ENHANCING OF CONSTRUCTION PROCESS PLANNING AND CONTROL WITH CYBER-PHYSICAL APPROACH BASED RFID

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Abstract: The ability to effectively progress monitoring in real-time can support managers in construction project to detect schedule delays early and to make timely recommendations for corrective action. This needs a close integration of the field where the physical objects are processed and their virtual models to enable data capturing on-site and a continuous comparison of actual with planned performance. Here, the Cyber-physical system based RFID is proposed to allow an effective continuous information flow, communication and data visibility during project execution. The analysis of collected real-time data facilitates the transform of these data into meaningful classifications that can be understood by the applications. This paper also presents a comprehensive solution to integrate the outcomes of analysis real-time data from construction site into a knowledge base for updating the entire progress, handling exceptions in execution and supporting efficient process alternative modeling.

Key words: RFID, CPS, process planning and control

1. Introduction

The ability to effectively progress monitoring in real-time can support managers in construction project to detect schedule delays early and to make timely recommendations for corrective action. However, in many field practices the planners still rely on manual process methods to collect information during project execution. Hence, the information of actual construction processes is incomplete, error-prone and/ or not available on time. In fact, the information problem has 27% of disturbance-causes in construction project (Gehbauer et al. 2008). Furthermore, the missing integration of the information in a flexible process modeling hinders an alternative process planning and causes process delays. To ensure an effective continuous information flow, communication and data visibility during project execution a cyber-physical approach is proposed. The proposed solution enables coupling the real and virtual one together to produce an environment where the physical and digital objects interact in real-time. Radio Frequency Identification (RFID) technology is used to identify the construction site

resources and to link both the physical elements and their virtual models.

The objectives of this research are: (1) monitoring of project progress during execution, (2) assessment project health on demand, (2) to identify exceptions in real time and (3) make timely corrective action in response to schedule delays. Implementation of this information in flexible process modeling approaches, like process configuration method, enhances an alternative process planning.

The paper presents (1) a mechanism to minimize manual inputs and enhance data acquisition on-site, (2) an approach to identify schedule delays and other exceptions at the early stage or even before they happen and (3) monitoring project health and analyzing of real-time data. Thereby, the focus will lay on analysis of collected data, determination of actual-schedule date deviations and suggest a classification approach of classes in comparison with project thresholds, priority of an activity (an activity belongs to the critical path of the project) and the floating time of an activity. Finally, a comprehensive solution to integrate these outcomes from construction site into a knowledge base will be presented for updating the entire process progress, handling exceptions in execution and supporting efficient modeling of process alternative.

This work discusses primary the prefabricated components of Fiber Reinforced Polymer (FRP) that can be used in modern bridge construction and their lifecycle. Since, these components have a high initial material cost which makes the overall project cost very sensitive to errors. Therefore, this work is driven by the “need” for accurate records of components and their status on construction site. The presented research is part of the ongoing FP7 European Project Trans-IND (New Industrialised Construction Process for transport infrastructures based on polymer composite components).

2. Background and Related Work

Recently, several researches have been investigated the integration of physical construction components and their virtual models using RFID technology. However, the early research in construction industry was focused on RFID applications for concrete handling, cost coding and material control. Goodrum et al. (2006) implemented the technology for tool tracking on construction site. Jang and Skibiwisiki (2009) introduced a new tracking architecture based on an embedded system for tracking construction asset by combining radio frequency and ultrasound signal. Klaubert et al. (2010) developed an approach based on Product data management

(PDM) systems and near field communication (NFC) technology to provide the construction project progress data to all involved actors. El-Omari and Moselhi (2009) proposed a control model based on different automated data collection form job-site for progress measurement purpose. Azimi et al. (2011) suggested a framework for automated monitoring system and a progress management system respectively for steel structure construction. Kadolsky et al. (2011) suggested a solution based on a knowledge management system comprising three components: RFID data component, knowledge base and optimization component. Thereby, the core of the knowledge base is formed by ontology which describes in a formal matter the contents and relations relevant for modeling on-site processes. Aknuma et al. (2012) proposed a solution based on Real-Time Location Sensing (RTLS) system to enable a Cyber-Physical System (CPS) for information exchange. Although this approach has a promise results; the expense of such a solution hinders a wide application in construction industry. Finally, the potential integration of RFID technology is evident by the Institute of Construction Informatics to control the dynamic construction process throughout coupling of flexible process models and the physical construction using cheaper passive RFID tag (Srewil et al. 2012).

