

Dynamic equipment workspace generation for improving earthwork safety using real-time location system



Faridaddin Vahdatikhaki^{a,1}, Amin Hammad^{b,*}

^a Building, Civil and Environmental Engineering Department, Concordia University, 1455 De Maisonneuve Blvd. West, Montreal, Quebec H3G 1M8, Canada

^b Concordia Institute for Information Systems Engineering, 1455 De Maisonneuve Blvd. West, Montreal, Quebec H3G 1M8, Canada

ARTICLE INFO

Article history:

Received 22 September 2014

Received in revised form 24 February 2015

Accepted 10 March 2015

Available online 7 April 2015

Keywords:

Dynamic equipment workspace

Earthwork equipment

Real-time location systems

ABSTRACT

Earthwork equipment accounts for a large proportion of the fatalities on construction sites. According to the U.S. Bureau of Labor Statistics, in the period between 1992 and 2002, struck by vehicles and struck by objects (e.g., vehicle parts, vehicle loads, or falling vehicles) were identified as the causes of 30% and 24% of fatal equipment-related accidents on excavations sites, respectively. It is therefore of a paramount importance to improve the safety of construction sites by increasing the peripheral awareness of the operators of earthwork equipment. Several research works have investigated numerous collision avoidance systems that exploit real-time location systems and proximity measurements to mitigate the risk of accidents on excavation sites. However, these systems often detect collisions based on using the workspaces that only account for the geometry and the degrees of freedom of the equipment, and thus disregard the state-dependent characteristics of equipment. This results in reserving a large space for every piece of equipment, which reduces the applicability of these systems in congested sites. Therefore, this paper proposes a novel method for generating dynamic equipment workspaces based on the continuous monitoring of a spectrum of equipment-related information, i.e., the current pose/state of the equipment, and the speed characteristics of each movement. This method uses the required operation stoppage time to determine how much space needs to be reserved for each piece of equipment. A case study is conducted to validate the proposed method. It is shown that the proposed method has a strong potential in capturing the hazardous areas around the equipment and triggering warnings in view of the impending movements of various pieces of equipment. Also, the proposed method proved to have potential applications in actual projects in congested sites where space is limited.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

With only less than 5% of the U.S. work force, the construction industry claims around 20% of fatalities and injuries in workplaces [30]. In the U.K., in addition to 25,000–30,000 injured, approximately 1500 people are losing their lives on construction sites in a typical decade [15]. Earthwork equipment accounts for a large share of injuries on construction sites. According to Hinze and Teizer [25], one-fourth of construction fatalities are due to equipment-related incidents. 52.6% of reported deaths in the excavation work between 1992 and 2002 involved vehicles [34]. Equipment-related incidents are usually categorized into struck-by and caught-in/between accidents [24]. In the U.S., 428 equipment-related struck-by and caught-in/between accidents were reported

between 1995 and 2008 [53]. In the U.K., of the total number of fatalities in a period of 7 years (1996–2003), 14% were identified to have been caused by being struck by a moving vehicle [26]. According to McCann [34], the reports from Bureau of Labor Statistics indicate that in the period between 1992 and 2002, the causes of 30%, 24% and 12% of fatal equipment-related accidents on excavations sites were identified to be struck by vehicles, struck by objects (e.g., vehicle parts, vehicle loads, or falling vehicles), and caught in/between, respectively. Among various types of equipment involved in struck-by accidents, truck and excavators are the most prevalent, together accounting for more than 50% of reported struck-by accidents between 1997 and 2000 [24]. Among those who fell victim to equipment-related fatal accidents in excavation work, 52% and 34% were the operators and workers on foot, respectively [34].

These statistics suggest that earthwork operations are in need of enhanced safety to avoid damages, injuries and fatalities. With this need in mind, many researchers have explored a wide range of solutions to mitigate the risk of accidents on excavation sites

* Corresponding author. Tel.: +1 (514) 848 2424x5800; fax: +1 (514) 848 3171.

E-mail addresses: f_vahdat@encs.concordia.ca (F. Vahdatikhaki), hammad@ciise.concordia.ca (A. Hammad).

¹ Tel.: +1 (514) 848 2424x7074; fax: +1 (514) 848 3171.

through reducing the possibility of collisions between equipment through a proper planning method [9,33,43,23,35]. These methods identify the spaces required for the safe completion of different activities, i.e., activity workspaces, and try to reduce the overlap between them.

Despite the effectiveness of these methods in reducing the possibility of collisions between different teams of equipment at a macro level, they are not fully capable of averting safety risks emanating from human errors and unforeseen circumstances. Additionally, space is a limited resource that many of earthwork projects do not have. These methods are not able to effectively improve the safety in congested sites, given that activity workspaces may overlap in many instances.

