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STRATEGY FOR APPLYING UBIQUITOUS COMPUTING AND SENSOR NETWORKS TO SURVEILLANCE OF CIVIL INFRASTRUCTURE SYSTEMS

This paper presents the conceptual understanding and strategy modeling which include both technical and operational frameworks. The paper describes the categories of functional dependencies among the project events to identify the resources of technology, and frames the interoperating interfaces of physical and digital events to formulate a collaborative communication for ubiquitous computing environment in the surveillance of civil infrastructure.

1. Introduction

Civil infrastructure systems are complex and dynamic large-scale systems that involve great amounts of resources and participants while ensuring the safety and convenience of users. For example, civil infrastructures such as bridges, highways and facilities are managed, throughout their entire life cycle, by multiple teams of government owners, engineering professionals, contractors, and user groups. Multiple participants reveal diverse roles and functional dependencies, and all process-related information need to be managed in a time- and cost- effective manner. While emerging IT-based sensor networks provide us with a vision of a powerful and ubiquitous computing environment in civil infrastructure, feasible methodologies and frameworks for the civil engineering industry - combined with advanced information technology - have not yet taken a concrete shape due to the lack of cooperation among different participants, lack of information sharing, and inefficient use of emerging technologies.

A ubiquitous computing network is an emerging concept in computing, which integrates computation capabilities into the physical environment rather than being perceived as a visible object, so that it can provide widespread access to shared services through a variety of diverse devices irrespective of whether individuals are mobile or not. Ubiquitous computing has as its goal the enhancement of computer use by making many computers available throughout the physical environment, but making them effectively invisible to the user [15 and 16]. Hundreds of embedded sensor networks are to be installed everywhere, interacting with people to enable them to move, work, and communicate more naturally than they can with a personal computer. With ubiquitous computing and sensor networks, sensor platforms associated with networks and mobile devices are able to automatically adapt to any

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change caused by user's needs and actions, so that users might not even be aware of the presence of computers processing sensory data. Since research institutions envision the future of ubiquitous computing as a second IT paradigm, its applications to the civil engineering industry have a potential of providing efficient interfaces between diverse groups of constituents. This can result in enhancing the management of projects related to planning, constructing, operating and maintaining the civil infrastructure.

It is widely believed that the emergence of ubiquitous computing and sensor networks, and the gradual elimination of personal computing as project management professionals know it today, will have profound impacts on the management of the project delivery in many aspects related to surveillance of civil infrastructure systems. In this paper, strategy model to apply the ubiquitous computing and sensor networks to the surveillance of civil infrastructure systems is presented. Additionally, this paper also presents technological issues and implementation frameworks arising from the development of ubiquitous computing environment in civil infrastructure systems.

2. Current State of Knowledge

A shift to ubiquitous computing is under way in civil infrastructure for project management and surveillance applications. With the emerging technology of advanced sensors and networking, an opportunity emerges for civil engineers to implement ubiquitous computing, promising greater effectiveness, automation, and improvement in project tasks. For the research activities of the development of sensor and networking platform applicable to civil infrastructure, Sazonov [14] presented a design of wireless intelligent sensor and actuator network (WISAN) for the applications of structural health monitoring, addressing the issues of achieving a low cost per sensor, higher reliability, sources of energy for the network nodes and energy-efficient distribution of the computational load. Akinci [2] focused on the reality-capture technologies, such as laser scanners and embedded sensing system, available to civil infrastructure, to capture the history of a project to be used during facility management. Krüger [8] proposed structural health monitoring with Mote platform for the bridge monitoring, and he concluded that wireless sensor network with Mote could enormously reduce the costs for structural health monitoring and will increase its application.

Several researchers have focused on the information processing, event/location model, and collaboration model to implement the functional components in ubiquitous computing environment. Liu [9] examined the two main issues of accessibility and collaboration in enabling a ubiquitous computing environment for engineering information services. Berger [6] presented a global scale ubiquitous computing architecture based on open standards and introduced context-aware location information system to augment device discovery and user communication. Becker [5] also discussed general requirements on location management, deriving position, range, and nearest neighbor queries, and proposed the classification of location models with respect to application requirements that can assist developers in their design decisions. Reinhardt [11] developed the navigational model framework to provide visual representations of information contained in a product, and proposed a process model that correspond to the data access and data collection needs of site superintendents on a construction site. Abrams [1] developed User Interface Markup Language (UIML) to describe user interfaces for the communication between device independent platforms, and Ali [4] also presented UIML transformation methodology to build the interface for very different platforms, such as VoiceXML, PDAs and desktop computers.

