Utilizing Field Data Capture Technologies for Monitoring Activities in Double Shift Construction Projects

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ABSTRACT

In projects with tight schedule, one common approach to accelerate the construction progress is to work two shifts (i.e., daytime and nighttime). However, due to (1) physical, mental and visual fatigue at night and changes in the working conditions, (2) lack of sufficient number of supervisors at site, lower productivity rates are observed between day and night shifts. To achieve the planned productivity level at both shifts, an effective monitoring and controlling approach is needed. Field data capture technologies, such as RFID, video cameras are promising technologies in improving current control and monitoring approaches. However, some of these technologies are disadvantageous in monitoring construction activities under nighttime conditions. In this paper, performance of the field data capture technologies for monitoring and managing double shift projects were evaluated by reviewing previous studies and an envisioned approach for monitoring double shift projects by using the selected technologies were provided.

INTRODUCTION

In projects with tight schedule, one common approach to accelerate the construction progress is to work two shifts (i.e. daytime and nighttime). However, there are some negative effects of working at night on labor, such as physical, mental and visual fatigue (Mostafavi et al. 2012), and thus on safety (e.g. higher accident rates) (Jun and El-Rayes 2010). This might result in productivity losses due to ineffective work of labor and raise safety concerns. Another factor that can decrease the productivity in night shifts is the change in the working conditions. For example, the work zone conditions and lighting conditions of night shifts are different than that of the daytime. This can cause disruptions in operations performed in the nighttime work (Mostafavi et al. 2012). Also, less number of engineers supervise the field work at site during night shift, and the data collected for documenting productivity is inaccurate and less reliable than that of the day shift. Therefore, decrease in the productivity levels cannot be clearly determined for night shifts. An effective monitoring and control of double shift projects is needed to better allocate resources and not to have lower productivity rates.

Field data capture technologies can provide accurate data that can be used for progress and productivity monitoring in construction projects (Taneja et al. 2011). The previous studies utilized field data capture technologies for tracking (1) labor to measure productivity (Sacks et al. 2003; Costin et al. 2012) and to evaluate working conditions in terms of safety (Cheng et al. 2012); (2) building components and/or materials to measure the physical progress (i.e., completed activities) (Golparvar-Fard et al. 2012; Turkan et al. 2012a; 2012b), and (3) equipment to provide safe working environments for operators (e.g. crane operators) (Teizer et al. 2010), and to monitor the productivity and progress of earthmoving operations by tracking hauling units (e.g. excavators, dump trucks) (Montaser and Moselhi 2012; Akhavian and Behzadan 2012; Pradhananga and Teizer 2013). Previous studies mostly focused on material or worker tracking, and equipment tracking studies were limited to the tracking of heavy construction equipment used in excavation and earthwork operations and in concrete delivery. However, it is not always economically and technically feasible to track labor and material. For example, the numbers of labor and material to be tracked at site are relatively higher than that of the equipment. Therefore, it is much more costly to tag each labor/material when a sensor-based approach is selected. Also, when tracking materials that are transferred in bulks and the materials that are frequently relocated throughout a construction site, obstructions will occur. This condition decreases the performance of image processing techniques for tracking materials. Furthermore, the workers can feel threatened and uncomfortable when they are tagged with tags or being monitored with cameras.

Previous research showed that the construction activities could be monitored based on the identified locations of the equipment used in performing the activities (Sacks et al. 2005). However, there are only a few number of studies that tracked the equipment used in construction of buildings, and in these studies the focus was on tracking the movements of cranes and buck hoists that were used to transport material and workers to determine the productivity of the performed activities (Gong and Caldas 2009; Costin et al. 2012; Yang et al. 2012). On the other hand, previous studies have focused mainly on monitoring the daytime work progress and there have not been any studies that focused on tracking resources under nighttime conditions. However, it is important to monitor the nighttime work in addition to daytime work, so that productivity rates can be closely monitored when there are not many supervisors at the site. Therefore, there is a need for an approach that can be used to track and monitor both the daytime and nighttime work effectively. In this paper, the performance of the field data capture technologies for monitoring double shift projects were evaluated by reviewing previous studies. An envisioned approach is presented for monitoring double shift projects by using data from the selected field data capture technologies that are installed on equipment used at construction site.

REVIEW OF AVAILABLE FIELD DATA CAPTURE TECHNOLOGIES

A summarized review of the available field data capture technologies is provided in two categories focusing on their capabilities for use at night.

