USING CONTEXT-AWARENESS AND WEB-SERVICES TO ENHANCE CONSTRUCTION COLLABORATION

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ABSTRACT

The information intensive nature of construction projects requires project team members to have on-demand access to project information. However, existing mobile communication deployments in the construction industry rely on static modes of information delivery and do not take into account the worker's changing context and dynamic project conditions. This often results in a mismatch between what an application can offer and the actual (data) requirements of mobile workers. This paper explains how awareness of user context (such as user profile/role, preferences, task, location, existing project conditions, etc.) can enhance construction collaboration by providing a mechanism to deliver pertinent information. Also, parallel to the recent developments in context-aware computing technologies, there are developments in Web Services which provide the ability to dynamically discover and invoke services regardless of operating system or programming language. This enables mobile workers to access, in real-time, different corporate back-end systems and multiple inter-enterprise project resources. This paper discusses how a combination of these two technologies allows for the creation of an intelligent communication infrastructure that can take intelligent decisions about when and how different resources and services should be used, based on the interpreted context. A framework is presented, which facilitates context capture, context brokerage and integration with legacy applications using a Web-Services based architecture. Aspects of the framework implementation which was based on a Pocket PC platform, are used to illustrate the use of context-aware computing technologies in realistic construction scenarios. Conclusions are drawn about the possible future impact of context-awareness and Web-Services technologies in the construction industry.

KEYWORDS

Construction Industry, Context Awareness, Web Services, Mobile Computing.

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1. INTRODUCTION

The potential of mobile Information Technology (IT) applications to support the information needs of mobile construction workers has long been understood. Also, in recent years there have been significant advances in mobile communication technologies in terms of improved wireless bandwidth, quality of service and cost. A wide range of portable devices, such as PDAs, mobile phones and other wearable equipment are emerging, supporting real-time connectivity and improved processing power and battery life. As a result, the opportunities for providing an intelligent support infrastructure to support mobile construction workers are increasing exponentially.

To exploit the potential of emerging mobile communication technologies, many recent research projects have focused on the application of these technologies in the construction industry. However, from a methodological viewpoint, existing mobile communication deployments in the construction industry see support for mobile workers as a "simple" delivery of the information (such as project data, plans, technical drawings, audit-lists etc). Information delivery is mainly static and is not able to take into account the mobile worker changing context and the dynamic project conditions. Many research projects on the use of mobile devices for field data collection (e.g. Mrawira et al, 2002; Yabuki et al, 2002) relied on asynchronous methods of communication with no consideration of user-context, by downloading field data from mobile devices onto desktop computers and then transferring this information into an integrated project information repository. Even in those projects where the real time connectivity needs of mobile workers were addressed (e.g. Boehling, 2002; Ward et al, 2004), the focus was on delivering static information to users such as project plans and documents or access to project extranets. Similarly, most of the commercially available mobile applications for the construction industry are designed primarily to deliver a pre-programmed functionality without any consideration of the user context. This often leads to a contrast between what an application can deliver and what data requirements of a worker are.

In contrast to the existing static information delivery approaches, the construction work, by its very nature, is dynamic. Due to the unpredictable nature of the construction projects, different activities are often difficult to anticipate and very often construction project plans, drawings, schedules, project plans, budgets, etc have to be updated periodically. Also, the context of mobile workers operating on-site is constantly changing (such as location, task they are currently involved in, construction site situations and resulting hazards, etc) and so do, their information requirements. Thus, mobile workers require that supporting systems rely on intelligent methods of human-computer interaction (such as having a knowledge of who they are, where they are located, what tasks they are involved in) and to deliver the right information at the right time on an as-needed basis. Such a capability is possible by a better understanding of the user-context.

This paper discusses how a combination of two technologies i.e. context-awareness (by enabling better understanding of the user context) and Web Services (by supporting resource discovery and integration in a context-aware environment) can be used to facilitate construction collaboration. This paper presents a framework and its implementation for a context-based information delivery system for supporting construction workers. The paper is organised as follows. Sections 2 and 3 review the key concepts of context-aware computing and Web Services. Section 4 presents the framework which facilitates context capture, context brokerage and integration with back-end systems using a Web-Services model. Section 5 discusses the aspects of the implementation which was based on a Pocket PC platform. Conclusions are drawn about the possible future impact of context-awareness and Web-Services technologies in the construction industry.

