APPLYING RADIO FREQUENCY IDENTIFICATION TAGS TO IMPROVE PERSONNEL SAFETY IN DREDGING CONSTRUCTION

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Falling overboard, slips, trips and falls cause most of the workplace injuries that occur in the dredging construction. Some of the factors that contribute to these accidents include very congested work areas; oil, ice or snow-covered decks; worker fatigue; lack of visibility; and rough seas that result in shifting work platforms. Utilizing RFID technology has the potential to help reduce these on-board accidents. The objective of this research was to evaluate the effectiveness of radio frequency identification (RFID) tag technology in providing individual personnel safety monitoring on a dredge. Four experiments using passive RFID tags were conducted to test the hypothesis that the use of RFID would create a safer environment on a dredge by providing the dredge captain with real-time monitoring of the dredge crew. This real-time monitoring would provide an immediate notification to the bridge should a crewmember fall overboard or be in an unauthorized mechanical space when the dredge is in operation. This preliminary research compared several types of passive RFID tags to determine which one is the most effective for this application. During these evaluations, RFID tags were worn on lanyards and on the front of the hardhats of the workers. The RFID readers were located in four locations on the dredge. Based on performance testing, the most accurate combination of RFID tags and readers were Smartrac R6 RFID tags and the Far Field RFID reader which reported crew locations with 92% accuracy. Future research will focus improving accuracy and installing a complete RFID reader system on a dredge in order to perform operational testing. If this future operational testing proves to be sufficiently reliable, this technology has the potential to improve safety and reduce fatalities in the dredging industry and other related marine industries.

Keywords: abstract, safety, dredging, RFID

INTRODUCTION

The specialty construction sector, marine construction, is unfortunately plagued with accidents. Three hundred and five workers were killed on barges or during towing operations in the United States between the years of 1997 and 2006 (OSHA 2009). Many of these accidents (and other recordable workplace accidents) occur due to slips, trips and falls. Root causes of these slips, trips and fall can include rapidly changing direction when walking, slippery surfaces due to oil, snow and ice, fatigue, lack of visibility, and unsuitable footwear (OSHA 2009).

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Specifically, work on dredger vessels is particularly hazardous. Hopper dredgers use suction pumps to remove sediment from shipping channels. The sediment is pumped into an open hopper in the hull of the ship. When the hopper is full, the ship travels to a disposal area out to sea. Once it arrives, the hull of the dredger opens like a clamshell allowing the sediment to be dumped into the disposal area. It is imperative that the dredger captain knows the location of all crewmembers during this operation to insure no one becomes caught between the moving machinery or cast overboard when the hull opens. Other hazards include falling overboard during dredging operations or falling into the dredger hopper and becoming trapped in the sediment as it is pumped on board.

Radio frequency identification is a method of communication that utilizes embedded radio waves and location-range imaging to provide non-contact automatic identification and location services. The construction industry is currently utilizing Radio Frequency Identification (RFID) tags to track material and equipment movements on civil and commercial jobsites. Marine construction contractors see the value of this technology, and RFID tagging is currently being tested for use in tracking material and equipment both on deck and underwater. However, the use of RFID tagging to track personnel in the dredging industry is non-existent. The balance of this paper describes an exploratory research study completed to discern (1) the effectiveness of tracking workers in a marine construction setting with RFID tags, (2) how placement of RFID tags on personnel (meaning the location of the RFID tag itself on the person) effects tracking capabilities, and (3) what currently available commercial RFID equipment is most effective in a marine construction setting. A brief literature review regarding RFID technology is provided, along with the methodology for the study. Conclusions are discussed, along with limitations of the study and future research avenues.

LITERATURE REVIEW

Information has been said to be the most critical resource in the post-industrial age, as labour was in the agricultural age, and capital was in the industrial age Donyavi and Flanagan 2011). Radio-frequency identification (RFID) is defined as a branch of automatic identification (auto ID) technologies in which radio frequencies are used to capture and transmit data (Jaselskis *et al*., 1995, Jaselskis and El-Misalami 2003). RFID systems consist of tags, antennae, readers, application software, and computing hardware. RFID tags consist of an integrated circuit with memory (i.e. a microprocessor chip) and can either be battery operated (i.e. active) or non-battery operated (i.e. passive) (Taneja *et al*., 2011.) The chip has a specific identity that is broadcast to a reader operating on the same frequency (Ngai *et al*., 2007.) The basic process includes the transceiver sending out radio frequencies to the tags within a given area (or a grid of specified areas), and the tags sending a signal back to the transceiver. Antenna are used for communication between the tags and the readers, to which design and placement of the antenna is a crucial part of determining the coverage zone, range, and accuracy of communication (Ngai *et al*., 2007.) A line of sight between the receiver and the RFID chip is not required for communication, which is the driving force for the usage of this technology over bar coding systems (Omari *et al*., 2009, Taneja *et al*., 2011, Awolusi *et al*., 2018). RFID technology is the most commonly used system for proximity detection of material, equipment, and workers (Awolusi *et al*., 2018).