Vision-based technologies. Vision-based technologies, such as video cameras or digital cameras, can be used to locate and track equipment, personnel and other resources. However, changes in the illumination conditions (e.g. too dark, too bright) due the existence of shadows or bad weather conditions, have negative effect on the performance of some technologies, such as photo-grammetry and video-grammetry (Park et al. 2011; Golparvar-Fard et al. 2012). Therefore, these technologies are not suitable for use during nighttime shifts. Also, occlusion of objects is another issue that vision-based tracking methods need to overcome, since the occluded/obstructed objects cannot be tracked properly (Brilakis et al. 2011; Golparvar-Fard et al. 2011; Park et al. 2011). One of the common problems that vision-based tracking techniques have is that the cluttered scenes which are observed in construction sites (Golparvar-Fard et al. 2009; Zhang et al. 2009). The images can only show what is within the range and view field, and the objects that are not obstructed by other objects, such as construction machinery (Golparvar-Fard et al. 2009). Moreover, it is challenging to define various mobile objects of different shapes and colors by the image processing algorithm (Park et al. 2011). Tests also reported that, as the object moved away in depth from the video cameras, the associated tracking errors increased (Brilakis et al. 2011).

Laser scanning is one of the vision-based technologies and it is used to collect the spatial data of existing buildings. However, the creation of parametric building models out of the point clouds collected with laser scanners is a manual and time consuming process. Although there are studies that focus on automating this process (Brilakis et al. 2010; Tang et al. 2010), laser scanning is still not fully automated. Since laser scanners use pulses of laser light to measure the distance to the target (i.e. time-of-flight (TOF)), they can operate at night. However, both purchase price and rental price are costly for most of the projects (Dai et al. 2012).

3D camera ranging utilizes TOF and infrared lights (Zhu and Brilakis 2009). The 3D video range cameras are reliable, robust, and easy to maintain, affordable and portable than a laser scanner (Zhu and Brilakis 2009). However, they are limited in terms of measurement ranges (i.e., below 10 m) (Zhu and Brilakis 2009); thus, is not useful for progress monitoring at large construction sites.

Image-based techniques (i.e., photogrammetry and videogrammetry) measures geometric properties of objects by using images and videos. Their performance varies with a some factors such as camera model, resolution, and data capturing range (Dai et al. 2012). Although photo/videogrammetry techniques are less costly and faster than laser scanners, they are negatively affected by occlusion of objects and poor lighting conditions. Thus, they cannot be effectively used in night shifts.

Sensor-based technologies. Sensor-based technologies (e.g., UWB, RFID and GPS) were successfully utilized in localization and tracking of construction resources (e.g., workers, materials, components) (Teizer and Castro-Lacouture 2007; Song et al. 2006; Ergen et al. 2007a; 2007b; Grau and Caldas 2009; Cheng et al. 2011) and of activities such as welding of pipes (Shahi et al. 2013). Another sensor-based approach is on-board instruments (OBI) that are built in construction equipment, for example OBI installed on trucks for tracking excavation work (Pradhan and Akinci 2012). Moreover, wireless sensors that measure a variety of parameters (e.g. movement, acceleration, pressure) can be used to track the necessary information related to the equipment to monitor the progress of the activity that the equipment is used for. Different sensor-based technologies can be fused to determine the type of activities being performed, such as combining Physiological Status Monitoring (PSM) technology and UWB for tracking the body posture and position of workers to track the repeated material handling activities (Cheng et al. 2013). The major limitation of the sensor-based tracking technologies is the need for tagging every item that needs to be tracked. This is especially costly in large construction areas (Brilakis et al. 2011; Golparvar-Fard et al. 2009). Table 1 lists the available field data capture technologies, and presents the disadvantages of these technologies. The technologies which are marked with "*" indicates the ones that can effectively operate both day and night.

Table 1. Comparison of technologies (adapted from Zhu and Brilakis 2009).

Technology	Disadvantages	Technology	Disadvantages
Laser Scanner *	- High cost - Nonportable - Non-real-time data retrieval - Not as accurate as photo/videogrammetry - Affected by occlusion - Cannot track fast moving objects - Need for training to operate	RFID, UWB*	- Affected by dynamic site conditions - Need to tag each element - Need network connection if data stored on network
3D Camera Ranging*	- Short-range distance - Low spatial resolution - Not as accurate as photo/videogrammetry - Cannot track fast moving objects	GPS*	- Cannot operate indoors - Need to tag each element - Costly when tagging large number of elements
Photo-Grammetry	- Manual 3D data retrieval - Non-real-time data retrieval - Low spatial resolution - Limited range distance - Affected by occlusion - Affected by poor lighting conditions	OBI*	- Not available in all equipment - Need to be fused with other data
Video-grammetry	- Limited automated 3D data retrieval - Limited range distance - Affected by occlusion - Affected by poor lighting conditions	Wireless Sensors*	- Need to tag each element - Difficult to set up and maintain necessary infrastructure

***** Technologies that can effectively operate both day and night

VISION

To automatically or semi-automatically track the performance of the critical activities during day and night shifts, it was envisioned to track the equipment (e.g.

concrete pumps, cranes, vibrators) and the temporary work instruments (e.g. formwork) that are used in the execution of these activities. Wireless sensors and RFID are the proposed technologies in this approach (Fig. 1).