2. CONTEXT-AWARE COMPUTING

Context-aware computing is defined by Burrell et al (2001) as the use of environmental characteristics such as the user's location, time, identity, profile and activity to inform the computing device so that it may provide information to the user that is relevant to the current context. Context-aware computing enables a mobile application to leverage knowledge about various context parameters such as who the user is, what the user is doing, where the user is and what mobile device the user is using. Pashtan (2005) described four key partitions of context parameters, including user static context (includes user Profile, user interests, user preferences), user dynamic context (includes user location, user current task, vicinity to other people or objects), network connectivity (includes network characteristics, mobile terminal capabilities, available bandwidth and quality of service) and environmental context (include time of day, noise, weather, etc.).

The awareness of user context (such as user profile/role, preferences, task, location, existing project conditions, etc.) can enhance mobile computing applications in the construction industry by providing a mechanism to determine information relevant to a particular context. In recent years, the emergence of powerful wireless Web technologies, coupled with the availability of improved bandwidth, has enabled mobile workers to access in real time different corporate back-end systems and multiple inter-enterprise data resources to enhance construction collaboration. Context- aware information delivery adds an additional layer on top of such real time wireless connectivity (Aziz et al, 2005) offering the following benefits:

- Delivery of relevant data based on the worker's context thereby eliminating distractions related to the volume and level of information;
- Reduction in the user interaction with the system by using context as a filtering mechanism. This has the potential to increase usability by making mobile devices more responsive to user needs;
- Awareness of mobile worker's context, through improved sensing and monitoring can also be used to improve security and health and safety practices on the construction site. At the same time, it is possible to use the knowledge of on-site activities to improve site-logistics, site-security, accountability and Health and Safety conditions on the site.

3. USING WEB SERVICES IN A CONTEXT-AWARE ENVIRONMENT

Web Services are self-contained, self-describing, modular applications that can be published, located, and invoked across the Web using standard Internet protocols. Once a Web Service is deployed, other applications (and other Web Services) can discover and invoke the deployed services regardless of operating system or programming language. As identified by Fensel (2001), the key to Web Services is on-the-fly software creation through the use of loosely coupled, reusable software components. In contrast, previously used systems based on established infrastructures such as CORBA, RMI and EDI were tightly coupled, each with their own transport protocol and inability to communicate with TCP/IP protocol. Using Web Services, data is free to move about the Web without the constraints imposed by tightly coupled transport dependent architectures (Coyle, 2002). Thus, the Web Services technology ensures standards based, low cost integration.

A major problem in the existing mobile communication applications in the construction industry is that they lack cohesion with the existing desktop based ICT infrastructure. They are often based on multiple technology platforms (e.g. Pocket PC, Tablet-PC, Palm, etc.) and rigid frameworks, that must be centrally managed and hand integrated at the source code level for integration with the existing desk-top based ICT applications. This creates enormous problems in integrating it with existing IT applications. Resulting complexity and heterogeneity results in inconsistent interface, redundancy and out-of-sync information. In recent years, the integration issue is being addressed through the use of proprietary or open standard API (Application Programming Interfaces). In this approach, each application needs a specialised API to communicate with another application. Some of the most obvious problems of using such an approach to system integration include lack of scalability (because of node to node connection) and lack of robustness (if one node is down, entire system can fail). As a consequence, such an ad-hoc approach towards mobile application development and integration has the potential to create another island of automation.

In contrast, the Web services approach towards application integration addresses some of these limitations. Web services based architecture is based on modular components, with each component representing a specific function. These modular components can be composed into solutions to offer the exact set of features required by a particular context. This raises the prospects for enhanced collaboration in the construction industry, as companies can combine their Web Services with that of partners depending on the project requirements or user context under defined constraints. Also, it is possible to discover services and use them on an as-needed basis based on the context of the mobile worker. Aziz et al (2003) discussed various application scenarios of using context-awareness and Web Services technology to support construction workers.

