REAL-TIME POSITIONING NETWORK FOR INTELLIGENT CONSTRUCTION

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ABSTRACT

Many problems related to loss of productivity in the construction of building projects arise from the lack of procurement information. The reasons for these problems include incomplete, incorrect or late information of material deliveries, resulting in extra cost and time to complete a project. Additionally, deliveries are often not properly planned; thereby scheduled materials do not arrive to site when required. The fragmented nature of materials management practices characterized by the lack of coordination among the different participants involved creates an opportunity for significant improvement.

This paper presents a methodology and a set of tools that will allow for the implementation of strategies, which facilitate the integration of the different project stages and allow collaboration among contractors, designers and material suppliers. This involves the implementation of an intelligent system that utilizes a Wireless Fidelity (Wi-Fi) network for the association of location data, tracking mechanisms and material identification during the preconstruction and construction tasks. Furthermore, this intelligent system facilitates associations between material takeoff, bill of quantities and actual assembly on site using e-Work. Previous attempts to associate design and as-built data with materials tracking and identification have consisted of isolated identification of components in the construction site through the use of bar codes, radio frequency identification systems, global positioning systems or laser radar imaging, and manual updates to the design documents. The new intelligent system develops a robust framework that incorporates product acquisition data from the early stages of design and estimating, and material location and tracking during the construction stage, with dynamic real-time updates to the design documents.

The benefits from the implementation of this intelligent system include automatically generating as-built drawings, expediting material delivery, streamlining submittal reviews, increasing process and facility quality, and performing an integrated construction process.

KEY WORDS

intelligent construction, positioning, as-builts, Wi-Fi, e-Work

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INTRODUCTION

At the present time, meaningful electronic communication in the construction industry is still difficult. Several initiatives have partially addressed certain isolated tasks in project management (e.g. electronic data interchange -EDI-, extensible markup language for architecture, engineering and construction –aecXML-, standard for the exchange of product model data –STEP-, etc.), but only in limited cases are there standards for communication available for the exchange of electronic technical drawings, or for procurement of construction products. An integrated, vendor-independent support for the complete supply chain or even of a realistic part of the chain is not yet available.

A framework is needed to incorporate alternatives for the integration of design, quantity takeoff, procurement and construction. It is currently possible to read structural drawings and prepare material schedules automatically, but improvements in scheduling, cost and project delivery will not be significant if the complexities in the interactions of parties involved are not addressed, or if preconstruction and construction data gathering tools are not integrated.

Current research and developments in the domain of asset location and tracking consists of tools designed to help workers and managers locate their equipment, personnel or tools anywhere in their premises. These tools include bar codes, radio frequency identification (RFID) and global positioning systems (GPS). Although these tools represent a valuable effort toward integration in the construction industry, still present limitations in terms of amount of data, middleware, interference and security. These research efforts are very positive and are gradually overcoming such limitations. However, new research avenues using innovative technologies and frameworks must be explored. With the use of architectures such as Bluetooth or Wi-Fi networks, it is also possible to observe and track the location of a particular element, while overcoming the limitations just mentioned.

The fragmented nature of the construction industry, with its lack of coordination and integration between the different disciplines involved in various stages of the project procurement process, creates a huge opportunity for improvement. These opportunities must be targeted for the implementation of strategies that facilitate the integration of the different project stages. This paper presents a methodology and tool that will allow collaboration among contractors, designers and material suppliers through the implementation of e-Work methods for the association of data location and tracking mechanisms between preconstruction and construction tasks.

BACKGROUND

Research output regarding the automation of preconstruction activities and its integration with project monitoring and control can be classified as: Automated categorization and capture of information, e-Work methods, component tracking and identification, and evaluation of web-based implementations. Below are listed some of the most significant accomplishments in those fields, indicating their scopes and potential opportunities for further development.

