USING TECHNOLOGY TO WARN CONSTRUCTION WORKERS OF DANGER

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ABSTRACT
Collisions between personnel on foot and heavy equipment or materials on a construction site can be characterized as a contact collision and are a common type on a work site. Pro-active real-time safety technology is needed to improve the safety of a work zone by alerting workers when they are in danger. Furthermore, technology may assist to collect (previously unrecorded) data on “near-misses”. The technology that is used in this paper uses the radio frequency wave spectrum to alert workers in real-time when they are in danger. This new approach leads to improve the overall safety performance in construction and elsewhere through improved learning and education by providing relevant information to decision makers at all levels. Various experiments are described that have been conducted in order to gain better understanding of the potential of several competing technologies.

Keywords: Danger warnings, Plant and equipment, Collision, Radio technology

INTRODUCTION
A construction work zone is mostly a dynamic place consisting of heavy equipment, materials, and personnel that are in motion to each another. The sometimes unstructured or almost random movement can lead to incidents between two objects. These incidents are then characterized as contact collisions and are often a threat to the safety of personnel that is in too close proximity to equipment. These collisions can be attributed to various problems that begin with the closeness in which vehicles and workers operate. Pratt, et al., explains how workers are often unloading materials from a vehicle for an extended period of time, and operators become unaware that workers remain in proximity. Workers become unaware of their surroundings due to fatigue and task repetition, which causes lower awareness and loss of focus on surroundings. These situations are dangerous for all workers, and machine operators must deal with machine blind spots, too. Therefore, there needs to be an alert that will alarm workers from their specific tasks and alert them to their surroundings.

Current safety statistics have been published by the Census of Fatal Occupational Injuries (CFOI) for 2007, while the report will not be completed until the spring of 2009, initial investigation shows that there is significant fatality rates for personnel being struck by vehicles. 21% of all occupational fatalities occur in the construction industry which accounts for 1,178 people. Within the construction industry, most fatalities of workers being struck by objects occurred in heavy construction and to specialty contractors (10% and 13% of all fatalities respectively). Statistics showed that 6% of all occupational injuries were from workers being struck by vehicles (CFOI, 2007; Garrett & Teizer 2009) nformation shows that there is a need for a “second chance” warning device that alerts workers that they are in danger.

Fosbroke (2004) published on the Construction Research Program created by NOISH which identifies the following contributing factors to the issue of contact collisions. There is lack of knowledge of specific risk factors; all data collected on incidents is collected after-the-fact and no real-time information is gathered during the incident such that the specific safety needs on a site have yet to be sufficiently identified. There is insufficient adaptation of intervention technologies used in other industries; the train industry and mining industry have both been implementing various safety technologies that if adapted could be used in the construction industry (Fosbroke, 2004). There is a lack of scientific evaluation for newly and existing intervention technology; emerging safety technology needs to be evaluated through research of current methods along with case studies and data analysis. These issues will be addressed in this research through the evaluation of current safety practices, uses of technology in safety, creation of proactive safety technology using active Radio Frequency Identification (RFID), and subsequent evaluation of the technology.

BACKGROUND

Technology can be seen as the first and last barrier of safety. The Causation Model for Accidents (Figure 1) has been adapted from the Swiss Cheese Model (Reason, 1990). The model shows how in each level of construction there are “holes” in the initial safety plan; as the plan advances to the construction phase the lack of safety planning results in more “holes,” and thus higher probability of incidents. The Construction Industry Institute (CII, 2003) reported that “the findings show that the better safety records occurred when site specific safety programs were prepared for the projects”. Therefore, better front end planning will result in safer worksites.