The number of academic research studies into RFID implementation in construction have grown substantially over the past 20-plus years. Ngai *et al*., (2007) reviewed 85 academic articles published between 1995 and 2005, two of which were related to construction. Li *et al*., (2016) expanded on this work, reviewing 75 articles published between 2005 and 2014, all dealing with real-time location tracking (RTLS) in the construction sector. One abundant RFID research topic has been the location tracking of materials and tools on construction jobsites and production facilities, including ready-mixed concrete production and delivery (Jaselskis *et al*., 1995, Moon *et al*., 2017), float glass production (Gil and Kahn 2004), precast concrete component tracking in supplier storage yards (Ergen *et al*., 2006), tool tracking via an intelligent toolbox (iBox) (Goedert *et al*., 2009), material, and equipment installation progress (Omari and Moselhi 2009), indoor management of construction materials (Kim *et al*., 2011), material movement by tower cranes (Li *et al*., 2013), and residential prefabricated panels (Altaf *et al*., 2017).

As stated by Kanan *et al*., (2018), “even though labourers are trained to stay away of potential dangers, there are still many types of risks that can occur within only a few minutes of carelessness.” RFID systems can be structured to work together on site to reduce the safety issues that may occur due to human error or lack of proper safety training (Donyavi and Flanagan 2011, Marks and Teizer, 2013), providing real-time information visibility and traceability for construction firms (Lu *et al*., 2010). Enhancing worker safety with the use of RFID has garnered much attention is worker safety, including general worker location tracking onsite (Song *et al*., 2006, Montaser and Moselhi 2014, Fang *et al*., 2016, Awolusi *et al*., 2018), the alleviation of worker back-over accidents around heavy equipment (Chae and Yoshida 2010, Kanan *et al*., 2018), worker personal protective equipment (PPE) usage (Kelm *et al*., 2011), worker location tracking on underground works (Ding *et al*., 2013), tracking of “near-miss” accidents (Wu *et al*., 2010), and tracking of “struck by falling object” accidents (Wu *et al*., 2012).

According to Li and Becerik-Gerber (2011), “academia has achieved remarkable accomplishments in RFID research, but the solutions must be better integrated with the industry to transform the academic development into industry productivity." This sentiment is echoed by several other researchers (Donyavi and Flanagan 2011, Ngai *et al*., 2007, Zhou *et al*., 2013). Li *et al*., (2016) found that of the RTLS publications reviewed, nearly half of the research was experimental in nature without implementation on actual construction projects.

Moreover, Fang *et al*., (2016) state that RFID integration into the construction process faces implementation challenges, including (1) poor system scalability for full-scale implementation on arbitrary sites, (2) heavy infrastructure on site for data processing and visualization, (3) lack of effective strategy for visualizing location information, and (4) limited capability for sharing location data of construction resources across remote users.

In summary, RFID is a highly researched and relevant technology in the construction field. Research into RFID implementation to improve worker safety on construction sites has been completed with promising results, but there is a research gap regarding RFID implementation to improve worker safety in marine construction settings. Lastly, RFID research that informs and involves industry is somewhat lacking, but highly regarded and suggested.

METHODOLOGY

The research methodology consisted of 3 steps to meet the research objectives:

- Outfit an active marine construction dredging vessel with RFID transceivers from different commercial suppliers
- Outfit construction personnel (i.e. crew members of the dredging vessel) with passive RFID tags (passive tags chosen due to their pervasiveness in the construction industry) from different commercial suppliers
- Collect data on construction personnel movement around the ship utilizing the RFID equipment

The research team chose to test the effectiveness of two RFID receivers: the Impinj Mini-Guardrail ILT, and the Impinj RHP Far Field RFID, and two RFID tags, the Omni-ID ADEPT 650P RFID Tag, and the Smartrac R6 Dogbone RFID Tag. The Omni Adept tag was connected to a lanyard and hung from the crew members necks (as shown in Figure 1), and the Smartrac R6 Dogbone RFID tag was attached to the crew member's hard hats (as shown in Figure 2).