Automated Categorization and Capture of Project Information

Several research initiatives have addressed the importance of automated monitoring of construction operations from the performance perspective (Navon, 2005). Research on the use of GPS in the construction industry has been characterized by the positioning of equipment and by construction metrology in field operations (Peyret et al. 2000; Cheok et al. 2000; Han et al. 2005). GPS has been complemented with laser radar imaging of construction sites, allowing for the assessment of construction progress and the automated comparison between schedule and as-built progress (Cho et al. 2002; Shih and Wang 2004).

E-Work

Research on the automation of preconstruction workflows has been documented with the application of e-Work methods in construction materials (Castro-Lacouture and Skibniewski, 2003), built upon previous research in the manufacturing domain. E-Work is composed of collaborative, computer-supported activities and communications-supported operations in highly distributed organizations, thus investigating fundamental design principles for the effectiveness of these activities (Anussornnitisarn and Nof, 2003).

Identifying Components in a Construction Site

Technologies for tracking material components on site have been mainly based on GPS, bar codes and RFID (Furlani and Stone, 1999; Akinci et al. 2002; Jaselskis and El-Misalami, 2003; Song et al. 2006). The adoption has been slow due to the dependence on physical proximity and sight for bar codes, and the limited information of the material detected by the RFID system. Wireless local area networks (WLAN) featuring Wi-Fi, also technically known as 802.11 for a 2.4 GHz radio-band, have been considered as a key opportunity for the construction industry sector (Böhms et al. 2003; Aziz et al. 2006).

Evaluation of Web-based Implementations

The establishment of Web-based construction project management trends intended for information sharing and performance monitoring has been covered in a variety of settings (Lam and Chang, 2002; Cheung et al. 2004). However, the expectations, performance and combination thereof of web-based project management tools have begun to be evaluated more recently, alongside the implications for materials workflows (Castro-Lacouture and Skibniewski, 2005; 2006).

As it can be seen, many important techniques have been developed using a variety of research tools. However, the practice of civil engineering has not taken advantage of them as a whole, but as scattered improvements in distributed subfields, thus lacking mechanisms for evaluating their impact and real benefits in the construction management domain. Practitioners are aware of the benefits of individual techniques in project monitoring and control, but are still reluctant to extensively adopt them due to the lack of research initiatives addressing the integration of tools for material location and tracking with preconstruction tasks. The methodology described in this paper addresses these challenges by formulating and developing an e-Work model that incorporates i) product data acquisition from the early stages of design and estimating, ii) RFI and submittal reviews, iii) material location and tracking at the construction stage that will lead to a near real-time generation of as-built blueprints, iv) expedites material delivery, and v) increases process and facility quality.

PROPOSED SYSTEM FRAMEWORK AND ARCHITECTURE

The sequence of activities that conforms the framework for the Wi-Fi e-Work system deployment and validation is shown in Figure 1.

