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# Predicting movements of onsite workers and mobile equipment for enhancing construction site safety

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ABSTRACT

Tens of thousands of time-loss injuries and deaths are annually reported from the construction sector, and a high percentage of them are due to the workers being struck by mobile equipment on sites. In order to address this site safety issue, it is necessary to provide proactive warning systems. One critical part in such systems is to locate the current positions of onsite workers and mobile equipment and also predict their future positions to prevent immediate collisions. This paper proposes novel Kalman filters for predicting the movements of the workers and mobile equipment on the construction sites. The filters take the positions of the equipment and workers estimated from multiple video cameras as input, and output the corresponding predictions on their future positions. Moreover, the filters could adjust their predictions based on the worker or equipment's previous movements. The effectiveness of the filters has been tested with real site videos and the results show the high prediction accuracy of the filters.



## 1. Introduction

The construction site is typically dirty, disordered, and cluttered with different kinds of resources. Also, it is characterized by a constantly changing environment with the movement and interactions between workers and equipment. In such a chaotic and dynamic place, an incredibly high number of construction activities take place, which easily lead to construction accidents and work-related injuries and deaths. For example, in Canada, around 27,000 accepted time-loss injuries and 200 fatalities were reported in the construction sector every year from 2010 to 2012, according to the Association of Workers' Compensation Boards of Canada [1,2]. Similarly, the U.S. Bureau of Labor Statistics noted that 183,000 construction workers were injured, and 775 workers died on the job with a fatal work injury rate of 9.5 deaths per 100,000 fulltime equivalent workers [3]. The large number of injuries and deaths makes the construction sector one of the most dangerous job sectors over the world.

Many of construction accidents are struck-by accidents, i.e. the workers being struck by mobile equipment on the construction sites [4]. The stuck-by accidents could occur, even when the workers wear high visibility clothing on the sites as required by existing safety codes and standards. In 2012, 156 fatalities due to the struck-by accidents were reported by the U.S. private construction industry [5]. In British Columbia, there were a total of 6622 claims related to the struck-by accidents from 2006 to 2008, which represented 22% of claim volumes and 14% of claim costs resulting from construction accidents [6]. The situation becomes even worse in road construction projects, where workers might be struck by mobile equipment for construction and maintenance as well as by cars, vans, and motorcycles. 442 fatal injuries (53%) on road construction sites during the 2003–2010 periods were due to the workers being struck by vehicles or mobile equipment [3].

In order to address this site safety issue, several research studies have been proposed. They focused on the use of remote locating and tracking techniques to perform simple equipment-worker close proximity alerts. These techniques include but are not limited to Radio Frequency Identification (RFID), Ultra Wideband (UWB), and Global Positioning Systems (GPS) [7]. They require remote sensors to be physically installed on the equipment and workers, so that the signals sent from the sensors could be read and interpreted. This way, the positions of the equipment and workers on the site could be located and tracked.

Compared with existing research studies, this paper relies on computer vision techniques to estimate the positions of construction

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workers and equipment. Moreover, the movements of the workers and equipment are predicted to get their possible positions in a short period of time. This way, the potential collisions between the workers and equipment could be avoided in a proactive way. In the paper, both position estimation and prediction parts have been integrated into one framework. Under the framework, the current positions of the equipment and workers are first estimated with the live videos collected by two or more cameras on the construction site. These positions are then input to a Kalman filter. In general, the Kalman filter is an optimal estimator that is able to infer parameters of interest from indirect, inaccurate and uncertain observations [8]. Here, the filter is specially designed to model motions (i.e. positions, velocities, and accelerations) of equipment and workers based on a series of position measurements, including noise and other inaccuracies, observed over time. The designed filter adjusts its prediction parameters with the positions newly input as well as the history of the positions estimated previously. This way, the predictions for the positions of the equipment and workers on the site could be made.

The framework in this paper does not require the installation of any remote sensors on the equipment and workers. This makes the method affordable at most construction sites, especially the large-scale ones, where hundreds of construction workers and equipment could be involved. Also, the method could be used in the case when the installation of physical sensors is not applicable. For example, in a highway construction project, the workers on the site might be struck by traffic vehicles, such as cars, vans, and motorcycles. However, it is difficult to install the physical sensors on the traffic vehicles and track their positions for the purpose of issuing the close proximity safety warnings to the workers.