Under the ubiquitous computing environment the collaboration model leverages the identification and formulation of the functional dependency of coordination and communication among diverse participants. Kraut [7] proposed an available command and control model that can benefit from many advantages of collaboration in communication and coordination of activities, decision making, information sharing, and multiple participating roles. Penã-Mora [10] presented the collaborative systems and mechanisms to facilitating communication in a distributed engineering environment and suggested a component-based architecture for online collaborative relief mission planning environments. Aldunate [3] presented the mobile ad-hoc space to provide the more efficient and consistent collaboration effort among first responders under the disaster situation. The simulation-based result in their research turned out that it is possible to improve the current collaboration medium and to support the work of local and remote civil engineers by adequately managing and disseminating information in the disaster scenario.

3. Ubiquitous Grids Layer Model

The role of ubiquitous grid layers is to provide the different services of communication with multi-device and distributed user group in civil infrastructure domains by integrating the sensing component and wireless network topology. Distributed sensor nodes and communication devices are embedded through the grid layers spreading over global project domains as environment-adapted locators, and provide a platform for the information sharing, collaborative communication, and multi-user accessibility [12]. The individual capacity of sensor nodes and mobile applications should be examined to function in the grid structure in order to dynamically interact with the neighboring grids. The deployment of new standards and suggestions for better performance of ubiquitous computing is called for in this model. In addition, network protocols and geographic network optimization addressed to the implementation of ubiquitous grid layers should be identified to develop this model. The motivation of analogies to neural system of spider ecology enables this phase to be interpreted as a sensing grid, and the following methodologies may be addressed for detail implementation of ubiquitous computing environment.

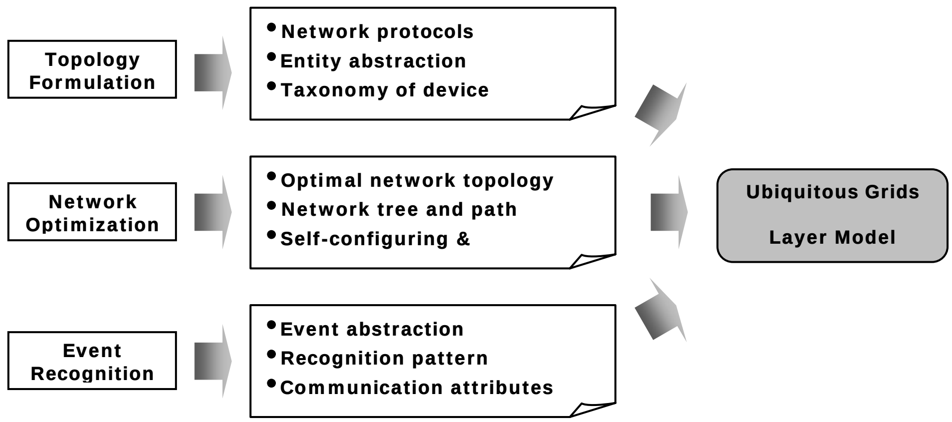

Fig.1. Operational model for ubiquitous grids layer

3.1 Topology Formulation

In the physical environments, identifying the abstraction of each entity is the precedent task to initiate the ubiquitous grid layer. Abstraction of each identity can be in general described as ID and advertises its ID to all its one hop neighbors based on the amount of power to be used and the transmission rate for communication. Different communication protocols and devices may be encrypted to a specified set of codes, and they are transmitted through different communication line to the database according to device specification. Hierarchical architecture or pervasive computing environment based on the characteristics of project events and taxonomy of device integration should be examined as the fundamentals of network topology analysis, so that the methodology to abstract the event attribution for the information processing can be identified and operated in order to exchange the information with several different applications. Classification of the entities and functionalities of physical events among different protocols will be the important task to initiate the ubiquitous computing strategy.

3.2 Network Grid Optimization

Network grid optimization in the ubiquitous environment is also one of the challenging areas in the real-time management framework of civil infrastructure systems. Even though enormous elaboration on the research has been proposed about developing the wireless sensors, data communications, hardware and software platforms [13], and data interpretation to be applied to the wireless monitoring system during past few years, more challenging approach can be found on the strategy of global-scale network topologies that provide the geographic communicator between sensor groups and collector groups in civil infrastructure. In the view point of local network applications, this issue can call for the data communication methodology between adjacent nodes, or transceivers, and is more focused on the specific technologies related to the signal processing, bandwidth analysis, data transfer rate and network coverage, as well as signal reliability. However, in the perspective of global network topology, it is also required to formulate and analyze the optimal network topology where each network tree and node is able to find its optimal network path based on the geographic environment of communication system over the large scale civil infrastructure. The optimal solution and criteria for self-configuring and reorganizing techniques, sizes and locations for network grid layer are needed to credibly execute specific tasks, capable of providing the effectiveness and efficiency in large-scale network management.