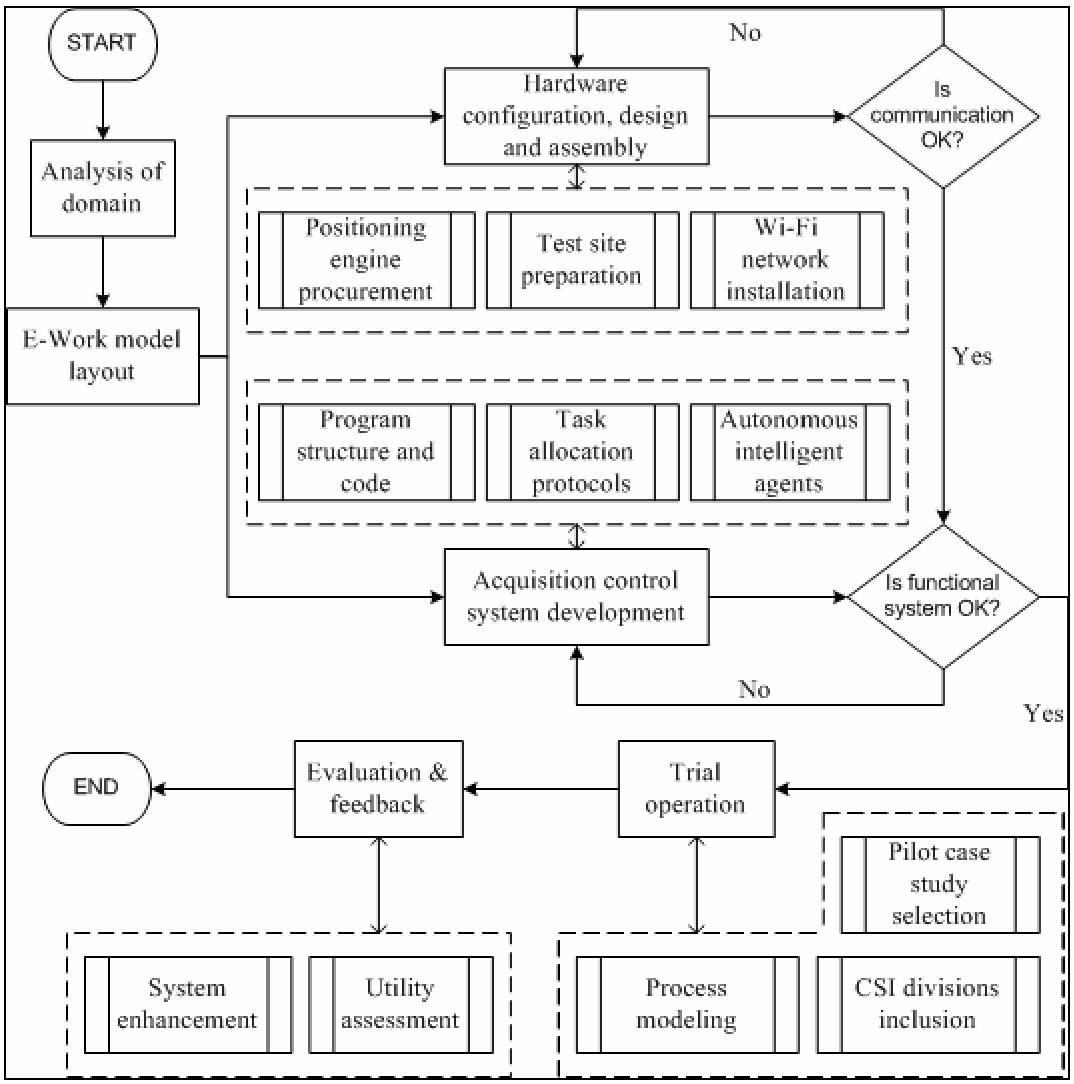

Figure 1: Flow Chart of Activites for Wi-Fi e-Work System Deployment and Validation

E-Work Model Layout

The development of the e-Work model is two-pronged: firstly, it comprises the hardware configuration, design and assembly, featuring the procurement of the positioning engine, the test site preparation and the installation of the Wi-Fi network. Site preparation is important for setting and adjusting the Wi-Fi network, and for configuring the positioning engine. The software component of the model consists of the development of the acquisition control system, which in turn is composed of the program structure and code, the task allocation protocols and the autonomous intelligent agents. The protocols for the e-Work model algorithm are defined in Table 1. Figure 2 shows the sequencing of messages.

Table 1: E-Work Algorithm with Task Administration Protocol (Adapted from Table 1 in Castro-Lacouture and Skibniewski, 2003)

Types	Protocols
Inquiry	A → B: request location X B → A: answer location (X) A,B – agents X – questions
Passing	A → B: tell location X A,B – agents X – message
Processing	(1) A → B, C: tell location X (2) B → A: If ValueB(X) OK, Tell 'acceptB' else Tell X' (3) C → A: If ValueC(X) OK, Tell 'acceptC' else Tell X'' (4) A → B, C: If acceptB and acceptC, end. If acceptB and X'', X=X'', go to (1) If acceptC and X', X=X', go to (1) If X' and X'', X=(X',X''), go to (1) A,B,C – agents X,X', X'' – alternatives
Announcing	A → B,C,D: tell location X A,B,C,D – agents X – message
Approving	(1) A → B: request location X (2) B → A: If ValueB(X) OK, tell 'approveB' else X' (3) A → B: If approveB, end. If X=X' go to (1) A,B – agents X,X' – alternatives, where X' is lacking approval

