Component Level Cyber-Physical Systems Integration: A Light Fixtures Example

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ABSTRACT

Digitally addressable lighting systems offer tremendous opportunities for performance monitoring and control of individual light fixtures. However, the locations of individual light fixtures within a building are not easily differentiable; as such, facility managers cannot easily distinguish and control each fixture. Virtual models contain semantic representation of objects which enable users to visually identify, distinguish and interactively monitor and control building components. To monitor and control light fixtures from these models, each physical fixture needs to be tightly integrated with its virtual representation such as to enable bi-directional coordination. Bi-directional coordination between virtual models and physical light fixtures offers tremendous opportunities for enhancing progress monitoring during construction, and performance monitoring and control during the operations and maintenance phase. Thus, this paper presents an approach to component-level cyber-physical systems integration using light fixtures as an example. A system architecture describing the enabling technologies and their roles is presented and a practical implementation is also presented to demonstrate the functionality and utility of the proposed approach.

INTRODUCTION

A significant proportion of electrical consumption in commercial buildings can be traceable to inadequate monitoring and control of lighting systems (Newsham et al., 2004). Yuan and Wobschall (2007) identified that enhanced monitoring and control of light fixtures is possible using digitally addressable lighting systems. Digitally addressable lighting systems consist of a network of controllers and lighting devices, having digitally addressable lighting interfaces (DALI). DALI systems are presently used in a number of construction projects and have been found useful for spaces with multiple uses and areas where lighting levels and configurations are likely to change over time (e.g. classrooms and conference rooms). Existing DALI control systems consist of a graphical user-interface for monitoring and controlling light fixtures. With this graphical interface, it is difficult to identify and distinguish each fixture for the purpose of controlling the fixtures. Also, locations of individual light fixtures within a building are not easily differentiable; as such, facility managers cannot control each item. Virtual models contain semantic representation of objects which enable users to visually identify, distinguish, interactively track and monitor the status of building components during construction (Chin et al., 2008). These virtual models are mainly used in the preconstruction and construction phases with few application in the operations and maintenance phases of buildings. However, much more benefit can be derived from these models by extending their use to the construction, operation and maintenance phases of a facility's lifecycle. Specifically, the virtual lighting models can be used for tracking and monitoring the status of light fixtures during construction and for performance monitoring and control during the facility management phase. This will enable users to visually identify each light fixture, and its location within a room or space, for enhanced control.

Anumba et al (2010) identified that integrating virtual models and the physical construction can improve the information and knowledge handling from design to construction and maintenance phases, hence enhancing control of the construction process. Thus, integrating virtual models and the physical light fixture components can enable installation status tracking, performance monitoring and control of light fixtures throughout a building lifecycle. An effective integration will enable bi-directional coordination between virtual models and the physical light fixtures. This approach is termed a cyber physical systems approach. In the context of this research, a cyber-physical systems approach is taken to mean a tight integration and coordination between virtual models and the physical construction.

This paper focuses on describing a cyber-physical systems approach to integrating virtual models and the physical light fixtures for the purpose of identifying and tracking the installed locations of light fixtures during for construction for the purpose of improving energy management in buildings. This paper presents the key enabling technologies required for a cyber-physical systems approach to integrating virtual models and physical light fixtures. A cyber-physical system architecture which brings together the key enabling technologies and their roles, is also presented. An implementation of the proposed approach with Triadonic lighting system is described.

ENABLING TECHNOLOGIES FOR BIDIRECTIONAL COORDINATION BETWEEN VIRTUAL MODELS AND THE PHYSICAL CONSTRUCTION

The key enabling technologies for enhancing bi-directional coordination between virtual models and the physical construction are discussed below:

Digitally Addressable lighting Systems. The DALI is an electrical interface and bus protocol mainly used for the control of lighting systems (Rubinstein, 2003). DALI is an international standard that enables the exchangeability of dimmable ballasts from various manufacturers. Figure 1 shows a DALI-bus segment that has bus-master controller installed. A bus-master can control up to 64 individually addressable ballasts. This means ballasts on the same circuit can be controlled independently. The DALI network allows the bus-master to communicate with all of the ballasts at once, groups of ballasts or individual ballasts. The communication functions include on/off, dimming level, fixture type and fading time. Another feature of DALI is the ability to diagnose problems, such as lamp brightness, lamp failure and lamp type. With DALI, individual addresses can be assigned to light fixtures. These individual addresses will enable system developers to link the physical light fixtures to the corresponding virtual light fixtures for control.

