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Real-time drill monitoring and control using building information models augmented with 3D imaging data

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ABSTRACT

The problem of placing embeds into existing reinforced concrete structures without damaging reinforcement bars is an industry-wide challenge for the construction industry. This paper presents research that investigated real-time monitoring approaches for hazardous engineering processes. A conceptual solution for processing and incorporating point cloud data obtained from 3D imaging technologies[1] into the drilling process in was developed. The 3D imaging technologies were used to map the locations of rebar within a section of a railway bridge deck. Once the point clouds were processed, zones which are safe for drilling were automatically detected and saved as a Building Information Model (BIM). The BIM was used to provide real-time feedback to the drill operator about whether it is safe to continue drilling based on the position and orientation of the drill. The results showed the feasibility of real-time feedback for improving the safety, productivity, and quality of engineering processes by helping avoid the time and cost of rework.

1. Introduction

The ability to perceive, comprehend, and analyze the spatial context of their work environment is imperative for construction workers, civil engineering personnel, and industrial workers to complete their tasks competently, efficiently, and safely. Construction worksites are dynamic, unstructured, and continuously evolving workspaces that result in unique characteristics compared to semi-structured workspaces such as industrial, manufacturing, and assembly line worksites [19]. Civil engineering projects, especially in urban areas, are characterized by narrow, constrained workspaces leading to limited visibility of resources resulting in an increase in the probability of collisions between equipment, workers, materials, and infrastructure [7,21].

Projects involving excavation and drilling increase the risk of collisions among equipment and worksite resources due to the occluded vision of operating personnel [16]. Moreover, large equipment operators are faced with the additional challenge of overcoming blind spots on equipment and haul roads [20]. Additionally, certain projects, such as two cranes working in tandem to lift heavy objects, inherently pose constraints on the operators' ability to comprehend their spatial context and challenge their ability to analyze their work environment in order to achieve their objectives [23].

Workers, performing drilling operations to place embeds into reinforced concrete decks, are faced with the risk of striking rebar and buried utility lines. As mentioned above, another example of occlusion hampering operator visibility, and therefore operation efficiency, is the case of excavation. Excavation operations in the presence of underground utility lines are faced with the constant risk of striking buried utilities resulting in significant damage to property, injuries, and fatalities. In the absence of equipment and infrastructure tracking, operators must rely on planning, judgment, and experience to estimate the areas safe for drilling and excavation. Therefore, applications that provide the operators with information regarding their spatial context would enhance their decision making accuracy and can help perform the operations safely with increased levels of efficiency.

Such context-aware computing applications periodically examine and react to changing context. Environmental variables that are typically used to communicate contextual information typically include, but are not limited to, location (where), identity (who), time (when), and activity (what) [5]. Context-aware computing applications are implemented using a mobile, distributed computing system — a collection of mobile

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and stationary sensing and computing devices that cooperate and communicate on the targeted user's behalf [17].

In this paper, the authors present a framework to develop real-time monitoring systems for civil engineering applications. The authors then present a motivating scenario and the technical approach, based on the developed framework, towards solving the scenario specific problems. The authors then present methodologies used to develop context-aware applications that address the scenario. The research that investigated and evaluated the performance of the developed methodologies in comparison with ground truth is also presented.

2. Importance of the research

The construction industry continues to have a high number of accidents and a poor record of safety compared to other industries, despite significant recent efforts to improve safety. The U.S. Bureau of Labor Statistics estimated that the construction industry historically has had the highest total number of fatalities in all industries as shown in Table 1 [4].

Furthermore, the rate of fatality in the construction industry is also relatively high. In 2010, the fatality rate for the construction industry was 9.8 per 100,000 employees — the fourth highest across all industry sectors as shown in Fig. 1 [4].

These fatalities have been ascribed to several contributing factors in order to better understand the factors contributing to these fatalities and to effectively implement safety management practices. The National Institute for Occupational Safety and Health (NIOSH) classifies the contributing factors into the following categories: lack of hazard recognition, lack of coordination of work tasks, worker inexperience, deviation from standard operating procedure, fast-track scheduling, and employers' lack of written task-specific work procedures [14]. Real-time monitoring systems usually address mistakes caused due to a lack of hazard recognition by using context-aware computing techniques.