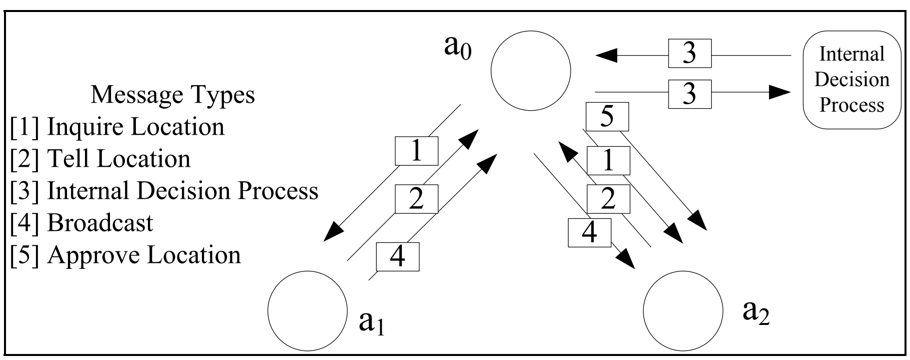

Figure 2: Sequencing in Task Administration Protocol

A characteristic scenario of construction material procurement is shown in Figure 2. The construction manager or superintendent interacts with agents from the end-user application in order to define the locations of targets. Two agents (a_1 and a_2) are inquired by user a_0 about the location of some construction material or component. One agent checks spatial information provided by the Wi-Fi network, while the other verifies scheduling information.

The two agents respond the request. Based on the responses, a_0 performs a checking routine and sends the decisions and approvals to the agents.

The main function of the e-Work model is to integrate the hardware components, such as application server, positioning engine server, finder client, with the software components such as task allocation protocols, autonomous intelligent agents, database of material information and the CAD drawings of the facility through a web interface in real time that allows the user to obtain material information from the site and trace it on the finder client's graphical interface. Presently, the positioning accuracy is up to a meter with current technology. Material design and procurement information will be integrated through the e-Work system. Field positioning data will be obtained by pinpointing the Wi-Fi tags attached to the construction material, or by conducting a scan of materials that cannot have tags attached due to limitations in size, shape or type of surface. The latter scan can be carried out with a Wi-Fi enabled device such as a laptop, PDA or Tablet PC, thus taking the device to the material's location. The combination of location tracking capabilities with WLAN networks allows for a flexible user mobility and asset visibility, since the e-Work system will have access to the CAD construction drawings and the materials database. Therefore, the user can see the drawings in the screen featuring design and placing elements, and by clicking an element, the interface will display selected information on material dimensions, properties, schedule, supplier and current status.

Hardware Configuration, Design and Assembly

Figure 3 describes the architecture of the e-Work hardware and its interactions with the construction site.