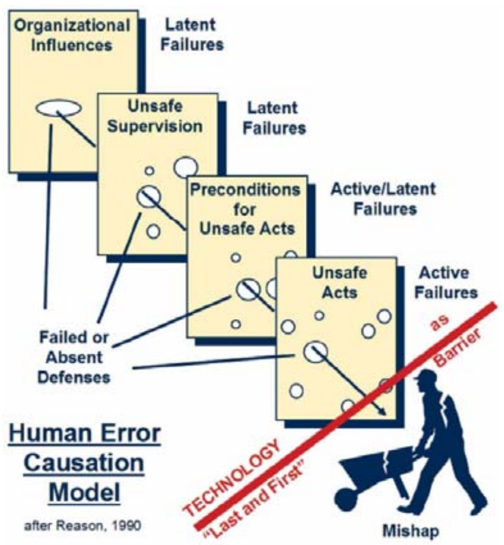

Figure 1: Human error causation model (after Reason, 1990).

There are many different technologies emerging in the construction industry; each technology has the potential to help improve site safety conditions. Technology can be used as a final barrier by giving workers a “second chance” of escape using a warning device. Information from the “near-misses” that occur through the alert can be collected and used to change future safety plans at the beginning of a project. Effective implementation will strive to close up the “holes” and decrease the number of accidents on worksites; the technology(s) will become a first barrier tool of safety. OSHA regulations are not enough to prevent these kinds of collisions from occurring. The Center for Disease Control (CDC), Pratt, et al. (2001), conducted a study in 2001 that categorized the various kinds of fatalities that occur on a construction site, both along a highway and off a highway. All gathered information is after-the-fact data (Pratt et al. 2001).

The statistics presented earlier from CFOI coincide with the statistics from previous years; it is evident that not much has improved in preventing workers from being killed by vehicles. The following information was also gathered from the CFOI but was compiled by Pratt et al. (2001) for NIOSH and displays statistics between 1992 and 1998. The study found that out of the 465 vehicle related fatalities, 318 of the fatalities were workers on foot. The type of vehicle they were struck by was most commonly a type of truck (60%) followed by a construction machine (30%). 110 fatalities were machine operators, most of those accidents occurred to a worker operating a construction vehicle (53%), and followed by a truck. The remainder of the fatalities occurred to supervisors and other personnel. The majority of the fatalities (51%) occurred when the vehicle was in reverse mode; this can be attributed to the large amount of blind spots that are prevalent in the backside of a vehicle (Pratt et al. 2001). During 2006, the CFOI reported 369 workers were killed by a motor vehicle during highway construction that accounted for 7% of all occupational deaths. 560 workers were reported killed by being struck by an object that accounted for 10% of all occupational deaths. There is limited data on the specific happenings of an occupational fatality. Of those incidents that did not result in fatalities, most workers were severely injured which resulted in missed days of work (Pratt et al. 2001). Figure 2 is an image of an unsafe situation; a worker on foot is working in between two pieces of heavy equipment and is unseen by the machine operator. This situation could lead to an accident as described earlier.

Figure 2: Hazardous situation on work sites measured using 3D laser scan image.

CURRENT SAFETY PRACTICES

There are different methods of maintaining safety on work zones including the modification of behavior methods employed on the work zone, passive safety technology, and active safety technology. Passive technology does not use any sensing technology once installed, for example, helmets, goggles, or safety vests. Active technology uses sensing technology and works in two different ways; the first is with two or more sensors that transmit information to each other and the second is the use of cameras that identify objects through image processing. Within active safety technology there is a distinct difference between reactive and proactive safety technology; reactive technology collects data in real time that can then be analyzed to determine the best way to change future situations to make improvements and proactive technology works in real-time to alert personnel of the dangers occurring at that moment.

Pratt et al. (2001) discovered that the first method to improve safety on a work zone is by altering the behaviour of the individuals on the safety zone. All ground workers and operators should be trained on how to use their tools and equipment, and machine operators should be trained not only how to use their machine but also how to work around the construction site since they too move on foot throughout the site. Supervisors should monitor workers performing their tasks and operators checking their machines to ensure they are in optimum working condition. By mandating refresher courses or by giving incentives for taking refresher courses the contractors and owners can ensure that each worker is up to date on their training (Rental Product News, 2007). Furthermore, pre-work fitness, driving performance, and physiological factors should be monitored on all machine operators to ensure there is no driver impairment.