Figure 1: Omni-ID ADEPT 650P RFID Tag

Figure 2: Smartrac R6 Dogbone RFID Tag

The research team also chose four separate locations on the dredging vessel: (1) On-boarding/off-boarding entrance to the dredge, (2) the staircase leading up to the bridge, (3) catwalk next to the dredge hopper, and (4) the entrance to the stern engine room, shown below in Figure 3. The entry staircase test location was selected since this is the point of entry/exit onto the dredger. This would be an obvious location to install a passive RFID reader should the system be implemented on an operational basis in the future. The bridge staircase location was selected because it was relatively unobstructed. This provided a good comparison to the more congested areas on the dredger. The catwalk next to the dredger hopper is a very narrow, congested area. Since this area is congested with a large amount of metal machinery, the thought was that this would offer a good test to determine if the passive RFID signal would be adversely affected by interference from the electrical systems and density of the large metal objects in this location. The last location, the entrance to the stern engine room was selected based on the dredger captain's suggestion. He stated that knowing if personnel are in the engine room is a critical safety concern during operation and maintenance of the dredger.

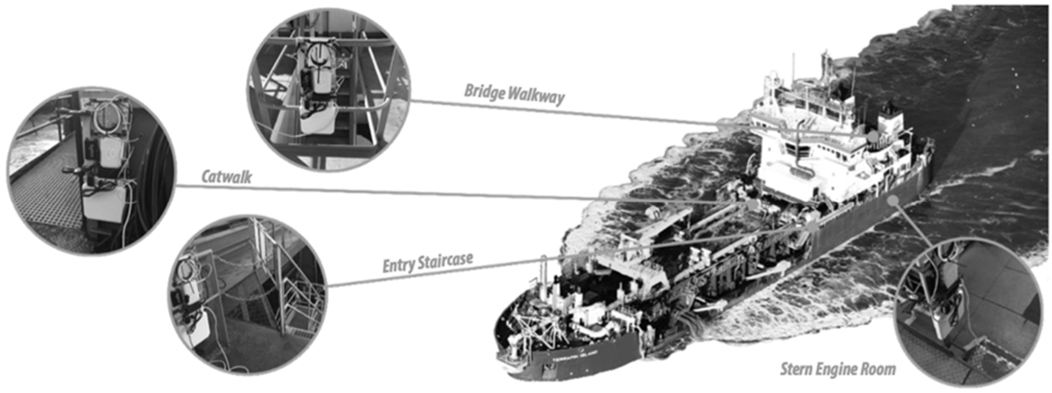

Figure 3: Location of RFID Readers

Five crew members were outfitted with both of the RFID tags. Each of the five crewmembers walked past each of the transceivers, the combinations of which are provided in Table 1. At each of the test four locations, five crewmembers wore a passive tag and walked passed one of the two readers. The five crew members were selected at random but varied in height from between 5'-6" and 6'-2". The number of crew members participating in the evaluations were limited to five due to availability. However, as can be seen below, each evaluation was conducted multiple times in order to obtain sufficient data. For each combination of tags and reader, the crewmember walked by four separate times. The exception to this methodology was at the engine where only four crewmembers participated in the testing. Therefore, 80 readings were taken at each location except the engine room where only 64 readings were taken. For the first two passes, the RFID readers were attached to their hardhats. For the remaining two passes, the readers were attached to lanyards.

Data collection of the test results were recorded using the Impinj Speedway Revolution R420 UHF RFID Reader Evaluation Kit (4 port) and recorded on a laptop in order to analyse the results.

RESULTS

The researchers conducted their experiment on a dredging vessel, the *Terrapin Island*, in the Savannah, Georgia harbour on the east coast of the United States. The experiment was conducted over two days in October of 2016. Table 2 contains the overall results for the four RFID reader/RFID tag combinations evaluated. A reading was considered to be "successful" if the RFID transceiver recorded the crew member's RFID tag as the passed the transceiver. As shown, the most accurate combination of RFID tags and readers was the Smartrac R6 tags and Far Field reader at 92% accuracy. The least successful combination was the Smartrac R6 tags and the Mini Guard reader at 0% accurate readings.