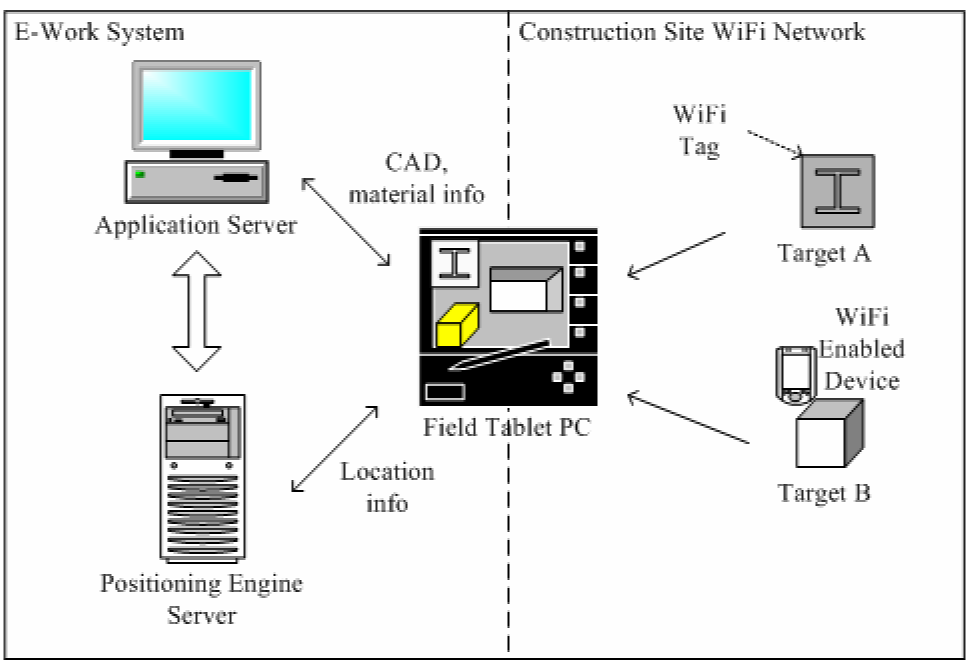

Figure 3: Architecture of the Wi-Fi e-Work System Hardware

The architecture consists of a client-server application composed of a server platform that runs the application, the positioning engine server for supplying location information, and the client (in this case is a field tablet PC). The server platform may also feature a web server for browsing capabilities. At the construction site and once the Wi-Fi is enabled with a standard 802.11 network, the locations of tracked materials and devices will be queried through the interface featured in the tablet PC. The interface will permit browsing targets that appear in the screen and are within the construction site Wi-Fi network, or allow for searching targets that are included in the database. As observed in Figure 2, there will be two types of targets in the construction site. Target A is composed of those construction materials or components than can be easily marked with Wi-Fi tags, given its site and ease. Structural steel members, large wood and plastic components, doors, windows, etc., are examples of this type of targets. In this case, the querying is automatic, and the user will track the location of the target even without physically seeing it. On the other hand, Target B is composed of those construction materials or components that are hardly suitable for tagging due to their size, shape or consistency. Querying of Target B will be possible if the user approaches the material with a Wi-Fi enabled device, like a PDA or even the tablet PC, and the location is pinpointed in the browser. The e-Work system will allow the user to understand more of the particular material by linking the CAD drawing to the material database and selecting the material of interest.

Acquisition Control System Development

Figure 4 shows the flow chart with the sequential acquisition control tasks to be incorporated into the Wi-Fi e-Work system.