SAFETY TECHNOLOGIES

The aforementioned safety techniques have been unable to eliminate contact collisions on the work site, because accidents occur daily. Active safety technology comes in two forms: Reactive and proactive. Reactive safety technology may include the use of video cameras, where the cameras would allow supervisors and owners to assess project on a daily basis. Assessments may include features like the impact of the weather, accurate accident investigations, and asset tracking. This information can then be used as a way to improve the productivity of the work site, monitor the safety by noting any potential hazards, and note any breach of regulation by workers and sub-contractors (Abeid & Aditi, 2002). Cameras can also be used in a proactive method; by transmitting the feed-back to a hub and incorporating the data with a 2D algorithm, the tracker can choose a worker, material, or piece of equipment to track in 3D real-time. This method gives a clear picture of the object selected and allows the tracker to monitor any potential threatening situations that could endanger the work zone.

Laser scanning is also a reactive method to improving the safety of the worksite. A laser scanner collects a three-dimensional point cloud of objects in its field-of-view. An accurate 3D model of the entire worksite can be assessed in the same ways video cameras work. By taking digital images of project sites in real-time, all project coordinators are able to monitor the progress through a virtual environment. Owners can then locate tasks or areas that are unsafe and inform workers of the issue without entering the site. Laser scanning will be used in this research as a way of discovering the blind spots on different pieces of equipment (Jaselskis, et al., 2005).

Radio Frequency Identification (RFID) can be coordinated to be used as a proactive safety measure. Traditionally RFID has been used as a method of coordinating a site by “tagging” various materials, equipment, and personnel as a way of tracking all the moving parts of a construction zone. This method has allowed supervisors and owners to monitor the movement and analyze ways to improve the site by increasing efficiency, but is a reactive use of RFID. RFID transfers data in real time, and is capable to observe real-time movements. However, this technology is moving forward and is being implemented as a method of proactively preventing collisions. An antenna, which reads the RFID from various distances depending on the tag being used, can be mounted within a truck along with a small alarm. When the antenna reads the tag the alarm will be triggered, which will alert the machine operator that a worker on foot is nearby. This research focuses on the use of RFID technology in proactively alarming workers when equipment, ground personnel, and materials are in close proximity of each other.

The system employed in this research uses active RFID technology and is comprised of an in-cab device and a hand-held device. The in-cab device contains a single antenna, reader, and alarm; this part is called the Equipment Protection Unit (EPU). The hand-held device contains a chip, battery, and alarm; this part is called the Personal Protection Unit (PPU). The battery on the hand-held device potentially allows for the tag to intercept the frequency at approximately 30 meters. Once the tag intercepts the frequency the alarm in the hand-held device is triggered and the information on the chip is sent back to the reader. When the reader intercepts the information the alarm within the in-cab device is triggered and both worker and operator are sufficiently warned that they are in close proximity. This sending and receiving of information is instantaneous; the whole process occurs in real-time.

PREVIOUS STUDIES AND CURRENT APPLICATIONS

Similar studies have been done with RFID in both work site productivity and safety. The North-South Bypass Tunnel Project in Brisbane, Australia that is currently in progress and plans to be completed by 2010, implemented passive and active RFID tags for different purposes. The passive tags were used as entry key cards to access the facilities of the construction site. The active tags are being used to track employees throughout the 4.8 km tunneling project. RFID technology improved safety by monitoring the location of all workers and was able to locate and identify anyone who was injured or missing within the tunnel. Furthermore, the tags contain important technical information involving the specific skills of each laborer such that specific workers can be located quickly, if needed. The active tags were found to be very useful in the tracking of employees to improve safety and efficiency simultaneously, so much so they were soon implemented as asset tracking by tagging all equipment (Jaselskis et al., 2005).

