component

$x_{id}^{k} =$ Position of particle i in k-th iterating for the d component

$p_{id} =$ Best position particle i has ever found for the d component

$p_{gd} =$ Best position the group particles have ever found for the d component

The procedure of implementing a standard PSO algorithm is as follows [8]:

1. Initialize the original velocity and position of a particle;
2. Calculate the fitness value of each particle;
3. For each particle, compare the fitness value with the fitness value of *pbest*. If the current value is better, update the position and fitness value with new values;
4. Compute the best particle with the best fitness value. However, if the fitness value is better than the fitness value of *gbest*, update the *gbest* and its fitness value with the position;
5. If the finalizing criterion is satisfied, quit the iteration; otherwise, return to step 2).

5.2.3 Stage 3: BIM-Microsoft Access Database

As shown in Figures 3 and 4, the list of steel members, their IDs and roles, proximity data and installation sequence are exported to a Microsoft access database. These information are obtained from the BIM model and the swarm nodes on the physical steel components. The contents of the database and the inputs defined in stage 1 will be the inputs to the particle swarm optimization and Navisworks plugin, respectively.

5.2.4 Stage 4: Swarm Nodes

The physical steel components are tagged with swarm nodes. The IDs of the swarm nodes are assigned to their corresponding virtual components. The ranger and verifier nodes range to each component and obtain their proximity data for each node. The host node extracts the proximity data from all the verifiers and rangers and sends these to the database.

5.2.5 Stage 5: BIM Module: Visualizing Project Status

The objective of this BIM module is to present to the designer, a visual display of the status of installation of tagged steel components. Navisworks has an open application programming interface (API) which enables developers to easily extend the capabilities of the software. Using the API, a plugin was developed within Navisworks. The plugin extracts and compares proximity data from the database with the data from the swarm nodes. The result of this comparison is used to update the status of steel components. The visual interface of Navisworks serves as a platform for tracking the status of installed/uninstalled steel components (i.e., it can highlight which members have and have not been installed to date).

5.3 Implementation

An experiment was designed to evaluate the performance of the swarm node on a steel construction site in Michigan. The project contains 1200 steel members of which 450 were un-identical. Prior to commencing the experiments, the nodes had to be activated in order to function effectively in the swarm. The nodes were activated using a swarm ranging demo application (from Nanotron technologies). Six nodes was utilized for the experiments. Five steel members were tagged with 5 of the nodes and the remaining node was used as the host. Figure 6 shows a tagged steel component. The swarm node was attached to the steel components using a Velcro. The host node was connected to a computer via a USB cable. The host node interrogates the verifier and ranger nodes and transfers the range data to the computer via the USB.

Figure 6. Steel component tagged with Swarm Node

On executing the swarm demo application, the range data obtained from the host node are populated on the swarm interface. The swarm application was programmed to collect range data every 500ms. Alongside the measurements taken with the swarm node, a Total Station was utilized to record the ground truths of each installed steel component. The Total Station measurements was taken, in order to understand the amount of error associated with the swarm node measurements.

5.4 Experimental Results

The results of the field test is discussed in the following paragraphs:

For each tagged steel, 285 results was collected in order to fully understand the consistency or inconsistency in the generated range data. Table 1 and 2 present a summary of the data collected for each of the tagged components at different placement positions. The average of the range results is shown in Table 1 together with their ground truth collected using Total Station. The error and standard deviation of each sets of range data is represented in Table 2. 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 ($R_{Total\ Station}$).

$$E_{Swarm\ node} = |R_{Swarm\ node} - R_{Total\ Station}| \qquad (9)$$

Table 1. Actual and Swarm Range Results

	Ranger (30H6D2)		Verifier (DC107F)	
Comp. ID	Swarm	Actual	Swarm	Actual
7C9524	7.17	6.99	4.69	4.84
2E5DC7	3.25	4.11	6.54	6.96
8F6542	8.35	8.33	4.10	5.36
20F7D7	7.01	5.16	12.63	11.98

Table 2. Error and Standard Deviation of Range Results

	Ranger (30H6D2)		Verifier (DC107F)	
Comp. ID	Error	Std. Dev	Error	Std. Dev
7C9524	0.18	0.36	0.15	0.42
2E5DC7	0.86	0.54	0.42	0.77
8F6542	0.17	0.32	1.26	0.54
20F7D7	1.85	0.14	0.65	0.15

6 Conclusions

This paper has shown that existing approaches to tracking the progress of construction activities has some benefits and limitations. Swarm nodes offer some potential for automated tracking of the progress of construction activities. This paper presents preliminary results on capability of swarm nodes for enhancing tracking automation of steel components installation. The effectiveness of the swarm nodes in providing the range between tagged steel components is discussed. The range data obtained from the swarm nodes is compared with the ground truth obtained from a Total Station. To apply swarm nodes to other components, future research is required to determine the optimal placement of the nodes.

This is because swarm nodes require line of sight in order to range to one another.

Because of the potential of swarm nodes in providing proximity data, further research may leverage swarm nodes to investigate applications for:

- Capturing and documenting near misses and close calls; and
- Delivering context specific information based on social networks.

ACKNOWLEDGEMENT

The authors would like to extend their appreciation to AVB Construction Company for their vital input and cooperation during the case study.

References

[1] Sørensen K.B.; Christiansson P. and Svidt K. Ontologies to support rfid ‐ based link between virtual models and construction components. *Computer ‐ Aided Civil and Infrastructure Engineering*, *25:* 285-302, 2010.

[2] Chin S.; Yoon S.; Choi C. and Cho, C. Rfid+ 4d cad for progress management of structural steel works in high-rise buildings. *Journal of Computing in Civil Engineering*, *22*:74-89, 2008.

[3] Turkan Y.; Bosche F.; Haas C.T. and Haas, R. Automated progress tracking using 4d schedule and 3d sensing technologies. *Automation in Construction*, *22*:414-421, 2012.

[4] Golparvar-Fard M.; Peña-Mora F. and Savarese S. D4ar–a 4-dimensional augmented reality model for automating construction progress monitoring data collection, processing and communication. *Journal of information technology in construction, 14*:129-153, 2009.

[5] Motamedi A. and Hammad, A. Lifecycle management of facilities components using radio frequency identification and building information model. *Journal of Information Technology in Construction*, *14*:238-262, 2009.

[6] Akanmu A.A.; Anumba C.J and Messner, J.I. An rtls-based approach to cyber-physical systems integration in design and construction. *International Journal of Distributed Sensor Networks, Article ID 596845*2012.

[7] Wan J.; Yan H.; Suo H. and Li F. Advances in cyber-physical systems research. *TIIS*, *5*:1891-1908, 2011.

[8] Mu A.-Q.; Cao D.-X. and Wang X.-H. A modified particle swarm optimization algorithm. *Natural Science*, *1:*151-155, 2009.