4. CONTEXT AWARE SERVICE DELIVERY FRAMEWORK

Figure 1 present a framework that combines context-awareness and web services to create a pervasive, user-centered mobile work environment, which has the ability to deliver relevant information to the workers by intelligent interpretation of their context so that they can take more informed decisions. Key layers of the framework are discussed as below:

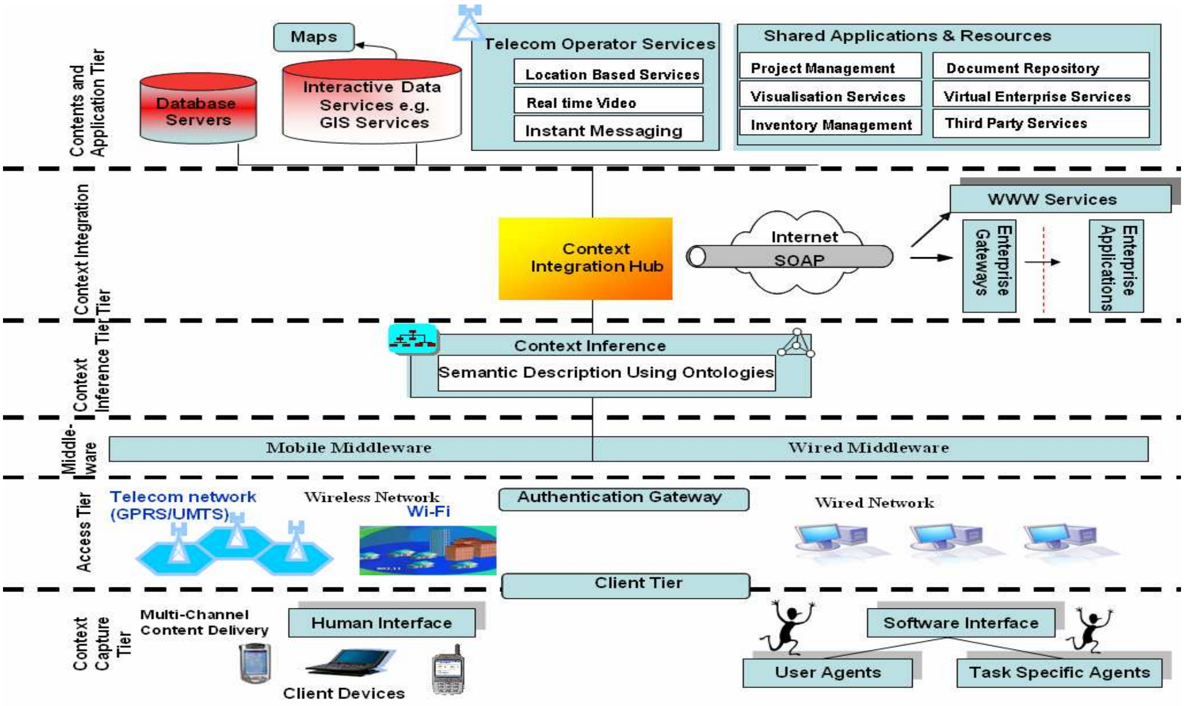

Figure 1: Context-Aware Services Delivery Framework

- ***Context Capture Tier:*** This tier helps in context capture and provides access to the system. This tier also supports mobile workers by providing context-relevant information through a human and a software interface layer. The human interface layer allows intuitive user interaction, by ensuring that data is delivered according to the worker's device type. The software interface layer ensures integration of software operating on the mobile workers' device with the back-end systems. User Agents allows personalisation of contents and services as per worker's preferences. The task specific agents help mobile workers in accomplishing a specific task by understanding the task context, and by identifying, filtering and accessing the services taking into account the physical conditions on the construction site.