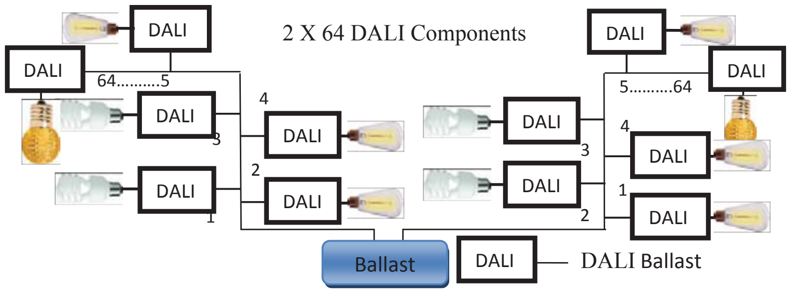

Figure 1. Layout of a DALI network

RFID and Wireless Sensors. Passive RFID tags and other environmental monitoring tags are proposed for this application. Passive RFID tags can be easily attached to each light fixture and scanned for their ID using a RFID reader. The scanned ID can then be used to bind the physical tags with their virtual representation in the model. Binding RFID tagged fixture components with their virtual representation in the model will enable the status (installation) of the light fixture to be tracked in the office. Also, this serves as a means of identifying and distinguishing each tagged fixture and their location in the model, thereby, enabling facility managers to control the fixture components in the constructed facility.

OVERVIEW OF CYBER-PHYSICAL SYSTEMS APPROACH TO MONITORING AND CONTROLLING LIGHT FIXTURES

The cyber-physical systems approach consist of two key features (as shown in figure 2), namely the physical to cyber and the cyber to physical bridge. The physical to cyber-bridge is the sensing process, which involves using passive RFID tags to identify, distinguish and bind the physical light fixtures to the virtual fixtures during construction. This bridge also involves capturing and monitoring the status during construction and post construction phases (such as light on and off, power failure and lamp failure) of the lighting systems from the model. The cyber to physical-bridge represents the actuation which shows how the sensed information affects the system. In this context, actuation is taken to mean making control decisions from the sensed information (from the physical to cyber-bridge) and/or using the sensed information to physically control light fixtures. Thus, the process of binding the physical light fixtures with their virtual representation and using the virtual model to monitor and control the light fixtures illustrates the bi-directional coordination between virtual models and the physical fixture components shown in Figure 2.

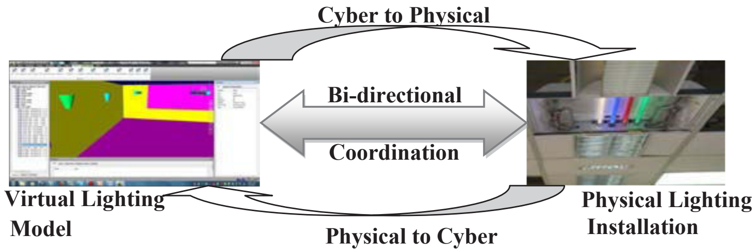

Figure 2. Features of Cyber-Physical Systems for Monitoring and Control of Light Fixtures

The Cyber-Physical System Architecture. The cyber-physical systems architecture in Figure 3 brings together the key enabling technologies as a framework for bi-directional coordination between virtual models and the physical light fixtures. The architecture is based on multiple layers, which are explained as follows:

Sensing and Device Layer. The sensing and device layer consists of wireless sensors (such as RFID system and occupancy sensors) and client devices. The RFID system consists of passive tags and readers for identifying and storing status information about light fixtures. The wireless sensors sense the environment and capture data such as daylight and presence. The client devices such as the tablet PCs provide access to the sensed data from the sensing layer and enables entry of information through the user interface.

Actuation Layer. This layer consists of the virtual lighting model which is accessed through the user interface. The model serves two purposes: it enables the electrical contractor bind each virtual light fixture with their corresponding physical representation in the model. The model also enables the facility manager/owner to visualize and monitor the sensed information from the contents and storage layer. They can also control each physical light fixture through the user-interface. By controlling each fixture through the user-interface, control messages are sent to the contents and application layer.

