VISUAL WARNING SYSTEM FOR WORKERS' SAFETY ON ROADSIDE WORK ZONES

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ABSTRACT
Growing traffic on US roadways and the use of heavy machinery on road construction sites pose a critical
safety threat to construction workers. This paper summarizes the design and development of a workers’
safety system using Dedicated Short Range Communication (DSRC) to specifically address the safety of
workers in an active work zone around heavy machinery. The proposed system has dual objectives. The
first objective is to improve worker safety by providing visual guidance to the operators of the
construction vehicles. This visual guidance keeps the operators of the heavy machinery well informed
about the whereabouts of workers in close proximity while the vehicle is in operation. The second
objective of the proposed system is to improve the work zone traffic mobility by dynamically posting
suitable speed limits and other warning messages on the DSRC equipped Portable Changeable Message
Signs (PCMSs). The PCMSs detect the workers’ presence in an active work zone and appropriately warn
the drivers of passing vehicles.
A prototype was developed and field tests were conducted to demonstrate and evaluate the
performance of the proposed system. The evaluation test results show that the system can successfully
identify the presence of workers around a construction vehicle on an Android tablet with acceptable
distance (1.5 – 2 m) and direction (15 – 20 degrees) accuracies. Furthermore, the test results show that a
DSRC equipped PCMS can successfully post a suitable speed limit corresponding to the presence of
workers in its vicinity.

Keywords: Work zone safety, DSRC, Construction vehicle, Worker safety, PCMS
INTRODUCTION

Vehicles present in and around a work zone can pose a major safety risk to nearby workers. Each year over 20,000 injuries and more than 100 fatalities occur at US road construction zones. The cause for nearly two-thirds of these fatal incidents is a worker being struck by a vehicle or being involved in a vehicle/mobile equipment collision. Most of these fatalities are due to runovers/backovers and 38% of them involve a heavy construction vehicle (7).

Although strict enforcement of lower speed limits and traffic control regulations is necessary to make the road construction sites as safe as possible, lower speed limits alone cannot guarantee workers’ safety. Furthermore, unnecessarily posting lower speed limits throughout a long work zone where workers are not present in all sections, potentially decreases traffic mobility. The resulting congestion may build up, exacerbating the risk of rear-end crashes (2).

Many studies and research projects have been performed to make work zones safer and improve traffic mobility through work zone sites (3-8). New technologies and systems have been proposed to issue lane departure warnings (3), to send forward collision warning messages in a work zone via a smart phone application (4) and to detect pedestrians approaching the vehicles using multiple cameras (5). Similarly, Dedicated Short Range Communication (DSRC) based traffic information systems for work zones have been proposed to estimate work zone travel parameters such as travel time and relay this information to the vehicles approaching the work zone (6-7). In a recent project, an intelligent awareness system has also been designed to estimate the trajectory of the passing traffic and evaluate the risk level that it imposes, using a Global Positioning System (GPS) based algorithm (8).

In most of the above mentioned approaches, the emphasis is on preventing work zone traffic accidents by providing situational awareness to the passing-by drivers, allowing them to practice caution when travelling through active work zones. However, these solutions do not target to provide situational awareness to the operators of the heavy construction vehicles which are present in active work zones. These construction vehicles can potentially cause harm not only to the workers but also to passing vehicles. In this work, the focus is on preventing work zone accidents such as workers being backed over by dump trucks or workers being struck by mobile equipment, by bringing situational awareness to the operators of the construction vehicles. The proposed safety/warning system uses GPS to determine the relative position of the workers around a construction vehicle and proactively provides constant visual situational awareness about the proximity of the workers to the construction vehicle’s operator. In this approach, each worker is required to wear a device containing a GPS receiver to determine his or her position as well as a DSRC device to communicate this position information to the construction vehicle, which is also equipped with a DSRC device, and a GPS receiver. The relative position of each worker with respect to the construction vehicle is then estimated at the onboard processing unit of the construction vehicle before communicating this information to the operator using a monitor screen. This mechanism will keep the construction vehicle’s operator constantly aware of the presence and movement of the workers in the vicinity, while operating or moving the construction vehicle.