3.3 Event Recognition

Event recognition is one of the core abstractions in the ubiquitous computing environment because it delivers information about the presence of people and devices. When a construction worker or material is placed in a certain location with RFID device containing the object's identification, an access point located near the object will sense the presence of the device, read serial numbers from the device, map it to project controller, and deliver the event/location attribute to server located in the network. Abstraction of various project events is a key context that determines communication method and type of device. In a large scale ubiquitous environment, sensor nodes and diverse device must self-configure their communication, location, and mobility. Any physical events and location is detected and configured by distributed device, and determines their patterns and location by the logical and geographical topologies. Abstraction approaches and recognition methodology which determines the communication attributes and event rendering should be investigated as a key context in recognition patterns, and the environmental constrains such as bandwidth limitation and loss of connectivity need to be considered as a checklist for exploring the different set of communication protocols.

4. Device Integration Model

In ubiquitous computing environment, a key consideration is to communicate with several programmable communication devices, such as RFID tag, active badges, smart sensors, PDAs, mobile phones, and laptops. They are embedded into the ubiquitous environment, so called ubiquitous network, in civil infrastructure systems, and they respond to project events with universal accessibility to network interfaces, capable of providing an information process among different applications needed. Different specification protocols on fixed or mobile device for dynamically interactive platform must be identified and operated in the middleware or server side, which in turn distribute the translated information to the remote user groups. The following methodologies will be examined to implement the integration of the multi-device, and provide the diverse accessibility and collaborated interface to end-user in terms of ubiquitous environment in civil infrastructure system.

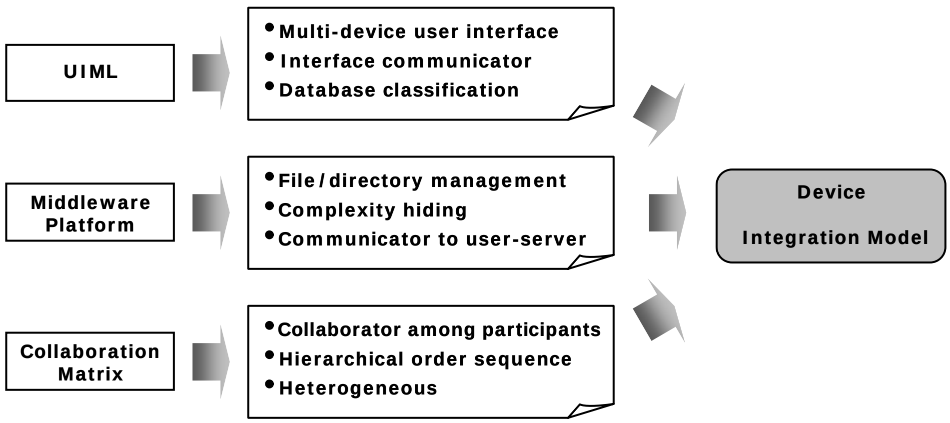

Fig.2. Operational model for device integration

4.1 User Interface Markup Language

User interface markup language (UIML) is a single language that is designed to provide the user interfaces for any device, and the concerns of interactive application can be separated by moving a program from one platform to another in a small amount of cost and effort [1]. As a higher level of declarative language, UIML provides the interface into a higher abstraction to be portable and multi collaborative across devices and operating systems, so that ubiquitous environment can manage the flow of information continuously among the participants who are involved in the network grid layer. Device interface (DI) handler and communication module reside in the client side to command the information process triggered by several device applications. The interface communicator (IC) located between DI handler and middleware re-organizes the information flow from generic sets of complexity identified by different type of devices, and promotes the access to middleware. IC comprises of several functional modules such as short-term storage and session tracking, and it characterizes the information type to be recognized in the middleware side. During these processes, UIML can function as a translator of attributed information between multi-client applications and middleware platform. Several categories of client side, i.e. portable computer, handheld computer, and smart sensor node, etc., need to be examined through the interfaces supported by UIML, and detailed abstraction methodology and database classification according to different communication protocols should be investigated.