NIOSH created a prototype called HASARD that uses a magnetic sensing system. Magnetic waves are emitted from a transmitter and whenever the magnetic wave is interfered with an alarm is triggered. The system is oriented in such a way that the transmitter is a magnetic loop that is coiled to condense the system and decrease the amount of power emitted yet still making it effective (Teizer, 2008). The prototype was tested for six months in a mine; a mine was chosen for the test because of the extremely harsh conditions (Teizer et al., 2007). The sensors were placed on people and walls to prevent collisions from a Continuous Miner (CM), a machine used to mine underground. The signal was found to penetrate through all coverings and could be calibrated to be used above ground as well.

Aker Yards, a shipping yard in Turku, Finland, has implemented RFID tags to monitor workers as they embark and disembark along the entry bridges to the various ships. This allows for fire and rescue to monitor in real-time the head count of all personnel on the boats in case of an emergency. Also, it allows for fire and rescue to quickly realize if someone has been on the boat for an exorbitant amount of time, in which they could be injured or trapped in some area of the ship. The tags were placed inside the helmets to prevent any contact of the tag with anything else; the tags also held important information about the worker including a picture to verify the person found was the right person in the helmet (Jaselskis et al. 2005).

Radio Frequency Identification Technology has been implemented into the health industry to track patients throughout the hospital and holds pertinent information about each patient to prevent misdiagnosis and improper care. Furthermore, it has been combined with asset management in tagging materials and equipment. RFID technology was chosen because it does not interfere with hospital equipment and machinery (Jaselskis et al, 2005; Teizer, 2008; Teizer et al., 2007a; Teizer & Kahlmann, 2008; Teizer et al. 2007b; Teizer, et al., 2005; Teizer, 2007; Teizer et al., 2006a; Teizer et al. 2006b; Teizer & Vela, 2008b).

RFID has also been seen in warehouses, mines, and train depots being used as a safety mechanism. In warehouses, forklifts pose a large threat to the safety of all workers due to blind spots and the small spaces in which they work; additional blind spots are created in such tight areas of operation. To warn workers on foot, warehouses have put RFID technology at corners that trigger alarms when a forklift is in proximity of the sensors. Furthermore, the forklifts can be tracked throughout the warehouse and monitored for any potential dangerous situations. The mining industry places readers on walls and tags the equipment within the mines to prevent operators from colliding into the wall.

RESEARCH OBJECTIVE AND METHODOLOGY

The primary purpose of this research is to increase work zone safety in heavy equipment operations by utilizing embedded radio frequency technology. Secondly, real-time pro-active warning devices also record information that once recorded can be analyzed to improve existing safety education and training programs. A major focus of this research is on sensing technology that will be deployed on ground personnel and equipment operators in order to detect and recognize hazardous situations, e.g., workers being too close to heavy equipment. In such an event of being too close, visual, acoustic, and vibration technology can be activated in the form of alarms. Several steps were undertaken to develop a test bed to design and validate several technologies that have the capability of issuing real-time pro-active alerts to ground workers and equipment operators. These steps include: (1) Identification of blind spots of heavy equipment; (2) Passive RFID alert device (SmartHAT) and active RFID alert devices (Teizer et al 2007c, Teizer et al. 2008, Walia & Teizer, 2008; Teizer & Vela, 2008; Sadeghpour & Teizer, 2009; Fullerton et al., 2009; Venugopal & Teizer, 2008; Teizer & Castro-Lacouture, 2007; RFID, 2008; Schiffbauer, 2001; Schiffbauer & Mowrey, 2001). Each of these technologies is explained further in detail.

Steps one and two pursue the idea of understanding the frequency and location when workers enter or are getting too close to heavy construction equipment. Steps three and four offer potential alert technology that activate once workers are located close or within a threshold safety radius of heavy construction equipment.

In the experimental validation phase of the alert technologies, first, blind spot measurements were taken for heavy equipment. The most common types of machines were selected for blind spot measurements including dump and articulated trucks, excavators, motor graders, rollers, wheel loaders, etc. Next, the trajectory of workers was recorded to understand the frequency of instances of being too close to heavy construction equipment. In a final step, the passive and active alert technology in optimal (laboratory) and field (job site) conditions were tested. The points at which the alarm is triggered yield the largest theoretical safety zone the system can create.