Furthermore, the proposed system addresses the issue of traffic mobility by posting a variable speed limit for passing traffic using DSRC equipped Portable Changeable Message Signs (PCMSs). Currently, static work zone signs are used to alert drivers to worker presence on many work zones, or if dynamic signs (e.g., PCMSs) are used, the display message still needs to be changed manually. Although, this could be done remotely through a wired or a wireless communication interface, some kind of manual input needs to be provided about workers presence, or to post lower speed limits. The proposed system overcomes this issue. The system can auto-detect presence of workers and post an appropriate speed limit on the DSRC equipped PCMS. This can be especially useful for longer work zones spanning many miles where some parts of the work zone may be actively populated with workers while some are inactive. The DSRC equipped PCMSs can alert drivers to workers’ presence and post lower speed limits on active parts of the work zone while regular speed limits can be posted on the inactive sections, improving overall traffic mobility.

In the proposed system, DSRC based wireless communication is used to transmit location information from workers to the construction vehicles and the PCMSs. However, various other wireless
communication technologies could be used for the same purpose. One potential advantage of using DSRC over other technologies is to include the trajectories of passing vehicles in the visual guidance provided to operators of heavy construction vehicles in addition to showing them the presence of the workers. This is possible as the market penetration of DSRC grows.

The rest of the paper is organized as follows. The next section describes the architecture and the objectives of the proposed system as well as its principle of operation followed by the field test results and discussion section, which gives details on the functionality of the newly developed system. The conclusions are given in the last section.

SYSTEM ARCHITECTURE AND OBJECTIVES

A visual warning safety system has been designed to improve workers’ safety on active work zones. The conceptual architecture of the proposed system is shown in Figure 1(a). The system has dual objectives; first to provide visual guidance to the construction vehicle’s operator about the presence of the workers in its close proximity via a monitor screen, and second to alert the passing traffic about active work zones and post variable speed limits depending upon the workers’ presence in the field. The proposed system requires each worker to wear a miniaturized DSRC device embedded in his or her safety vest, which will constantly broadcast that worker’s GPS location to the DSRC device installed on a nearby construction vehicle or a nearby DSRC equipped PCMS, using DSRC based communication. The DSRC unit on the construction vehicle is connected with a monitor screen (shown in Figure 1(c)) that will show the real time positions of the workers to the operator to warn him or her if a worker is dangerously close. The system also helps improve traffic mobility by dynamically changing the work zone speed limit posted on the PCMS depending upon if the PCMS’s DSRC unit can detect at least one worker’s presence within its direct wireless access range. To achieve the above mentioned objectives, the proposed system will need to have three critical components which are described in more detail below after explaining the principle of operation of the proposed system.
FIGURE 1 Conceptual architecture diagram of (a) proposed system (b) DSRC-PCMS interface, and (c) DSRC-Monitor interface.

**Principle of Operation: The Concept of Relative GPS Accuracy**

Before discussing various components of the proposed system, we would like to describe the concept of relative GPS accuracy, which is critical for the proposed system to work. To provide visual alerts to the construction vehicle’s operator, the position information for both the worker and the construction vehicle is needed. In the proposed system, we are using GPS receivers to acquire the position information.

Absolute position error of ordinary GPS technology is around 5 m (9-11) which is too high to provide accurate visual guidance. However, differential GPS technology can predict the position with less than 1 m error (10-11). Differential GPS units work on the principle of subtracting two GPS signals, which cancels out the major part of the position error resulting from atmospheric (troposphere and ionosphere) disturbances, since that error remains the same for both GPS signals (10-13). When two separate GPS receivers of the same kind are used, to determine the distance between them the same principle of cancellation of common error is applicable and the relative distance error is reduced significantly as compared to absolute position error, which is conceptually shown in Figure 2(a). The error in the absolute position (bigger circle) of each receiver is in the range of 4-5 m but the error in the relative distance becomes much smaller (the small circle) as shown in Figure 2(a). The residual error in the relative
distance measurement depends upon the inherent GPS receiver accuracy and in some cases multipath interference, if present.

To further examine this hypothesis, we measured the relative distance between two different GPS receivers in many orientations and compared that to the calculated distance achieved by their GPS locations as shown in Figure 2(b). Although, each time, the absolute position error was much bigger, the relative distance error was less than 2 m suggesting that ordinary GPS receivers can be used in the proposed system.

FIGURE 2 Conceptual diagram to show (a) absolute and relative position errors, and (b) measured test results.