- ***Access Tier:*** The access tier provides the vital communication link between the wired back-end and the wireless front-end. The use of IP-based technologies enables handover and seamless communication between different wireless communication networks such as wireless wide area networks, local area networks and personal area networks. The access tier supports both push and pull modes of interaction i.e. information can be actively pushed to mobile workers (through user configured triggers), or a worker can pull information through ad-hoc requests, on an as-needed basis.

- ***Middleware Tier:*** It ensures separation of data from presentation and applications. This separation allows for the re-use of the same middle tier for services delivery to wired and wireless clients. Mobile middleware connects desktop based back-end systems with different mobile networks, addressing the limitations imposed by mobility e.g. device limitations, bandwidth variation, etc. Use of XML transformation technologies allow support for a wide range of mobile devices with varying form factors.

- ***Context-Inference:*** It provides the ability to reason about the captured context using the Semantic-Web based model to describe a knowledge model for a corresponding context domain, thereby helping context description and knowledge access (by supporting information retrieval, extraction and processing) based on the inferred context. The understanding of semantics (i.e. meanings of data) enables creation of a relationship between the context parameters and available data and services. Output from the context-inference layer is fed into applications to make them aware of events on the site.
- ***Context Integration Tier:*** This tier will help the construction workers (or their agents) in service discovery. The service hub will use semantic mark-up for resource and service type description. Semantic mark-up will also allow users (or agents) to make intelligent decisions about when and how these resources and services should be used, based on the interpreted context. Adherence to open standards technologies will allow applications to share data and dynamically invoke the capabilities from other applications in a multi-domain, multi-technology, heterogeneous remote collaboration environment.
- ***Contents and Applications Tier:*** This tier contains construction project data and applications. Applications may be provided by project partners or application service providers (ASP).

5. THE FRAMEWORK IMPLEMENTATION

The framework implementation involved a proof-of-concept demonstrator and provided an initial working model of a large, more complex entity. Figure 2 presents the deployment architecture, and its key features are discussed as below:

5.1. Context-Capture

In the implementation, context was drawn from the following sources:

- Current location, through a wireless local area network-based positioning system. A client application running on a user's mobile device or a tag sends constant position updates to the position engine over a WiFi link. This allows real time position determination of users and equipment. It is also possible to determine user location via a telecom network based triangulation;
- User Device Type (e.g. PDA, TabletPC, SmartPhone, etc.), via W3C CC/PP standards (CC/PP,2003). These standards allow description of capabilities and preferences associated with mobile devices;
- User identity (e.g. Foreman, Electrician, Site Supervisor, etc.), via the unique IP address of the mobile device. User profile was associated with user identity;
- User's current activity (e.g. inspecting the work, picking up skips, roof wiring on the ground floor, etc.), via integration with project management application;

- Visual context, via a CCTV over IP camera;
- Time via computer clock.

