ARTICLE IN PRESS

Automation in Construction xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Image-based construction hazard avoidance system using augmented reality in wearable device

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ARTICLE INFO

Keywords:
Construction site
Safety management
Proximity warning system
Visualization
Wearable device
Augmented reality

ABSTRACT

Construction sites are inherently dynamic due to continuous resource changes. As construction projects become bigger and more complex, this dynamism can lead to more frequent incidents on jobsites. Safety training, personal protective equipment, and regulations have been applied to improve the safety of construction sites. However, because of the dynamic and congested nature of construction sites, these practices still cannot guarantee safety. This paper proposes a vision-based hazard avoidance system that proactively informs workers of potentially dangerous situations. The system enables workers to recognize and consequently avoid dangers before accidents occur by displaying augmented hazard information on a wearable device. The system comprises of three modules; a vision-based site monitoring module that utilizes image capture device and wearable devices to identify site hazards, a safety assessment module that uses captured image data and fuzzy-based reasoning to evaluate the safety level of each object, and a visualization module that provides actionable information such as hazard orientation, distance, and safety level. The safety information provided by the proposed system can mitigate hazards and improve construction site safety.

1. Introduction

The ever-increasing needs of large-scale infrastructure have resulted in an increase in complex and congested construction sites. The dynamic movement of construction resources and constantly changing site environments in large-scale construction tend to produce a variety of hazards. According to statistics from the United States (US) Department of Labor [1], fatal injuries on construction sites account for 18% of total occupational fatalities in 2014. Thus, safety management on construction sites is crucial for the successful management of construction projects.

Conventionally, to improve safety on construction sites, a safety supervisor utilizes safety management practices such as personal protective equipment (PPE), safety training, and safety regulation. However, the abovementioned statistics show that these efforts provide subpar results for construction workers. PPE can protect only limited areas of the body. Further, safety training is not underpinned by real learning environments [2], and safety regulations incorrectly implemented or implemented under the wrong conditions function poorly [3]. In addition, the poor environment of jobsites including outdoor work, the utilization of heavy equipment, and high noise levels, make it difficult to minimize accidents using conventional safety management practices.

Traditional safety management measures are implemented on a particular jobsite based on lagging information about hazardous situations. Lagging information is here defined as historical information that is generated after accidents occur [4]. Following an accident, the safety manager collects information about the accident context, such as working environment, types of related objects, movement of objects, and construction activities. Countermeasures can then be devised based on the obtained lagging information. However, the lagging information does not allow people to take proactive actions that will enable them to avoid future construction accidents [5,6]. The information may not represent actual hazards on a particular site because working environments on different construction sites vary. Without considering to the uniqueness of the specific jobsite, fatalities cannot be properly avoided.

Leading information associated with safety can be utilized for proactive accident prevention. Leading information is defined as information generated on a particular jobsite on a real time basis. In other words, leading information includes the current surrounding hazards of workers, such as moving vehicles, falling holes, and electrical wires. It is not easy for workers to recognize these hazards because they tend to become less sensitive to their surroundings when carrying out repetitive tasks on noisy jobsites [7]. However, if leading information is appropriately delivered to the workers, their awareness of the working

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http://dx.doi.org/10.1016/j.autcon.2017.06.014
Received 4 August 2016; Received in revised form 14 April 2017; Accepted 10 June 2017
0926-5805/

circumstances can be enhanced, thereby avoiding hazardous situations. The manner in which the information is presented is also paramount. For example, textual information is accurate but it requires interpretation. Conversely, visual information with respect to the worker's perspective can be intuitively understood. Thus, the information should be generated and visualized in a manner that fosters effective recognition of the hazards.

This study focused on struck-by accidents on construction sites. According to the 2014 Census of Fatal Occupational Injuries in the United States (US), "struck-by objects or equipment" is the second biggest cause of occupational injuries, excluding transportation incidents. Struck-by accidents accounted for 10% of the total of 4821 incidents, just next to "falls to lower level" incidents (14%). In the US excavation industry, > 60% of deaths were attributed to struck-by accidents between 1992 and 2002 [8]. Considering the dynamic, noisy, and complex nature of construction sites, it is not difficult to see why struck-by accidents are the leading cause of occupational injuries in the construction industry. Moreover, most struck-by accidents are caused by the failure to recognize the dangerous approach of objects. Misunderstanding a hazardous situation is the most frequent human factor contributing to struck-by accidents [9]. This means that proper recognition of dangerous approach by objects can be a practical solution for struck-by accidents on construction sites.