The effectiveness of the proposed framework has been tested on real site videos collected by two cameras. The results showed that the average estimation errors were 0.26 m and 0.28 m for the movement of the worker and vehicle, while the corresponding prediction errors were 0.38 m and 0.18 m. The longer the predictions were made, the more accuracy the predictions could reach. The low estimation and prediction errors during the tests indicated that the proposed method in this paper could approximately estimate and predict the movement of the equipment and workers in advance. The predictions could be used to reduce the chance of struck-by accidents and therefore has the potential to enhance construction site safety. The enhancement of on-site construction safety will bring several benefits. For example, it could improve the workers' morale and job satisfactions, and increase their productivity. Also, it could reduce project costs directly and indirectly, especially considering that the average cost per case of death or injury could reach tens of thousands of dollars in the construction industry. The prevention of one death or injury per day might lead to the cost savings of millions of dollars per year.

## 2. Remote locating and tracking for site safety enhancement

Construction researchers and safety professionals believe that existing site safety regulations are not sufficient, considering the unsatisfactory safety records in the construction industry. Therefore, it is necessary to add an extra level of safety measures to protect construction workers [9]. One of the proactive safety measures is to provide equipment-workers close proximity warnings. It means that a safety warning will be issued to an equipment operator for his/her attention, when on-foot workers are near-by [4,10]. The close proximity warnings were expected to reduce the accidents that happened in the blind areas of equipment, as investigated by Ruff [7]. Another proactive safety measure is to create virtual fences. Typically, the virtual fences are created around known dangerous areas on the job site. If workers are approaching the areas, alarms will be issued to alert them [11–13].

In order to provide both proactive safety measures, it is necessary to remotely locate and track on-foot workers and mobile equipment on the construction sites. So far, several remote sensing techniques have been investigated, including GPS, RFID, UWB, etc. GPS is an outdoor satellite-based worldwide navigation system, which relies on a constellation of Earth orbiting satellites to determine the positions of GPS receivers [14]. RFID is an automatic identification technology. It is mainly used for the identification of objects on the site, but could also approximately locate them based on the radio waves communication between the RFID tags and readers [15]. UWB is a short pulse radio frequency waveform, which could provide accurate object location information based on the time-difference-of-arrival measurements [16,17].

These remote sensing techniques mentioned above all require attaching physical signal readers and tags on the equipment and workers. For example, in the method of Marks and Teizer [4], they have an in-cab device for mobile equipment and personal device for ground workers, which contain antenna, reader, chip, battery, etc. Similarly, Ruff had the GPS antennas installed on the surface mining equipment in order to locate the equipment and evaluate its GPS-based proximity warnings [7]. If the workers and equipment need to be physically tagged, it would lead to a significant amount of additional costs for the general contractors, although the price of the tags and sensors keeps decreasing. In addition, tagging construction workers could be opposed by the unions due to the associated privacy issues and health concerns. Moreover, in a highway construction project, the workers need to be protected from traffic vehicles, such as cars, vans, and motorcycles, but it is impossible to tag, locate and track those traffic vehicles for providing the proximity warnings.

Compared with the remote sensing techniques with physical signal sensors, readers, and tags, the vision techniques could also provide the potentials to remotely locate and track the workers and equipment on the construction site. One of well-known techniques to provide three dimensional (3D) position information is referred to as stereo vision, which reconstructs the 3D position of an object through the camera calibration and triangulation principles [18]. So far, several research studies based on stereo vision have been introduced and applied in the construction field, but most of them focused on the reconstruction of static scenes. For example, Son and Kim used a stereo vision system to acquire and recognize 3D structural components [19]. Rashidi et al. relied on stereo vision to generate dense depth maps for the transportation infrastructure, such as highway bridges [20]. Fathi and Brilakis proposed a novel method for creating as-built models of sheet metal roof panels to facilitate the digital roof fabrication process with the aid of stereo vision [21].

As for enhancing site safety, Steele et al. once mount a stereo camera on the rear of an off-highway dump truck [22]. The stereo camera helped the truck driver to identify possible obstacles on the mining site [7]. Han and Lee analyzed workers' unsafe actions that may cause incidents (e.g. fall from a ladder due to leaning too far to one side or reaching too far overhead) from the videos captured by stereo cameras [23]. Weerasinghe and Ruwanpura developed a conceptual model, Automated Multiple Objects Tracking System, to track construction objects, such as workers and tools, with fixed video surveillance cameras [24].

One main benefit of using vision techniques to locate and track construction workers and equipment is that the workers and equipment do not have to be physically tagged. Therefore, several issues related to physically tagging the workers and equipment in the remote sensing techniques could be addressed. Also, it becomes more and more common to place the cameras around the site to capture job site activities and record project construction progress [25]. The cameras could take pictures or videos with a high resolution and wide field of view. Therefore, the workers equipment, and even non project-related entities, such as traffic vehicles in highway construction projects, could be remotely monitored with a limited number of cameras.

## 3. Objective and scope

The ultimate goal of this ongoing research work is to investigate the feasibility of creating a proactive, real-time safety alert system with the