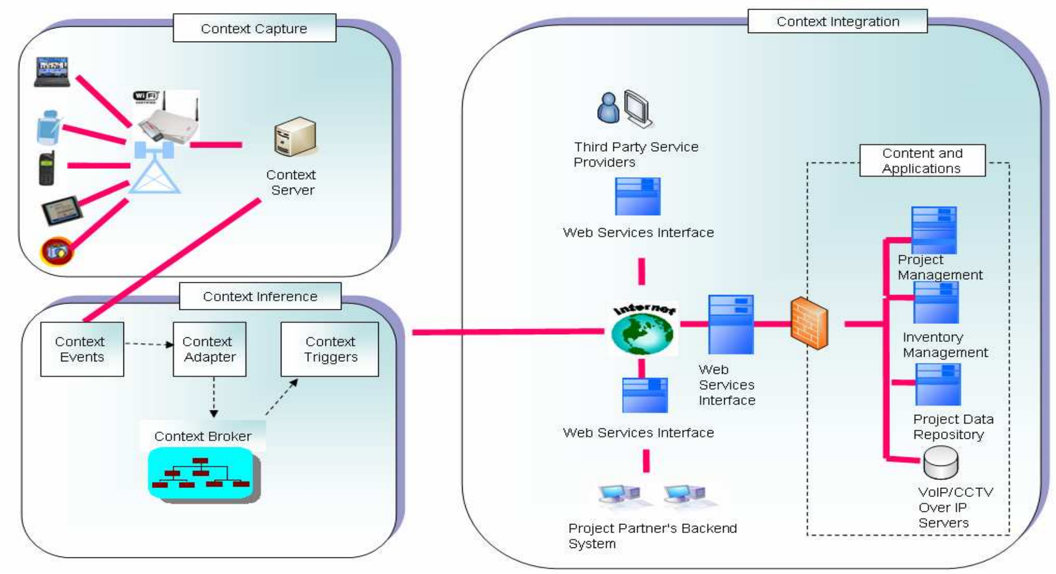

Figure 2: The Deployment Architecture

5.2. Context Inference and Integration

Various context events are fed in the context engine. The context adapter converts the captured context events (e.g. user id, user location, time, etc) into semantic associations. RDF schema (RDF, 2004) was used to provide vocabulary and structure to express the gathered contextual information. Being XML-based, RDF also ensures provision of context information in an application and platform-independent way. Also, using the RDF schema, the context broker maps captured contextual information to available data and services. Mapping includes:

- **User Profile to Project Data:** Mapping of information, based on the role of user on site;
- **Location to Project Data:** Mapping user location to project data (e.g. if electrician is on floor 3, he probably requires floor 3 drawings and services);
- **User Task to Project Data:** Mapping information delivery to the task at hand.

RDF was also used as a meta-language for annotating construction project resources and drawings. Such a semantic description provides a deeper understanding of the semantics of construction documents and an ability to flexibly discover required resources. A semantic view of construction project resources logically interconnects project resources, resulting in the better application of context information. At the same time, semantic description enables users to have different views of data, based on different criteria such as location and profile.

Changes in the context prompt the context broker to trigger the pre-programmed events which may include pushing certain information to users or an exchange of information with other applications using Web Services, to make them aware of the events on the site. As the user context changes (e.g. change of location, tasks), the context broker recalculates the available services to the users in real time. Some of the implemented services illustrated use of context-aware services delivery in realistic construction scenarios and are discussed below:

PROFILE BASED TASK ALLOCATION

In the implementation tasks were allocated to site workers based on their identity, profile and location. Task list (Figure 3) specifies the activities a site-worker must perform and it also includes the associated method statement, describing how tasks need to be performed. Using an administration application, the site manager assigns tasks and method statements to site worker. As the site worker arrives for work, the site server detects the unique IP address of their mobile device and prompts the worker to log-in. On a successful log-in, the server pushes the worker’s task list and associated method statement. The client application running on the site worker mobile device detects that data on the server has been changed. Modified files are then synchronized using WLAN-based synchronization. Synchronization is a two ways process (i.e. synchronizing files between the mobile device and the server application). This way, the completion of tasks can be monitored in real-time and an audit trail maintained.

CONTEXT-AWARE ACCESS TO PROJECT DATA

Mobile workers were provided access to project information based on their context (i.e. location, profile and assigned task) (Figure 4). The context broker played the key role of capturing the user context and mapping the user context to project data, at regular time intervals.