Communication Layer. This layer contains the Internet and wireless communication networks: local area networks (which use Wi-Fi to enable access to the internet). These communication networks connect mobile devices to the office to allow for collaboration and information sharing. The communication networks also allow the control messages from the office PC or facility manager's office to be transferred through the internet to the DALI layer.

Contents and Application Layer. The contents and application layer contains the database server and the control application. This layer stores, analyses and is constantly updated with information collected from both the communication and actuation layers.

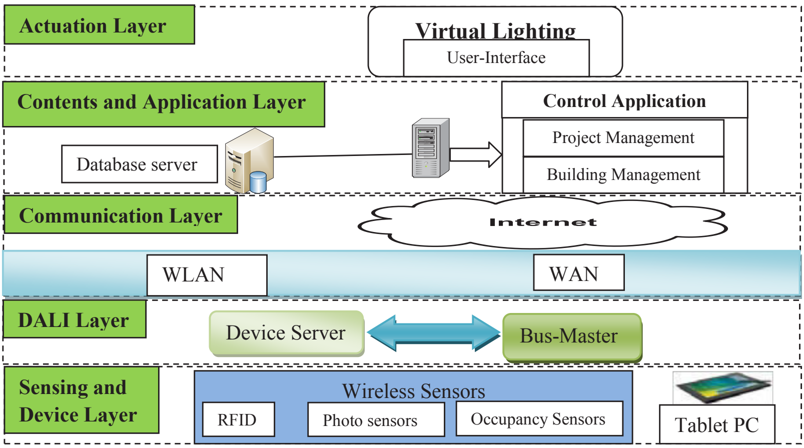

Figure 3. The Light Fixtures Cyber-Physical Systems Architecture

The stored information includes fixture type, location, status, model update information and component lifecycle data. The control applications use the sensed data from the database to make control decisions which can be visualized using the virtual prototype interface in the actuation layer.

DALI Layer. The DALI layer serves as the main interface to the light fixtures. It consists of the device server and bus-master. The device server collects and transmits control messages from the communication layer and fixture ballasts respectively. The control messages transferred through the communication layer is used to control the ballasts using the bus-master. The bus-master also captures fixture or ballast condition messages and sends it to the contents and applications layer through the communication layer.

Two aspects of the approach

There are two aspects to the proposed approach namely, tracking and monitoring light fixtures during construction and performance monitoring and control during the post-construction phase.

Tracking and Monitoring of light fixtures during construction. This involves tracking the status of light fixtures from arrival on the job site to installation. On arrival at the site, the light fixtures are tagged with passive RFID tags (if the light fixtures are not already tagged from the manufacturer's yard). As each tagged fixture is installed, the electrical contractor scans the fixture tag using a tablet PC with an integrated RFID scanner. The tablet PC has a virtual model of the facility. On scanning the tag on the fixture, the electrical contractor binds the tagged fixture with the corresponding virtual fixture in the model and changes the status to 'installed' in the model. Binding the physically tagged fixture with the virtual fixture (in the model), creates opportunities for the electrical contractor to create individual controls for the fixtures. This virtual model can be shared by the model coordinator, who monitors the progress of work in the site office and can identify which components have been installed and uninstalled.

Performance monitoring and control of light fixtures. During the building lifecycle, the facility managers and owners can remotely use the virtual model to identify and distinguish the locations of each fixture within a physical space for the purpose of enhancing access to individual lighting units and controlling the energy performance of buildings. When the light fixtures are controlled remotely, control messages are sent over the Internet using the TCP/IP protocol to a device server. The device server sends the control messages in the form of an IP address to the bus-master. This bus-master filters and sends the control messages to the appropriate light fixture, as each fixture has a unique address from 1-64 or 0-63. Facility managers can also remotely observe and query the status (ballast failure, lamp failure, power failure, device type) of each or group of fixtures remotely through the model. For example, the status and specification of defective fixtures can be communicated to the facility managers (in real-time) through the model so that they can replace them. This is particularly important as problems can be identified and diagnosed early, thus, reducing the need for routine maintenance checks and enabling the owner/facility manager control over the facility.

IMPLEMENTATION OF ACTIVE MONITORING AND CONTROL SYSTEM FOR LIGHT FIXTURES

This implementation is a proof of concept consisting of two phases (discussed in detail below). For demonstration purposes, only the ‘Performance Monitoring and Control’ system was implemented.