3. Cyber-Physical System (CPS)

CPS can be defined as a tight coupling (integration and coordination) between virtual models and physical construction to enable data bidirectional coordination (Aknuma et al. 2012). Basically, the CPS architecture (Fig. 1) encompasses the virtual models, physical entities (construction elements, site objects and network objects) and interfaces in both directions (cyber to physical interface and v.v.) based on data acquisition technologies like RFID. CPS enables bidirectional coordination between physical construction components and their virtual model in real-time. In this work, CPS is not only a part of the passive identification process but also part of the active response procedure as it is closely integrated with the process control method. It endorses the challenge of ensuring accurate and timely update of information during construction process.

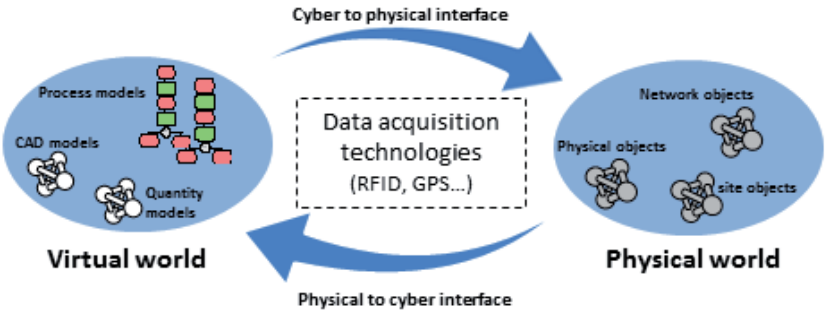

Figure. 1. CPS architecture: interaction between virtual and physical world problem via data acquisition technologies (like RFID system, sensors…)

3.1. Automatic Data Capturing Based RFID

The process of collecting data can be automated by emerging Automatic Data Capturing (ADC) technologies like RFID, GPS, Barcode, Laser scanning, Photogrammetry, Video, Audio, etc. It represents the technical part of CPS. Although these modern technologies are mature enough in many industry sectors like automobile industry, the feasible applications in construction industry are still under development and available only in few prototypes. Since RFID has relative advantages over other technologies, it is used to generate and aggregate information about real world objects (i.e. Products, machines, shipments and personal information). This technology can facilitate progress measurement through the set of captured data and comprehensive monitoring of project's status.

Recently, RFID technology has become one of the appealing methods to facilitate progress measurement in constructions. The RFID tag can be classified mainly as passive, active or semi-active. The passive tags receive power to transmit data from the reader. They have a cheap price, small data storage capacity and short read range. The active tags use a built-in battery to transmit data. Typically they are expensive, have high data storage capacity and a long read range (Erabuild 2006). Thanks to its excellent features for the identification of static or even moving products, machines and crew in harsh environment, Ultra High Frequency (UHF) RFID system can be used in this proposed system.

3.2. Construction Site Arrangements for Effective Data Acquisition

To allow a continuous monitoring of all relevant components and resources throughout all construction phases, a methodology is required for detecting these physical objects, their positions, and their states undisturbed, automated and in real-time. The illustrated approach in figure 1 considers three characteristic layers of job site: (1) Event layer representing where the construction processes take place, (2) Network layer for the mapping of events from the event layer to network configurations to make them tractable and (3) construction site layout layer; it links the network devices to their corresponding physical locations. Breaking down the construction site into work zones enable predefined entrances of the construction site, stores and lay-down areas, and constructed facility places. At this, status of the components can be easily updated at the job site gate, store or lay-down areas, cranes at constructed facility site, etc. These places are mounted with RFID reader (stationary and/or mobile). Accordingly, the data (Product ID, timestamp, product status, location, etc.) can be gathered automatically at each process level, or semi-automatically by the foremen, who can also add their comments. Therefore, the suggested system keeps the process information continuously updated. Lastly, the collected real-time data will be handled in a knowledge base. The advantages of the proposed method are minimizing manual inputs and leveraging collaborative RFID technology.

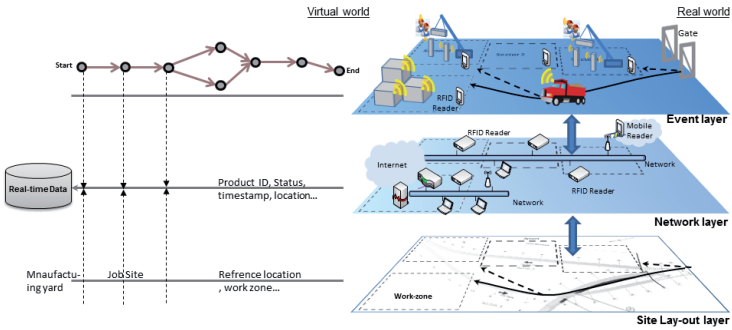

Figure. 2. A concept system for embedded UHF RFID technology based on RFID reader.