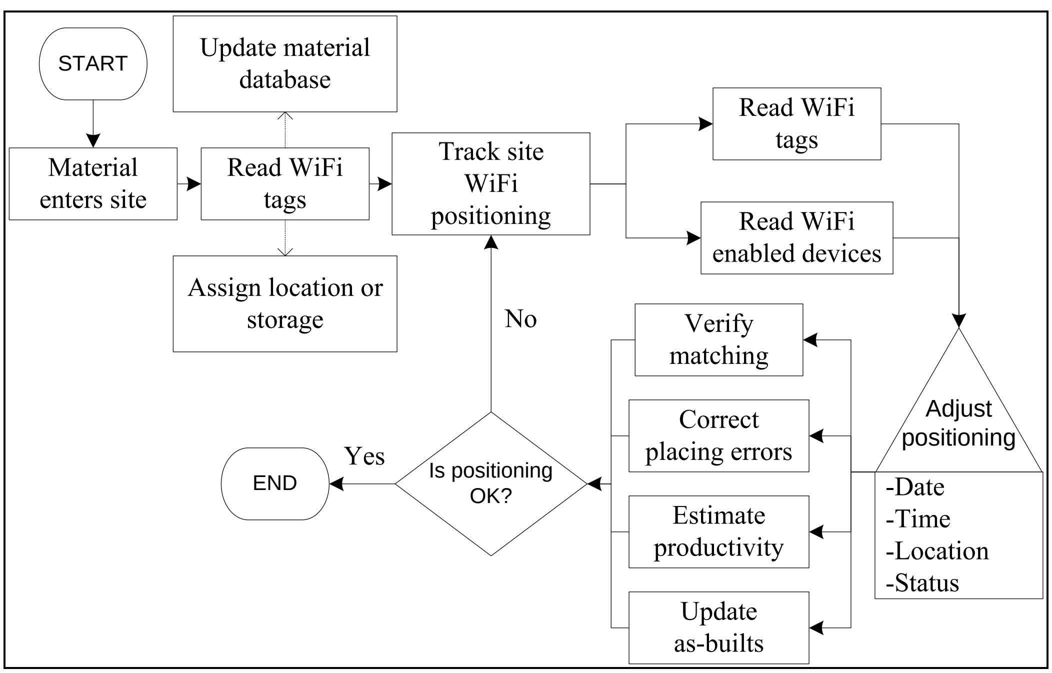

Figure 4. Flow chart of acquisition control tasks

Task allocation protocols and intelligent agents will be embedded in the setup of the Wi-Fi e-Work system in order to achieve a sound decision making process based on the design and assembly criteria established by the designer, construction manager and material supplier, as well as to perform database operations with external repositories and past projects. When a tagged material enters the construction site, the database is automatically updated, indicating the user that the material has arrived. Also, based on a previous determination, a task allocation protocol will indicate where in the site should that material be stored or placed, and when is it scheduled for installation. Once the material is installed, the client interface will track its position in relation to the Wi-Fi network. As explained before, the material can be either a Target A or B depending on the available tag or the use of a Wi-Fi enabled device.

System Functions

The client interface will receive data from the positioning engine, the application server and the Wi-Fi tag, thereby stamping in the database additional information about data, time, location and identification status. The location will be graphically observed and automatically entered in the CAD drawing being deployed on the client interface. Four final functions will be performed by the system

- Verify that the construction material matches the element intended in the design phase or modified by a change order or a submittal.
- Detect and correct placing errors. The web-based capability of the e-Work system will allow for the designer to have immediate access to the problem, as well as other subcontractors involved in that particular CSI division.
- Calculate productivity measures, since the e-Work system has information on installation time, type of material and calculated quantities.
- Update as-built drawings based on the locations and type of material. Autonomous intelligent agents will be acting in this part of the software in order to supply the database with data from current or completed projects, and finding out information required by the user. As-built drawings and project repositories will be updated and automatically regenerated, thereby expediting the revision and approval processes by project participants.

CONCLUSIONS

Ongoing research at Ohio University is aimed at facilitating the association of design data, positioning mechanisms and material identification during preconstruction and construction tasks. An intelligent system is presented, comprising the hardware configuration, design and assembly of a Wi-Fi network and the software component of the model, which features task allocation protocols and autonomous intelligent agents. An e-Work model is proposed to integrate the hardware components, such as application server, positioning engine server, finder client, with the software components such as task allocation protocols, autonomous intelligent agents, database of material information and the CAD drawings of the facility. The integration is done through a web interface in real time that allows the user to obtain material information from the site and trace it on the finder client’s graphical interface. Field positioning data will be obtained by pinpointing the Wi-Fi tags attached to the construction material, or by conducting a scan of materials that cannot have tags attached due to limitations in size, shape or type of surface. The combination of location tracking capabilities with WLAN networks allows for a flexible user mobility and asset visibility, since the e-Work system will have access to CAD construction drawings and the materials database. Therefore, the user can see the drawings in the screen featuring design and placing elements, and by clicking an element, the interface will display selected information on material dimensions, properties, schedule, supplier and current status. The benefits from the implementation of this intelligent system include to automatically generating as-built drawings, expediting material delivery, streamlining submittal reviews, increasing process and facility quality, and performing an integrated construction process.

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