Tracking and Binding the Physical light fixtures with the virtual representation. The interface shown in Figure 5 was created for capturing the ID of the tagged fixture and tracking their status. Clicking on the ‘Track and Bind’ button, the application prompts the user to scan a tagged fixture. On scanning a tagged fixture, the tag ID number is captured in the TagID textbox (Figure 4) and the user selects the virtual fixture from the selection tree. The captured ID number appears in the property tab of the selected fixture in Navisworks (Figure 4). Clicking on the ‘Install’ or ‘Uninstall’ button, changes the ‘Status’ property in the model.

Performance Monitoring and Control. This was implemented using the Triadonic DALI system installed in the DALI laboratory in the Department of Architectural Engineering at the Pennsylvania State University. The DALI laboratory is a 1,200 sq. ft. facility housed in the Engineering Unit on campus, and contains over 70 examples of state-of-the-art light fixtures, including color changing fixtures, TV lights, spotlights, and typical commercial lighting. On accessing the performance monitoring and control system the interface in Figure 5, is initiated. Each button on the interface represents commands for controlling the light fixtures. The user selects a fixture from Navisworks selection tree and clicks on any of the command buttons on the interface.

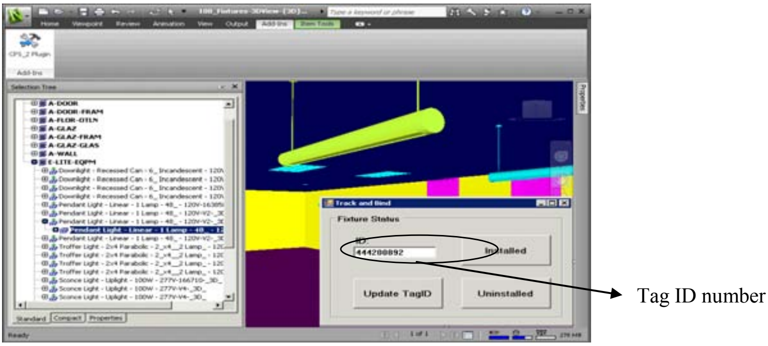

Figure 4. Track and Bind Interface with selected fixture and TagID

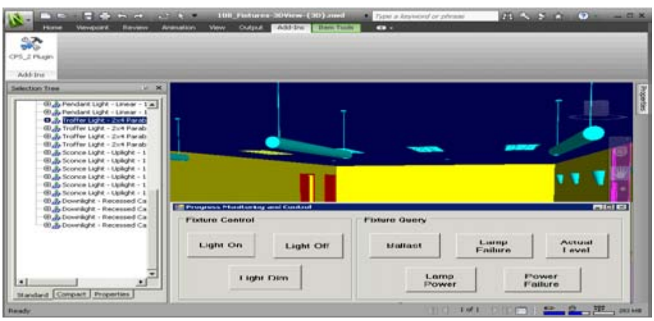

Figure 5. Initiated interface for progress monitoring and control

The clicked command button sends control messages in the form of IP addresses wirelessly through the device server to the bus-master. The wireless technology was used to synchronize the control messages between the tablet PC and the DALI system (Figure 6). The bus-master interprets this command and sends it to the appropriate fixture.

Figure 6. Triadonic DALI system

The bus-master also monitors the light fixtures for messages or responses on the status of the fixtures. For example, when a lamp is turned on in the lab, the corresponding virtual fixture is turned on in the model and the status property updates to illustrate this change.

SUMMARY AND CONCLUSIONS

Cyber-physical systems approach offers potential opportunities for enhancing bi-directional coordination between virtual models and the physical components. The cyber-physical system approach described in this paper involves the use of passive RFID tags to identify, distinguish and locate tagged components, from the design model. The sensed information from the tags is used to make control decisions and to physically control the construction process/constructed facility. This approach has been demonstrated through the development of a system for tracking, monitoring and controlling light fixtures throughout a facility lifecycle. A system architecture is presented which describes the key enabling technologies including, DALI system, RFID and wireless sensors, mobile devices, communication network and virtual prototyping technology. The key conclusions that can be drawn from this work are:

- RFID tags can identify and distinguish components; this makes the technology suitable for tracking and monitoring the installation of light fixtures during construction;
- Bi-directional coordination between virtual models and the physical construction has potential opportunities for improving progress monitoring and lifecycle performance monitoring and control of light fixtures, thus improving energy management;
- The proposed approach indicates that cyber-physical systems approach plays an important role in enhancing bi-directional coordination between virtual models and the physical construction;
- There is considerable potential/opportunity for the application of cyber-physical systems to other aspects of the construction project delivery process, facility management, and other operations.