4. Real-time project progress monitoring

Real-time monitoring is a continuous process that takes place during the whole life-cycle of the construction phases. It links the field where parts are processed (physical world) on the proposed CPS to the virtual one via RFID technology, which provides a stream line of data of

the location and time for all resources on-site; therefore a real-time status update is on hand. Several research works were made to manage and transform raw data into meaningful events that can be understood by the applications. The real-time monitoring process comprises the following sub-processes in sequential order which are necessary steps for harmonization of the construction process and interoperability of CPS components:

- Managing RFID data: Generally, the major steps for managing RFID data are: data capturing, data filtering, and event processing and integration onto an application which was discussed in detail in previous work (cf. Srewil et al 2012, Li et al. 2008).
- Identifying related construction process from the virtual part of CPS: The entire construction project is described by a set of construction processes or activities depending on the level of description; each process needs to be accomplished within a defined period of time. These processes can be extracted according to Work Breakdown Structure (WBS) of the project. Therefore, WBS and scheduling define the logical relationships between processes and assign dates and resources (i.e. components, equipment, crew…) to construction processes. To identify the processes affected by a triggered event, the updated resources within a certain process window containing the current processes and the next direct successors will be detected. Then, the formulated relationships between processes and resources allow the identification of the corresponding processes.
- Deriving process progress: To derive the current progress of the identified processes. A few indictors corresponding to RFID application scenarios are applied. These indicators depend on the process duration, process dependencies and the required resources. Thereby, the underlying metric and the available information of the resources influence how detailed the process progress can be specified. On the next level of detail, the exact start and end time can be indicated. A further detailed specification provides information about the certain process state during its execution.

At this, Key Performance Indicators (KPIs) are used for monitoring the assembly process of prefabricated components on construction site and measuring progress. KPIs commonly aim to evaluate the success and the performance of a company. In this approach KPIs are considered to determine the progress of ongoing assembly processes. For this purpose two indicators are discussed:

The components availability: Each element (prefabricated elements, palettes…) is associated with a RFID tag. While elements move through different phases (logistic and/or on-site) the

corresponding RFID tags are tracked by RFID readers. The retrieved information consists of Tag-ID, the Reader-ID and the current reading Timestamp as well as reader's position. This information will be stored and regularly updated into a knowledge base. The querying of an Element–ID and its last location in well pre-defined construction site as proposed (Fig. 2) can concern the availability of this element and its current status (in transportation, stored at lay-down area, in assembly, or mounted) (Srewil et al. 2012).

Process time: It is an important indicator for process progress tracking and process alternative planning. Estimating the process time is a complex task. However, the approximate process time can be estimated by identifying the start and end dates for each activity. The dates are determined as the states of objects are changed. For instance, beam assembly process starts as soon as the beam state changed from beam-stored into beam-in-assembly (as discussed above) and it ended as its status changed into beam-mounted. For this purpose the query of an Element–ID, current Location and Timestamp from the knowledge base is needed to identify start and end date for each change in an object state, which is considered as start and end of the related activity. The aggregated event dates are used for estimating the process time and hence the progress of these processes.

4.1. Real-time data analysis

This step aims to detect process deviations and achieve a continuous comparison of actual with planned performance at real-time. Here, the accomplished detection of deviations is for historical, actual and even prediction value measurements at different levels of detail (process or even activity). The process in this case can be defined as a set of activities. The comparison encompasses the resource (as build, as planned) and the date variations of current process. Based on deviation values, the outputs can be categorized into three classes according to the project thresholds, the activity priority (an activity belongs to the critical path of the project) and the floating time of an activity (Fig. 3). These classes are:

1. Class 1: early[1] or on schedule "even very close to on schedule" → no or accepted risk detected.
2. Class 2: nearly on schedule → risk or potential risk detected
3. Class 3: late (i.e. activity on critical path of project) → problem detected

Depending on these outputs, the process states will be derived, detecting delays in project execution and planning for alternative which is discussed in the next section.