4.2 Middleware Platform

The ubiquitous computing environment requires the multi device platforms of different capacities in terms of processing power, sensor node, input facilities, middleware, and wired/wireless network connectivity. The middleware in the device independent platform plays an important role in remote call process and file/directory management, hiding the complexity of the environment from the end-user using the protocol handling, and acting as an interface between sensing applications and operating system [17], i.e. database server. Middleware platform exploit the functionalities to provide a collaborative service, instance awareness service, and discovery/location service. IC is endowed with the accessibility to the subsets of middleware platform, and client application can utilize these middleware services. The design of the middleware platform needs to be performed throughout the interoperability among heterogeneous devices based on the attributes and components of the sensing information. Interaction strategy associated with the UIML for the device independent platform should also be investigated in terms of dynamic system configuration and adaptation.

4.3 Multiparty Collaboration Matrix

Collaborative network algorithm serving all entities surrounding the civil infrastructure systems requires a set of communication and coordination of activities, decision making, information sharing, and multiple participating roles. Ubiquitous network environment must be able to organize and control the way in which the participants can interact with the diverse information throughout the network and diverse device interfaces. Multiparty collaboration matrix will allow us to establish a prototype to be used for the collaboration between individuals, entities, and technologies involved in the civil infrastructure to make their collaboration more flexible in the large scale of the civil infrastructure domain. Adequately comprehensive and representative taxonomy based on the collaboration heuristics and strategies need be assessed for the realization of ubiquitous computing network before, during, and after the project activities associated with the civil infrastructure systems. In addition, detailed framework for the hierarchical order sequence and heterogeneous communication flow among the distributed participants and devices should also be included in the formation of multiparty collaboration matrix.

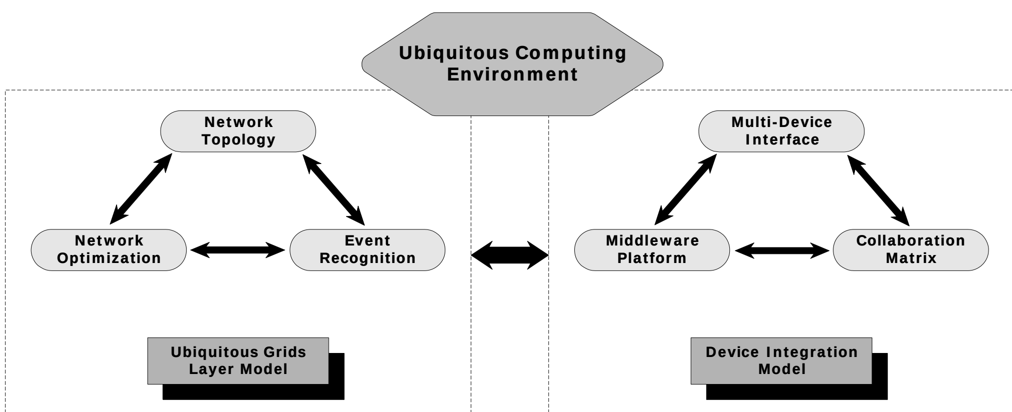

Fig. 3. Conceptual model of ubiquitous computing environment for the surveillance of civil infrastructure systems

5. Conclusion and Future Work

Civil infrastructure projects are dynamic and large-scale systems involving large amounts of resources and participants. Multiple participants involved in the projects exhibit diverse roles and functional dependencies While emerging IT-based sensor networks provide us with a vision of a powerful and ubiquitous computing environment in civil infrastructure, feasible methodologies and frameworks for the civil engineering industry - combined with advanced information technology - have not yet taken a concrete shape due to the lack of cooperation among different participants, lack of information sharing, and inefficient use of emerging technologies.

This paper presented the conceptual understanding and strategy modeling in terms of both technical and operational frameworks: formulation of ubiquitous grid layer, integration platforms of fixed or mobile devices, hardware architecture, and multiparty collaboration matrix. The paper also describes the categories of functional dependencies in construction management tasks to identify the resources of technology, and frames the interoperating interfaces of physical and digital events to formulate a basic unit for communication in a ubiquitous network domain. Operational strategy for integration and collaboration of multi-dimensional technology infrastructure was also discussed for the implementation of ubiquitous computing environments in the surveillance of civil infrastructure systems.

In this paper, we have identified the conceptual strategy for applying the ubiquitous computing and sensor networks in the surveillance of civil infrastructure systems. We expect that the emergence of ubiquitous computing and sensor networks proposed in this paper will have profound impacts on the operational strategy in many aspects related to the surveillance of civil infrastructure systems. Based on the associated components described in the paper, we plan to continue our investigation of the design architecture and system development. Specifically, detailed technical configuration of networks, development of multi-communication protocols, and hardware/software algorithms will be created for practical implementation.

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