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3D-Modeling For Crane Selection And Logistic For Modular Construction On-Site Assembly

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ABSTRACT

Adequate crane position on construction site required large amount of site data to be collected, prior to any lift operation. Existed permanent/ non-permanent obstructions as well as objects being placed on their final position, must be considered for each lift. This paper presents a methodology for crane selection and on-site utilization evolutionary algorithm for multi-lifts for modular construction. The proposed methodology accounts for cranes capacity limitation as well as evaluates the crane carrier/body position and orientation. State-of-the-art methodology incorporate evolutionary algorithm that reacts to dynamic changing site conditions.

This paper introduces a case study where the objectives were to simplify and optimize the field assembly operation for 5- three-storey dormitory buildings including bridges and large roofs in McGregor Village for Muhlenberg College in Allentown, Pennsylvania, USA. Each dormitory contains three types of modules and a total of 18 separate modular units. Fully habitable elements were delivered securely on flatbed trailers to the site in advance. An all-terrain mobile hydraulic crane placed in the center of construction site lift each module and placed like a puzzle floor by floor for each building at predefined position. All 100 lifts were conducted in only 10 working days.

INTRODUCTION

Construction industry recognizes modular – or manufacturing housing as a one of any construction method. Its primary advantages are quality workmanship and on-site completion time. When off-site completed products are transported to the construction site, then crane lifted in the final spot in a matter of days. Research in modular construction is extensive and some authors refer it to the low-rise multi-family housing development [Murdock]. Use of robotics method to automate the model development process and reduce on-site labor has been presented in [Nasereddin], [Bock], and [Editorial Leonard]. Also, the challenge related to a crane selection at construction site is addressed [Al-Hussein 2001, and Al-Hussein 2005]. Most effective way of utilizing modular off-site construction can be recognized in the construction of school/ dormitories, campuses buildings or affordable housing [Cardenas, and Atkinson]. Other examples successful modular construction implementations are health care units, from single check-up rooms to operating theaters or pharmacy centers [Editorial Health, Editorial Hospital, Editorial Operating, and Editorial Pharmacy]. When complicated mechanical components or multi-dimension construction site movement are involved, transforming the intellectual ideas into drawings is not a complicated task. The paper sketches are the first media to receive human brain idea output. Often, these "data" are the only evidence of new development and they are not recorded any other way. Capturing a knowledge of bright and successful ideas may be challenging if is not digitally recorded in the form of CAD solid modeling, mathematical algorithms and then presented virtually as animation or simulations. Analyzing and testing cranes in 3D has a proven record of success in assisting the construction industry or analysis assembly and complicated movement using tilt-up panel construction method [Al-Hussein 2005, Manrique]. Closing the gap between simulation and visualization and address visualization of the design constraints are the other examples of computer technology assistance [Olearczyk 2009, Olearczyk 2010]. Communication as an important way of exchange information and solve the problem is a key factor not only on construction site. To better understand concept of design, schedule and allocation resources over construction time virtual reality (VR) tool plays significant role. This dynamic graphical depiction is able to shows the proposed design just as the final product would appear in the real world.

METHODOLOGY

The proposed methodology is based on four modules, as illustrated on Figure 1. Input section contains all available lifted object parameters and available crane/rigging configuration arrangement.

Main process includes crane load and capacity check, crane location assessment, crane boom clearance arrangement and lifted object trajectory evaluation, which will be in detail elaborated. The main process is subject to criteria restrictions including lifted object size, crane renting cost, and specific ground preparation for crane placement, schedule or weather conditions. As an output user may extract information flowing between the main segment modules or analyze final results, such as object path, obstruction conflicts or lifted object sequence priority suggestions.

Crane load capacity check. Total lifting weight may not exceed current crane configuration lifting capacity with added industry standard safety factor. When controlled equation is not satisfied, crane capacity is lower than total weight, and the analyzed crane configuration is rejected. Rejection does not terminate operation but activates the re-define operation. Thus operation modifies input parameters within own criteria and introduces again for load capacity check. At the same time operator is notified that lift capacity reach its 85% instead of 80%. Final limit (corporation