EXPERIMENTS

The following paragraphs detail the experimental procedure in two stages and present the results.

Blind Spot Measurements of Machinery

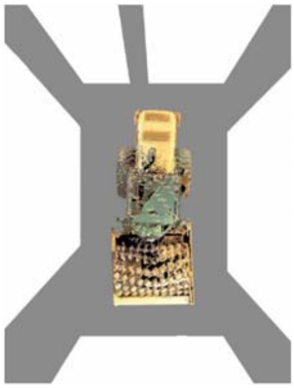

Figure 3: 3D geometry of different poses of roller spots. **Figure 4: Schematic blind spots.**

The blind spots of common construction equipment including, but not limited to, excavators, rollers, dozers, dump-trucks, and cranes, may be determined through the use of 3-D laser scanning. A complete 360-degree laser scan of each machine will be collected, and each completed scan will yield a virtual model, in which anyone can navigate around on a computer. These 3-D models will aid in determining all blind spots (direct and indirect) of the machinery in different types of scenarios and poses, including operator height differences. Direct line-of-site is what the operator can see in front of him/her without the use of cameras or mirrors. When direct line-of-site is blocked it is termed a direct blind spot. An indirect blind spot is an area of visibility that is obstructed even with the use of cameras or mirrors. Once these blind spots have been determined, the necessary safety zone can be established for each machine. The safety zone is the area in which an alarm sounds, alerting both the operator(s) and worker(s) that the safety zone is breached, and a collision is probable.

DESIGN OF PROXIMITY DETECTION AND WARNING DEVICE (FULLY PASSIVE UHF RFID WITH ACTUATION FOR SAFETY APPLICATIONS)

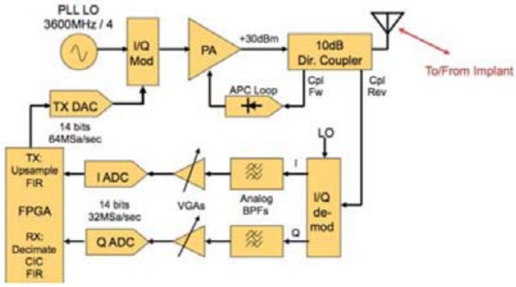

Figure 5: UHF backscatter modem circuit SmartHAT system.

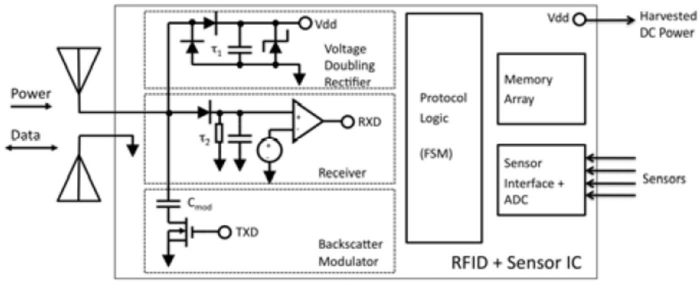

Figure 6: External RF transceiver (reader) for the developed for the SmartHAT system.

Fully passive, battery free long-range UHF RFID systems have recently been developed primarily for asset tracking and supply chain management applications. These systems have two components. The first is a tag, or transponder, which in the SmartHAT system is integrated with a worker's plastic hard hat. It contains a long range power harvesting and bidirectional communication circuit that does not require an on-board battery as it harvests its operating power from an incoming radio signal (see Figure 5). The second is a reader, which is a transceiver device, similar in principle to radar, which sends power by means of a radio frequency signal to the SmartHAT transponder. The reader device also transmits and receives control information to the SmartHAT transponder by observing the magnitude and phase of the reflected signal from the transponder- this signal vector yields the desired data transfer. The chief advantage of the fully passive SmartHAT transponder is that it is battery free. Safety warning effectiveness is not compromised by premature battery failure including failure over time or temperature extremes as may be observed in a construction scenario. Because there is no need to change the battery, the transponder can be fully plastic-encapsulated and thus resistant to environmental degradation or accidental damage.