DSRC Based Wearable Safety Device
The wearable safety device (WSD) needs to be worn by each worker at all times for the successful deployment of the proposed safety warning system. For this purpose, WSD can be embedded in the worker’s vest or safety helmet, or can be designed as a wrist band. The preferred method is to embed WSD in the vest since the workers almost always wear the vest while in the field. The conceptual high level architectural design of the proposed WSD is shown in Figure 3. The WSD’s essential components are a GPS receiver and a DSRC radio to respectively obtain worker’s location and communicate it to construction vehicle. Additionally, the WSD may also contain a ‘panic’ and a ‘caution’ trigger button.

The vision behind panic and caution modes is that these can be activated by the worker under special event driven circumstances. Both options override the normal operation of the WSD and force the device to transmit event specific messages. The panic mode can be activated by the worker when the worker has been involved in an accident or is in dire need of help. The caution mode can be activated when the worker feels that he or she is working in a potentially dangerous situation, so he or she can activate the caution mode to ensure that his or her presence is noticed by the construction vehicle’s operator.
The various components of the WSD except the GPS receiver antenna can be integrated in a small manageable device, which can be embedded in the vest as shown in the inset of Figure 3. The GPS receiver antenna is proposed to be located near the shoulder strap of the vest because GPS receiver works the best in an open-to-sky scenario. We have worked with a DSRC device manufacturer to evaluate the feasibility and develop such a WSD based on the proposed design. According to our initial findings, it is feasible to develop a small WSD to be embedded in the worker’s vest. However, we have not yet actually developed such a device so regular vehicle DSRC units were used for the field tests which will be described later in the paper.

![FIGURE 3](image)

**FIGURE 3** High level architectural design of the proposed WSD for worker. The inset shows the worker’s vest with embedding locations of WSD and GPS antenna.

### Onboard DSRC and Monitor

On a construction vehicle, there needs to be a monitor screen through which the visual information will be communicated to the operator of the construction vehicle, as well as a DSRC device which can receive location information from nearby workers and process it before displaying on the monitor screen. In the developed prototype system we have used a regular vehicle DSRC unit as onboard unit for construction vehicle and an Android based tablet to provide visual alerts about the presence of the workers (shown in Figure 1(c)). We have developed a Java based software application for the Android tablet to display the workers’ locations around the construction vehicle on the tablet screen. The communication interface between DSRC onboard unit and the tablet is a wireless communication link using User Datagram Protocol (UDP) and the DSRC onboard unit’s local Wi-Fi network. The developed DSRC-monitor interface and Java based application are used for the field tests of the proposed system, which are described later.

### DSRC Equipped PCMS

Another crucial aspect of the proposed system is to inform the drivers of passing vehicles about the presence of the workers and post a variable speed limit depending upon if workers are present in the vicinity, to improve traffic mobility.

PCMSs are usually controlled either by using a hand-held terminal connected to the sign, or by using a remote central computer which requires an operator to control the messages that need to be displayed on the sign. In either case, the human input is necessary to make proper use of the PCMS on the construction sites, which is prone to human error as well as issues like delays when the sign needs to be changed to a different message due to local work zone situational changes.
The proposed system eliminates human error by auto-detecting workers’ presence in an active work zone to display a suitable message without the need for any kind of manual input. To accomplish this, the PCMS needs to be equipped with a DSRC device. The DSRC device installed on the PCMS receives location signals from nearby workers and is able to post a speed limit depending upon workers’ presence in the vicinity. PCMS could also warn the passing-by drivers about the presence of the workers on a particular section of the work zone. Although, the theoretical wireless range of DSRC technology is 1 km, the practical range is about 500 m (1/4). Therefore, if multiple PCMSs need to be placed along the work zone, the preferred spacing between two adjacent PCMSs is 1 km so that a worker present over the span length of 1 km can be detected at least by one of the two PCMSs. The programming of the PCMSs can take into account the traffic direction, and the relative location of the workers with respect to the PCMS to post appropriate speed limits for the incoming vehicles. However, a detailed study of state safety requirements about posting variable speed limits according to workers’ presence in and around a work zone is needed before programming DSRC equipped PCMSs and determining the spacing between them.

FIELD TEST RESULTS AND DISCUSSION
We developed the prototype systems and performed the tests for the visual monitor system and DSRC equipped PCMS, separately. The detailed test results are given below.