This paper proposes a safety information system capitalizing on the study presented in [10]. The system enables workers to take proactive measures by using safety information associated with their unique construction sites. The safety information encompasses the spatial context of the jobsite with reference to each particular worker. This safety information is derived from an image-based safety assessment system and visualized using augmented reality in a wearable device. With this system, both the manager and also the worker can instinctively recognize a hazardous situation and take timely and proper action against it. The system comprises of three modules: vision-based site monitoring, safety assessment, and hazard information processing and visualization modules. The vision-based site-monitoring module acquires images and sensor data from a stationary camera and a wearable device and extracts construction site hazard information from them. The safety assessment module assesses the safety of each object using fuzzy inference logic. It can quantify the safety condition of workers on the jobsite without human judgment. Finally, the hazard information is visualized using the safety condition and the worker's spatial information. The hazard information is processed from the perspective of the worker and displayed in augmented reality using the interface of the wearable device. The results of a field experiment conducted on a real construction site confirm the efficacy of the proposed system.

2. Proximity warning system: current state and challenges

2.1. Proximity warning system (PWS)

PWSs have been proposed as a way to inform workers of approaching objects. A PWS is designed to warn workers of close equipment that is dangerous [11]. PWSs are widely used to prevent collisions with objects [12]. They operate based on the location of each object so that the spatial relationships among objects are identified. Once the distance from an object is determined, predefined rules are used to decide whether or not to sound an alert. Various types of warning signals, including visual, acoustic, and tactile signals, are employed.

The performance of a PWS depends on the type of technology used for object tracking, such as radio frequency (RF) sensing, global positioning system (GPS), ultrasonic sensing, radar, magnetic field, and vision-based technology. Each method has distinctive features that allow it to measure the proximity between objects. These distinctive features include detection range, existence of additional sensors attached to the object, processing time, and installation cost. Technologies representative of PWSs are reviewed in terms of their advantages and disadvantages below.

2.1.1. Radio frequency (RF)

RF sensing technology employs electromagnetic signals emitted from devices mounted on objects to determine their proximity to each other [13–19]. This technology empirically determines the distance between objects with attached tags using signal strength. Warning signals are activated to inform users of approaching objects when the objects are closer than a predefined distance. RF technology can be classified into two types, active and passive, according to the existence of a power source in the signal tags. Active RF technology requires a power source for each object for longer-range detection, whereas passive RF technology needs a power source only in the signal-emitting device for shorter-range detection. The location of an object can be estimated using as little as three signal stations. Ultra-Wideband (UWB), an active RF technology, can be utilized to track objects [20–22]. Using UWB technology, signals can be robustly transmitted using relatively low power for object localization with centimeter-level errors.

Using RF, a PWS can easily be implemented on construction sites. It requires only the adjustment of signal strength and a data processing step. The technology is not dependent on line of sight, thus allowing objects located behind obstacles to be detected. However, RF-based systems are limited in the sense that RF signals can experience interference with multipath fading effects [12] and the fact that every object to be detected must be equipped with a tag.

2.1.2. Global positioning system (GPS)

GPS is used to identify the absolute location of objects [12,17,18,23,24]. Latitudinal and longitudinal data is obtained from the GPS sensor of the particular object and, using the absolute location of objects, the proximity between the objects of interest can be monitored. The speed and heading direction can also be extracted to detect the dangerous approach of equipment [12]. A safety supervisor can manually limit access to a dangerous area by using this hazard zone information [23].

The latitude and longitude data from a GPS sensor can provide location information in a more global coordinate system than other tracking methods. GPS sensors can also cover wide areas of construction sites. However, GPS sensors have various cost ranges that increase in accordance with their accuracies. In addition, the performance of the GPS sensors is not guaranteed if the signal is blocked by other objects or buildings.

2.1.3. Vision-based systems

Computer vision has been applied to track objects from a series of images, without human intervention [25–30]. Objects are localized based on their pixel information including changes in brightness, intensity, and other local features. Based on the tracked objects in images, object categories, velocities, locations, and violations of safety rules can be monitored using an image-based safety monitoring system [26]. Sudden slope failure can also be detected based on changes in pixel intensity [28].

The computer vision technique is capable of identifying multiple objects' information from construction site images without additional devices such as tags and other sensors. The location of objects and also detailed information such as types and velocities of objects can be derived from these images. However, vision-based systems do not perform as designed under poor lighting conditions, such as in snowy, rainy, and/or dusty weather.

2.2. Challenges and methodology selection

Each of the systems above has distinct advantages and disadvantages. RF-based PWSs do not require high-level algorithms or