While there could be various different root causes behind the equipment-related fatalities, e.g., loss of attention, unsafe driving habits, distractions, visibility and blind spots, etc. [25], the majority of equipment-related accidents can be avoided if the dangerous areas around the equipment are monitored in real time and the operators are warned against any intrusions into these areas. As a result, it is of a paramount importance to devise a complementary real-time mechanism to reduce safety risks based on the current pose and state of the equipment. To this end, researchers considered systems that generate warning against dangerous proximities using radar-based proximity sensors [39,13], vision-based tracking [12], and Real-time Location Systems (RTLs) such as the Global Positioning System (GPS), Radio Frequency Identification (RFID), and Ultra Wideband (UWB) [5,8,45,6,54,22,52,55]. These methods are applied at the monitoring phase with the intention to ensure that different pieces of equipment do not collide with one another. Similar to the methods used at the planning phase, these methods consider the space around the equipment that should not be trespassed by other equipment to avoid potential collision in the immediate future. Because these spaces are applied to equipment, as opposed to the activities, and their shapes are dynamically changing based on the current pose of the equipment, they are referred to as Dynamic Equipment Workspaces (DEWs) in this paper. The correlation between the two types of workspace is that an activity workspace must be the envelope that contains all the DEWs generated by the fleet assigned to that activity over the scheduled period. Although DEWs are alternatively termed in the literature as “safety envelopes” [5,55] or “safety zones” [40], the authors believe that, given the above correlation, it is preferable to use the unified term “workspaces” for both activity and equipment.

Nevertheless, to the best of the authors' knowledge, the existing methods for generating DEWs do not take full advantage of the combination of valuable pose, state, geometry, and speed characteristics of the equipment to accurately estimate the shape of DEWs. Consequently, the present research aims to leverage a set of information regarding the geometry, pose, state, and speed characteristics of the equipment to determine the shape and size of the workspace based on the required stoppage time of the equipment so as to secure the early identification of potential collisions while making a more economic use of space.

The structure of the paper is as follows. First, the previous relevant studies are presented. Then, the DEW generation method is elaborated. Next, a case study is elucidated as a means to validate the proposed method. Finally, the conclusions and future work are presented.

2. Literature review

2.1. DEWs related research

Two approaches can be found in the research addressing the generation of DEWs. While some researchers use only the

equipment geometry and pose for the generation of DEWs, others also consider the speed characteristics of the equipment.

2.1.1. DEWs based on the equipment geometry and pose

Several methods have been developed to generate DEWs based on the application of different types of RTLs. Generally, the methods of generating DEWs based on the proximity measurements can be categorized into two groups. Some methods are totally independent of the pose, state and speed data; and therefore they over-conservatively reserve the space within a radius (r) of the equipment (called here cylindrical workspace, Fig. 1(a)). For instance, CRC Mining [14] developed the Shovel Load Assist System that uses the combined data from a laser scanner, GPS and pulse radio to locate the trucks and dozers in the vicinity of the shovel to avoid the potential collision with them. There are many examples of cylindrical workspaces in previously proposed systems for collision avoidance on construction sites [7,45,11,32,31,37,29]. Other methods detect the shortest distance between the two pieces of equipment and use a minimum acceptable threshold for generating the warnings, which is equivalent to considering only the pose of the equipment and creating a buffer of width (b) around the equipment (called here buffer workspace, Fig. 1(b)). For instance, Kim et al. [28] proposed a method for real-time collision avoidance systems that uses laser range finders to model the obstacles on the site and then calculates the shortest distance of the equipment to various surrounding obstacles. If a threshold distance is violated, the warning is generated. A GPS-based collision avoidance system was developed by Wu et al. [52], with the central objective to assist crane operators with handling concrete buckets in a dam construction project. Talmaki and Kamat [42] proposed the application of hybrid virtuality for the simulation of the actual jobsite and detecting hazardous proximities between various objects using a combination of 3D CAD models, terrain models, GPS and sensory data, and input from a Geographic Information System (GIS). This method uses proximity measurements as the basis for the collision detection. Zolynski et al. [55] developed a two-layer safety mechanism for autonomous excavators that generates a safety buffer around the equipment based on the present pose of the equipment and avoids collisions with the surrounding objects using a laser scanner. Another instance of the methods that use buffer workspace is developed by Guenther and Salow [22].

However, as stated in Section 1, the cylindrical workspace reserves a large space for the safe performance of the equipment, considerably diminishing its effectiveness for the application in a

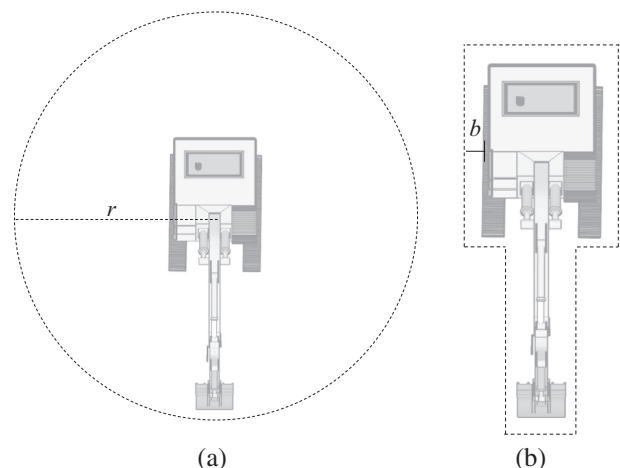


Fig. 1. (a) Cylindrical workspace, and (b) buffer workspace (the model of excavator is obtained from Google 3D Warehouse [21]).

Download English Version:

<https://daneshyari.com/en/article/10281707>

Download Persian Version:

<https://daneshyari.com/article/10281707>

[Daneshyari.com](https://daneshyari.com)