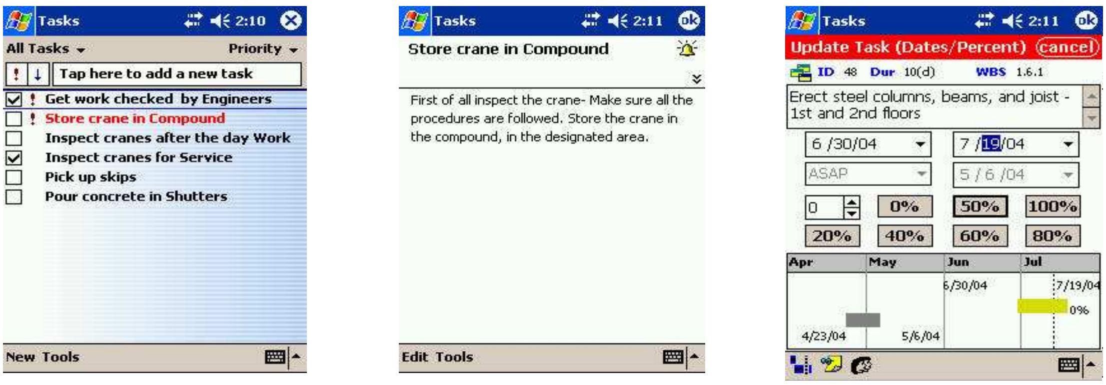

Figure3: Profile based task allocation and updates

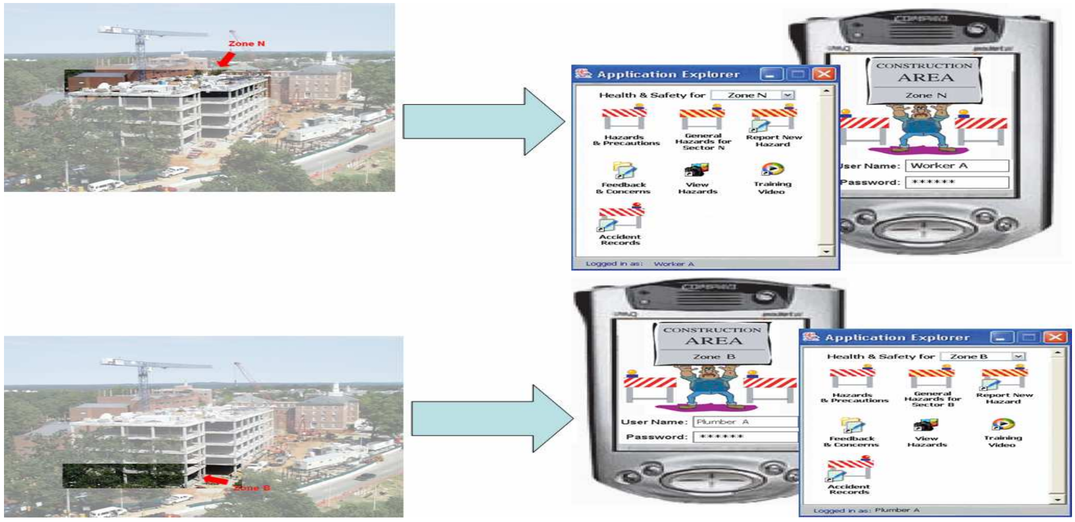

Figure 4: Context-Aware Access to Project Data

CONTEXT-AWARE INVENTORY LOGISTICS SUPPORT

WLAN tags were used to store important information about a bulk delivery item. XML schema was used to describe the tag information structure. As the delivery arrives at the construction site, an on-site wireless network scans the tag attached to the bulk delivery and sends an instant message to site manager's mobile device, prompting him/her to confirm the delivery receipt. The site-supervisor browses through the delivery contents and records any discrepancies. Once the delivery receipt is confirmed (Figure 5), data is stored locally on the site manager's mobile device. Local information stored on the mobile device is subsequently synchronized with the site server, resulting in an update of the inventory database.

Figure 5: Inventory Logistics Support

6. SUMMARY AND OUTLOOK

In this paper, the architecture and implementation of a context-aware information delivery system for mobile construction workers was discussed. Better context- awareness has the potential to cause a paradigm shift in construction management practices, by allowing mobile workers access to context-specific information and services on an as-needed basis. The proposed framework can be adapted to different implementations. In future, using different enabling technologies such as wireless communications, smart materials, sensors and actuators, it will be possible to capture a wide range of context variables. Also, new application scenarios are becoming viable by the continuing miniaturization of devices, developments in sensor networking, the increase in computational power. However, realization of the real potential of context- aware services for mobile computing in the construction industry needs to satisfy the constraints introduced by technological complexity, cost, user needs and interoperability. The next step in this research is to undertake field trials to test the prototype system in a real life construction project.

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