Construction Vehicle Visual Monitor Alert System
The DSRC-Monitor interface for construction vehicle was developed using an Android based tablet and a DSRC onboard unit. We used the same kind of DSRC unit for the construction vehicle as well as the worker to simulate WSD. However, we developed separate software applications for both these units. The DSRC units which we used had built in GPS receivers. The worker’s DSRC unit was programmed to periodically acquire its GPS location, and transmit that information using the standard DSRC Basic Safety Message (BSM). BSMs were used only because a WSD has not yet been developed and a regular vehicle DSRC device was used for the worker to evaluate the system performance. Once a WSD is developed, it does not have to use a standard BSM to communicate the location information because most data fields in a BSM contain vehicle specific information. Instead, a different message standard could be used to represent worker specific information including worker’s location.

The construction vehicle’s DSRC unit is programmed to acquire its own GPS position, and calculate relative distance between itself and the positions of those workers from which it has received location information in the form of BSMs. After calculating relative distances, construction vehicle’s DSRC unit sends this information to the Android tablet using UDP data packets on a local Wi-Fi connection. This process is repeated every second to update workers’ positions on the tablet.

The experimental setup of the field tests is shown in Figure 4, which also shows pictures of the developed construction vehicle monitor system (Android tablet and DSRC/GPS antenna) and a worker’s DSRC unit, which is powered by a portable battery and being carried in a basket in one of the pictures. We used a regular vehicle as the construction as shown in Figure 4 to demonstrate functionality of the system. The field tests were performed in a parking lot instead of an actual work zone to demonstrate proof of concept.
Using the experimental setup of Figure 4, the accuracy of worker’s displayed position with respect to construction vehicle was evaluated against the physically measured distance. Only one worker was considered close to the construction vehicle for this test. The test results are shown in Figure 5 where snapshots of tablet screen are given for three distinct worker positions. First, the worker was placed in an approximately South-East direction of the construction vehicle at a distance of 5 and 7 m shown in Figure 5(a) and (b). The point in the center of the tablet screen shows the position of the GPS receiver on the construction vehicle. The bigger blue circle around the center point of the tablet screen has a 2 m radius showing the approximate boundaries of the construction vehicle. In these tests, the position of the worker is continuously updated every second for one minute, to see the error distribution of displayed position. For measured distance of 5 and 7 m, the average distance was respectively 6.19 and 7.55 m, and the standard deviation was respectively 0.9 and 0.86 m. Finally, the worker was placed at a 2 m distance from the construction vehicle (at the border line of construction vehicle) in the North direction as shown in Figure 5(c). The average calculated distance was 1.78 m with standard deviation of 0.47 m against the measured 2 m distance. To conduct these tests only one GPS receiver was used for the construction vehicle (GPS receiver built in the DSRC unit) and achieved relative distance accuracy was within the range of 1 – 2 m.

FIGURE 5 Tablet screen snapshots showing distance accuracy when the worker is (a) 5m (b) 7m, and (c) 2m from the construction vehicle.
Worker’s Relative Orientation

The relative distance test results show that the worker’s position can be shown to the operator with acceptable distance accuracy needed for visual observation. However, the relative orientation or direction of the worker with respect to the construction vehicle can only be accurately shown to the operator as long as he or she is facing towards North. This is due to the fact that the relative direction between the construction vehicle’s and worker’s GPS positions can only be calculated with respect to a fixed reference direction. If the construction vehicle rotates while staying at the same geographical position, its GPS coordinates will remain the same but its relative direction to the worker will change. Consequently, the operator will not be able to locate the worker’s correct relative orientation on the tablet screen with respect to the vehicle. This problem is illustrated in Figure 6 where a worker is standing at about 20 m north of the construction vehicle while the construction vehicle is also facing north. The tablet snapshot given in Figure 6(a) shows this accurately, placing the worker about 20 m north of the construction vehicle (in front of it). When the construction vehicle rotates towards East at the same location, the worker is now actually on construction vehicle’s left side at a distance of 20 m. However, the tablet will still show the worker erroneously in front of the construction vehicle as shown in Figure 6(b). This problem can be corrected if an absolute direction reference is provided to the construction vehicle, which can be done if the construction vehicle keeps moving in addition to rotation. In which case, comparison of the two different positions obtained by the same GPS receiver can be used to determine the direction. However, this solution is not acceptable for a construction vehicle because it needs to rotate without moving in many of its operations. To overcome this issue, we have used two GPS receivers on the construction vehicle to provide the necessary direction reference. When two GPS receivers were used for the construction vehicle, the orientation of the worker was correctly shown to the operator of the vehicle when facing East (Figure 6(c)).