1 At this case, the activity has an opportunity which is beyond the domain of this research work.

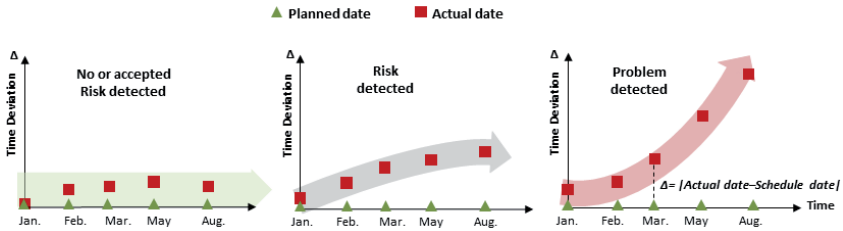

Figure. 3. Outputs of analysis real-time monitoring data of project activities "actual vs. schedule"

4.2. A Comprehensive Construction Process Monitoring and Control

Real-time monitoring of construction processes is necessary to anticipate and identify schedule delays and exceptions at the early stage and even before they happen. Nevertheless, the analysis of these data facilitates the assessment of project health and to make timely recommendations for corrective action in response to these exceptions. Because of construction project nature some exceptions (risks) can be realized early at the planning phase. However the realism of the risk assessment increased as project proceeds (i.e. considering a new risk and omitting others). This work proposes a comprehensive solution (Fig. 4) for construction process monitoring and control in real-time and a mechanism to add corrective action during execution. This comprehensive solution encompasses three main components:

- The real-time monitoring represents data aggregation and analysis which was discussed before and the result of this analysis was classified into: no or accepted risk, risk and problem. These results can be derived in more specific identification and assessment steps (i.e. beyond as-build/as planned assessment in real time) (cf. PMBOK 2004).
- The second part is a suggested mechanism to add suitable treatments and recommended actions. These treatments can be an Ad-hoc solution, or configurable fragments (preplanned treatment) added to the process model as a proactive treatment and to configure such configurable fragments as reactive treatment based on continual monitoring of process execution (Srewil et al. 2012). Here, the treatment is a standardized process description that offers enough flexibility to be used in a different context. And the configurable fragments in the course of the process model express the uncertain parts of the process. Recent work proposes to use templates that are a type of configurable fragments within the process models. These templa-

tes are generic and supposed to provide the flexibility needed in the process model (Sharmak and Scherer 2011). The real-time monitoring of ongoing activities supports the configuration of such templates by selecting the most suitable fragment for each variation point.

- Finally, all alterations are documented, the process models are updated to the project knowledge base and the monitoring cycle is resumed. The knowledge base roles are to manage the entire process model, formulate dependencies in a logic-based manner and to derive additional information required for filtering events, identifying risk types, configuring process fragments.

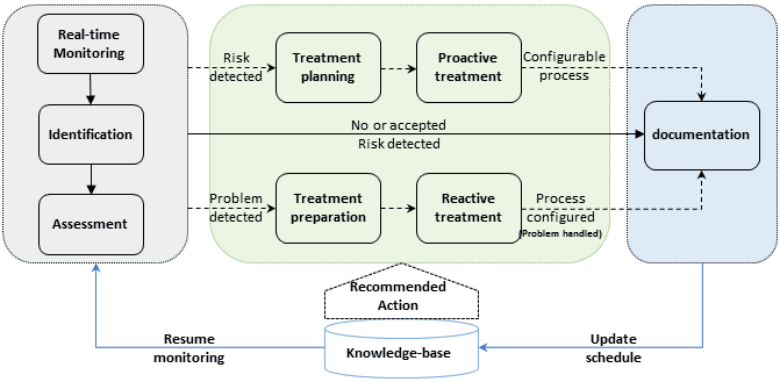

Fig. 4. Comprehensive approach based CPS for real-time monitoring control changes

5. Outlook and future work

The discussed approach showed significant opportunities of using the CPS based RFID. It enhances the real-time construction process monitoring and aids an early decision making and control. Moreover, the proposed construction site arrangement, that supports RFID system for effective data acquisition, can minimize the manual inputs of data and lead to automation of data acquisition. The analysis of the real-time data collected on-site can give a clear view of project progress. Furthermore, it facilitates the transform of these data into meaningful classifications that can be understood by the applications. The direct application of this classification is to control the construction process in real-time. Hence, the comprehensive real-time monitoring and control solution promises a flexible modeling method. That method is based on a mechanism to configure the recommended actions. Thereby, configurable process templates can be used to respond to the frequently changes in construction site conditions. In future work CPS approach will be realized in details. Also the configuration templates should be further elaborated and extended with information of the certain domain.

Acknowledgments

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