The current SmartHAT transponder design is based on discrete component technology; to reduce the cost and manufacturing complexity of the SmartHAT device a single chip circuit is in development that will yield lower power consumption, and thus longer communication range, as well as a smaller, more rugged physical package.

DESIGN OF EXPERIMENTS FOR VALIDATION

Through the examination of safety needs on a construction site, which was determined from background information and blind spot measurements, a prototype for a safety device was devised. The following describes the technology that was manifested.

PRELIMINARY TESTING (STAGE 2)

Laboratory like conditions were created to initially test the prototype. The tests were done outside on clear days in open areas free of obstructions and without any outside interference. A commercial 1” Robotic Total Station (RTS) was used to take distance measurements. The RTS records the distance at which the wireless antenna reads the tag, and the reference frame established by the User allows for approximate angles/azimuths for each point recorded, with respect to the antennae “field of view.” The RTS was placed in the center of the field along with the EPU, and a tester walked around with the Data Collector and PPU. The following steps were taken to test the technology:

1. Reference frame established on the RTS.
2. Tester starts about 35-40 ft away from reader and heavy construction equipment.
3. Tester walks toward the RFID reader holding the RFID tag in line-of-sight to reader, while also holding the prism rod for the RTS.
4. Tester stops when RFID Reader “reads” the tag.
5. Tester records the distance from tag to RFID reader.
6. Tester moves to the next angle until map is complete.

This process was followed to establish a base perimeter around the EPU, before any obstacles were put into place. The manner in which the EPU would be placed on the equipment and the PPU would be placed on the worker was also determined for use in stage 2.

PRELIMINARY TESTING (STAGE 3)

The system was then tested in field like conditions; harsh construction settings with equipment and obstacles were used to mimic the day-to-day setting in which the device was intended to be used. Machinery was kept stationary but was set in close proximity of materials, other equipment, and lab personnel acting as workers. The EPU was set inside the cab of the equipment and the PPU was placed on a person. The technique used to take measurements of the alarm sounding was the same technique used in Stage 1, except the checkpoints were at about every 30 degrees instead of 20 degrees. The proximity warning device was tested on a forklift, excavator and dozer. The reader was placed inside the cab of the machine. Figure 7 displays the results obtained by an active RFID experiment. The grey area is the unsafe zone, the general blind spots area – the area in which the alarm must sound. Outside that area the worker is in the safe zone. The orange lines represent the points where the proximity alarm sounded. The worker never entered into the unsafe zone. The dozer and excavator were in close proximity of each other and a worker was standing between them as seen in Figure 2.

FIELD TRIALS (STAGE 4)

The next step is to implement the system into a long-term field trial. The prototype will be integrated into the safety measures on a construction site of a project. A long-term case study will demonstrate the defaults of the prototype in dealing with the rigors of a construction site, the ability for it to stand up to various weather conditions, different tasks such as excavations and multiple story projects, and different obstacles that have the ability to obstruct or diminish the signal will be shown. Then the impact of safety will be measured by calculating the number of "near-misses" that occur through the use of the proximity detection system.