Using two GPS receivers, the necessary direction reference can be provided but the accuracy of final direction or orientation will depend upon the distance between the two receivers. The longer the distance between them, better the accuracy is. Depending on the size of the vehicle, we are suggesting that the two GPS antennas on the construction vehicle be placed at least 2 m apart as it was done in the tests described above. The direction error while using two GPS antennas with 2 m separation, was in the range of 15-20 degrees which is sufficient for visual guidance purposes i.e., the operator was able to easily locate the position of the worker around the vehicle in the correct direction.

![Figure 6](image_url)

**FIGURE 6** Tablet screen snapshots showing relative orientation of worker with respect to the construction vehicle.
Finally, in this set of tests, the construction vehicle stayed at one place without moving or rotating and the worker moved around it in a circle. Regardless of which direction the construction vehicle was facing, the operator was able to locate the correct orientation of the worker on the tablet as shown in Figure 7.

**FIGURE 7** Tablet screen snapshot showing the trajectory of a worker walking around the construction vehicle in a circle.

**Multiple Workers**

The developed visual alert system for construction vehicle is capable of handling multiple workers at the same time. The proposed system was tested for multiple workers present around the construction vehicle using three DSRC devices for three workers. All three workers were simultaneously shown on the tablet correctly (figure (8)) with acceptable distance and direction accuracies.

**FIGURE 8** Two tablet screen snapshots showing three workers simultaneously present around the construction vehicle.
To evaluate the performance of the DSRC equipped PCMS regarding its ability to detect workers’ presence in the work zone and posting a corresponding message, a DSCR unit was interfaced with a PCMS unit via serial communication connection.

The DSRC unit was programmed to control the display messages on the PCMS based upon whether it receives a worker’s transmitted message or not. If the DSRC detects at least one worker, it will assume the workers are present in the work zone and that work zone section is active at least around a radius of 500 m (DSRC’s practical wireless access range). In this case, the DSRC sends the command to the PCMS to alternatively display two messages, “WORKERS PRESENT” and “SPEED LIMIT 35 MPH”. This is assuming that the work zone is located on a road with a regular speed limit of 55 MPH. In case the DSRC unit of the PCMS does not receive any messages from a nearby worker, it will send a command to PCMS to post the regular speed limit i.e., “SPEED LIMIT 55 MPH”. The speed limits and alternating message timings are set in compliance with the Minnesota Department of Transportation’s guidelines (15-16).

The DSRC-PCMS interface was successfully tested in the lab and the results are shown in Figure 9. The worker was successfully and quickly detected when the worker’s DSRC unit was turned on, indicating that a worker is present in the work zone around the PCMS, and PCMS message was successfully changed. Similarly, when the worker’s DSRC unit was turned off, the DSRC unit of PCMS could not detect the worker and successfully changed the PCMS message.

A warning system for work zones is proposed and developed to enhance workers’ safety by providing visual guidance to the operators of the construction vehicles. The proposed system requires each worker to wear a device containing a GPS receiver and a DSRC radio to periodically transmit its location information. The system also requires construction vehicles to be equipped with a DSRC onboard unit, which can receive the location information from nearby workers. The construction vehicle is also equipped with a monitor screen to show the positions of the workers in the vicinity. In addition to the enhanced worker safety, the system also improves traffic mobility by dynamically posting suitable speed limits and/or warning messages on the PCMSs around the work zone. This requires each PCMS to be equipped with a DSRC unit so that it can detect the presence of the workers to determine the message that needs to be posted for oncoming traffic.

A prototype system was developed and field tests were conducted to demonstrate functionality and evaluate the performance of the proposed system. The test results show that the system displays the workers’ positions on an Android based tablet with acceptable distance (1.5 – 2 m) and direction (15 – 20°).
degrees) errors for successful visual guidance. Furthermore, the test results show that the DSRC equipped PCMS can post a variable speed limit depending upon presence of a worker in its vicinity.

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