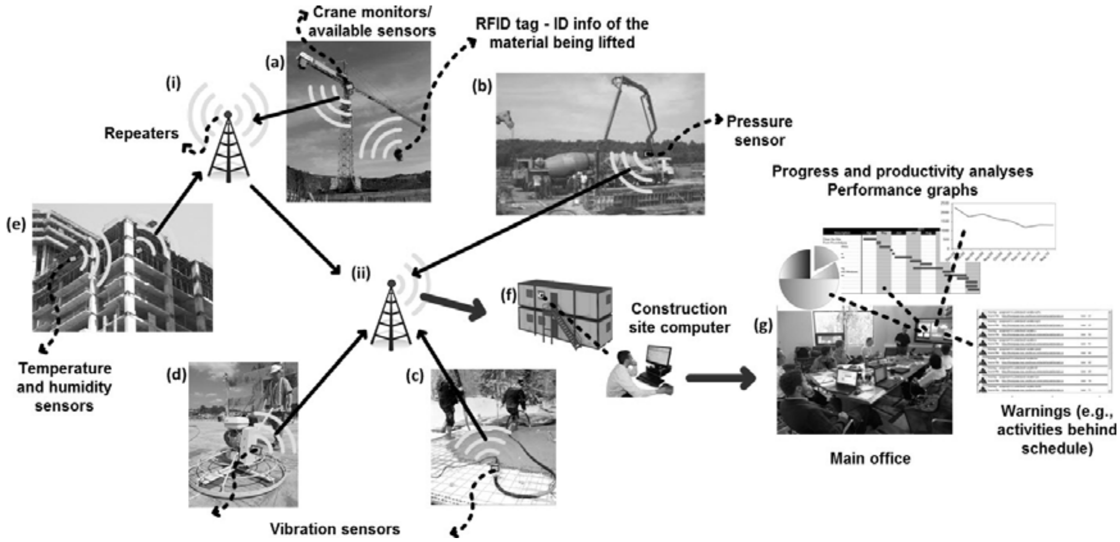

Figure 1. Envisioned approach for tracking equipment in double shift projects.

Existing performance monitoring instruments in equipments are envisioned to be used together with the sensors attached on the equipment. For example, monitoring panels inside crane cabins can provide some information, such as the beginning and final location of the crane boom during a lifting cycle (e.g. carrying the material from the assembly area to the 6th floor of the building), the weight of the material/building component being lifted (e.g. 2 tons of reinforcement planned for installation on the 6th floor). This information can be combined with the ID of the lifted material obtained from an RFID tag to identify the type of material (e.g. reinforcement prepared for 6th floor columns) (Fig. 1a). If the information from a crane panel is not sufficient, data from load sensors will be fused to determine when a material is picked (i.e., stockyard) and consequently where it was dropped (e.g. 6th floor slab). Other means of material handling (e.g. material lift systems and suspended material platforms) can also be tracked to identify the ongoing activities at related locations. Another example is the tracking of concrete pouring activity. Mobile or stationary concrete pumps can be equipped with sensors that can measure parameters such as pressure, vibration, etc. to obtain the duration (e.g. 6 hours) and location (e.g. columns and shear walls on the 6th floor) information of the concrete pour activity, and the amount of the poured concrete (e.g. 200 m^3) (Fig. 1b). Also, other tools can be equipped with vibration sensing devices to obtain the related progress and productivity information of concrete pouring activities by recording where the equipment was used and for how long. For example, concrete vibrators used for settling the concrete in the formwork (Fig. 1c) and power trowels used for providing a smooth finish to concrete surfaces (Fig. 1d). Temporary work instruments, such as table formwork systems used on every floor of the building construction, can also be tracked with temperature and humidity sensors to detect the maturity of concrete and to obtain the time for formwork removal (Fig. 1e). Information obtained via different types and number of sensor devices attached on several equipments will be retrieved by a site office computer (Fig. 1f). As the sensors can directly communicate with the site computer, repeater devices (Fig. 1i and 1ii) that are strategically deployed throughout the site can also transfer the collected information to the site computer in case of obstructions (e.g. walls) between the site computer and the sensors. The collected raw data need to be fused and evaluated to provide the related performance data of the monitored activities. Then this information will be used to determine low productivity rates and to take precautions to prevent delays by the decision makers (Fig. 1g).

CONCLUSIONS

The focus of the previous studies on tracking the performance and monitoring of work at construction sites is daytime activities. However, an approach for monitoring performance and progress for double shift projects are needed. The review of existing field data capture technologies show that technologies pose different challenges for monitoring the work during daytime and nighttime. The vision-based technologies are not suitable monitoring of nighttime work, since they are either (1) sensitive to lighting conditions as in the case of imaging techniques (e.g. photo/videogrammetry) or (2) costly as in the case of laser scanning. Therefore, in this paper an approach that uses sensor-based technologies combined with on board instruments installed at equipment is proposed for performing both daytime and nighttime work tracking. The future work includes identifying the parameters that should be tracked during monitoring construction equipment to obtain progress and productivity information of construction activities.

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