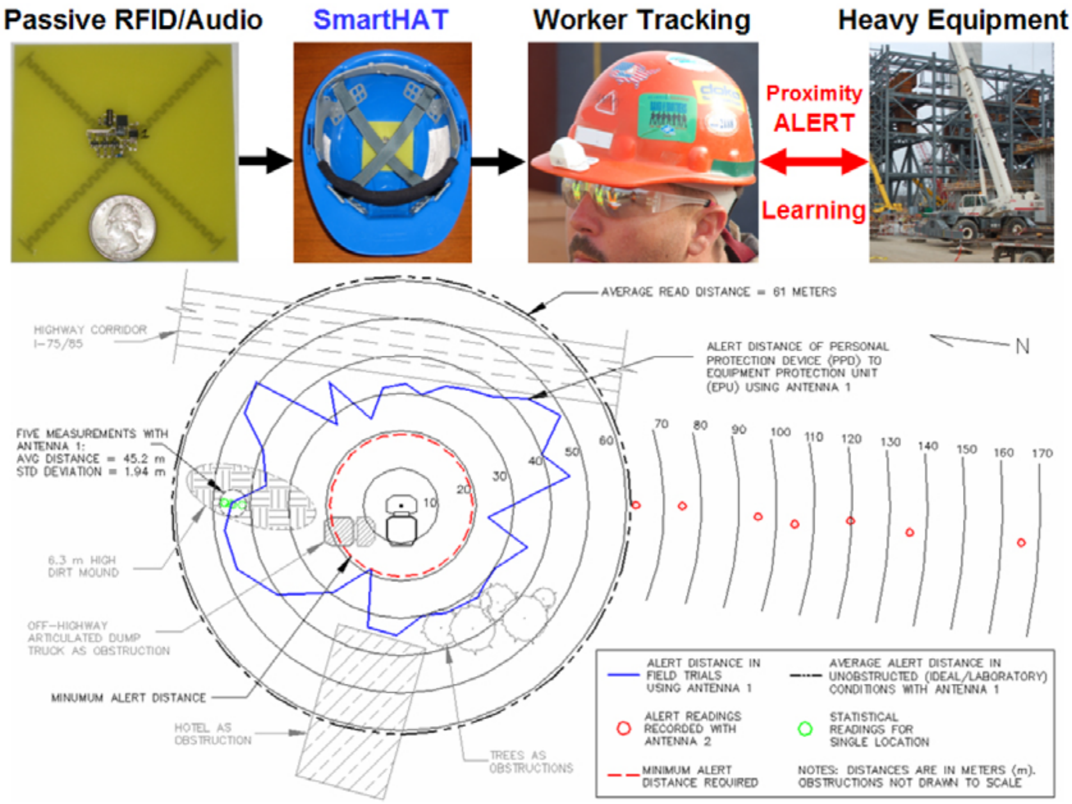

Figure 7: Proximity of ground personnel to heavy construction equipment when safety alert activates

FURTHER EVALUATION

Once testing of the sensors is completed the technology will be assessed. Interviews will be conducted with the workforce to establish what kind of safety the workers feel is needed on the construction site. The interviews will hopefully discover what kind of intervention the workers are willing to have, how much monitoring and watching they do not mind having, and what they think of the proposed technology. The interviews will determine if workers think pro-active-real-time-warning-system will make a difference, and if they think the PPU is a comfortable, good style of protection device. Also, the impact of the device on safety will be evaluated along with a cost-benefit analysis. Limitations could be the form factor of the technology (size, weight, and mounting position), general worker objections to wear a device, and others. Initial field trials with the technology indicate: Since proximity alert devices do not reveal the location of a worker, rather give an alarm, workers (so far) do not mind wearing the device. Changes to where the devise is mounted (on or inside a helmet or on an arm?) and what form it has, however, are necessary before any product is commercialized.

CONCLUSIONS

From the preliminary results and background review the proposed alert technology has proven to have the possibility of being effective in aiding the safety needs in the construction environment. The SmartHAT and other alert devices can detect the presence of workers being close to heavy construction equipment such as excavators and dozers. Based on signal strength the passive and active RFID alert devices have the potential to simultaneously activate and warn ground workers and equipment operators from being too close to each other. In various environments, auditory, visual, and vibration alarms have been tested loud and strong enough. The technology further has the capability to record previously unrecorded data of close-calls aka. near-misses. Further research is necessary to improve signal noise and loss ratio for the passive RFID alert device (SmartHAT), and extensive field trials are to be conducted over longer time intervals to analyze SmartHAT as well as other real-time pro-active alert technology. Data can then be recorded, analyzed, and used to improve positioning of workers and equipment and assist in the development of new safety concepts, such as advanced safety education and training courses that include visualization technology.

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