Lack of hazard recognition occurs either due to the failure to perceive a potential hazardous scenario or due to the failure in interpreting the perceived scenario as hazardous. As mentioned previously, urban construction projects are characterized by narrow, constrained workspaces leading to limited visibility of resources [7,21] resulting in an increase in the probability of failing to perceive and identify hazardous scenarios as such.

A significant percentage of highway construction takes place during night time when the traffic flow is minimal [2,11]. In such projects, the lack of visibility becomes a major contributing factor for workplace accidents. Poor visibility and lack of lighting were found to be a leading cause for accidents involving workers colliding with traffic and construction equipment [2]. Blind spots and obstructions were found to account for nearly 75% of visibility related fatalities in construction [11].

Certain projects, that involve concealed or buried infrastructure, are inherently fraught with problems concerning limited visibility and occlusion. Drilling, excavation, and trenching operations result in frequent accidents when equipment strikes the concealed infrastructure and account for a significant amount of contingency cost, to compensate injured personnel and damaged property, on such projects. Context-sensing technology and/or computer vision techniques are employed to obtain environmental variables that complement and enhance personnel perception in order to identify hazards.

Table 1
Historic chart for number of fatalities per occupation.

	Construction	Protective services	Farming, fishing and forestry	Manufacturing
2010	780	261	276	363
2009	838	244	239	326
2008	977	306	286	354
2007	1172	346	258	380
2006	1273	284	297	423

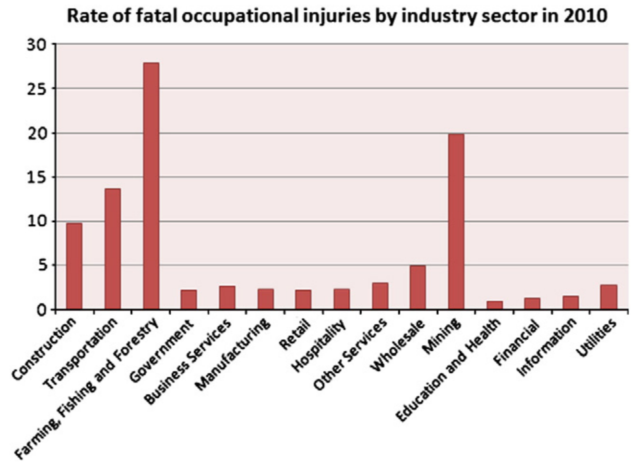

Fig. 1. Fatality rates by occupation in the year 2010 per 100,000 employees.

Localization and tracking technologies have been used to capture changing worksite information to develop real-time monitoring systems to warn workers of danger [1,6,8,15,20–22]. Real-time monitoring systems track the resource's (worker, equipment, objects) spatial-context variables, such as location and orientation, in real-time using localization and tracking technologies and automatically compare the identified spatial-context with predefined scenarios identified as being dangerous. Such monitoring systems help prevent accidents by alerting personnel to potential dangers.

3. Real-time monitoring

By their nature, projects in the civil infrastructure domain consist of mission critical tasks whose failure will result in the failure of operations. In order to avoid operational failure, it is highly desirable to have decision-making support in real-time or near real-time. Real-time systems are defined as systems whose operational effectiveness depends on both the logical correctness and the performance time. Real-time systems and their performance time deadlines are classified based on the consequences of failing to meet their deadlines, as shown below [12].

1) Hard real-time: Systems where missing a deadline leads to a total system failure.
2) Firm real-time: Systems where missing occasional deadlines is tolerable but where the usefulness of a result is zero after its deadline.
3) Soft real-time: Systems where the usefulness of a result degrades after its deadline thus degrading the quality of service.

A system is required to adhere to hard real-time standards if the operation it supports requires events to occur within strict deadlines. Such strong standards are usually required of systems for which not reacting within a certain deadline would result in a great loss to life or property. For example, consider a drill control system used to warn drill operators when they are about to strike rebar or utility lines while drilling for embeds into reinforced concrete decks. Striking rebar might lead to a loss of structural integrity, and striking utility lines might result in injuries, casualties, disruption in service, and loss of property. The drill control must be designed such that the time required for the operator to react to the warning (or for the drill to shut down) is less than the time period after which the drill is expected to strike rebar or utility lines. It is integral that the drill control system is designed with adherence to hard