Table 1: Combination of tags and readers at locations

Location	Equipment	Test #1	Test #2	Test #3	Test #4
Dredge Entrance	RFID tag	Omni-ID	Omni-ID	Smartrac R6	Smartrac R6
	Tag reader	Far Field	Mini-Guardrail	Far Field	Mini-Guardrail
Bridge Stairway	RFID tag	Omni-ID	Omni-ID	Smartrac R6	Smartrac R6
	Tag reader	Far Field	Mini-Guardrail	Far Field	Mini-Guardrail
Catwalk	RFID tag	Omni-ID	Omni-ID	Smartrac R6	Smartrac R6
	Tag reader	Far Field	Mini-Guardrail	Far Field	Mini-Guardrail
Engine Room	RFID tag	Omni-ID	Omni-ID	Smartrac R6	Smartrac R6
	Tag reader	Far Field	Mini-Guardrail	Far Field	Mini-Guardrail

Table 2: Summary of test results for each equipment combination

RFID Reader/RFID Tag Combination	Percent Successful Readings
Omni-ID/Mini-Guardrail	76%
Omni-ID/Far Field	67%
Smartrac R6/Mini-Guardrail	0%
Smartrac R6/Far Field	92%

Table 3 summarizes the test data for each equipment combination based on where the crewmembers wore the RFID readers. As shown, the location of the RFID tags on the crewmember's hardhats provided successful readings greater than 80 percent for three of the four RFID transceiver/tag combinations, while the lanyard location only provided successful readings greater than 80 percent with one of the combinations.

Table 3: Summary of test results for placement of RFID reader

RFID Reader/RFID Tag Combination	Location on Crewmember	Percent Successful Readings
Omni-ID/Mini-Guardrail	Hardhat	97%
	Lanyard	53%
Omni-ID/Far Field	Hardhat	84%
	Lanyard	39%
Smartrac R6/Mini-Guardrail	Hardhat	0%
	Lanyard	0%
Smartrac R6/Far Field	Hardhat	92%
	Lanyard	92%

ANALYSIS

Research objective (1): Discern the effectiveness of tracking workers in a marine construction setting with RFID tags

The research results showed that the use of RFID tags to track worker movement on an active dredging vessel is effective. Overall, the equipment tested provided accurate readings of crew member movements in various positions on the ship. These results show that RFID technology could be utilized by marine construction contractors as a safety measure to track the movements of personnel, and warn them when entering areas of potential danger on an active dredging vessel.

Research objective (2): How does placement of RFID tags on personnel (meaning the location of the RFID tag itself on the person) effect tracking capabilities

The most successful location for wearing the RFID readers was on the crewmember's hardhats, as opposed to the lanyards, in this experiment. That being said, the researchers observed six items that may have been a factor in these results:

1. Omni-ID tags, worn as lanyards, would move behind and be blocked by the crewmember's jackets or safety vest.

The crewmember's hands or arms sometimes blocked Omni-ID tags, worn as lanyards, as they passed the readers.

On occasion, two crewmembers walked by the reader at the same time, wearing the Omni-ID tags. During the experiment, one person blocked the other person's tag and prevented it from being read.

The distance from the location of the Smartrac R6 sticker, worn on the hardhat of the crewmembers, to the Mini Guardrail reader, was too far to create a reading.

The Dredge Entrance Stairway, contained large amounts of steel that, on occasion, impeded the Mini Guardrail reader from picking up both the Omni-ID tags and the Smartrac R6 tags.

During two tests at the Catwalk, two of the five tags were not read while using the combination of Omni-ID tags and the Far Field readers. The cause for this error could not be determined. It is assumed an equipment technology error occurred. The definite cause remains unknown.

The testing indicated the best place for the RFID tags to be worn was on crewmembers' hardhats since this minimized the possibility of the interference from clothing, arms, other crewmembers, etc. However, it should be noted that wearing the RFID tags on hardhats is not as secure as wearing the tags on lanyards since crewmembers are not required to wear chin straps on their hardhats. Therefore, if hardhats fall off or are taken off, the ability to track crewmember locations will be lost and may result in the issuance of a false alarm. This potential problem can be mitigated by requiring the crew to use chinstraps when wearing their hardhats.

It should also be noted that the crewmembers who were test subjects had numerous questions how this technology might be used in the future. It was evident from the nature of their questions they were concerned about the captain having real-time data concerning their locations. In other words, they were concerned about "big brother watching". If this technology were to be implemented in the future, a key component of implementation would be crew education to assure them that the system would be used to enhance their safety.

Research objective (3): What currently available commercial RFID equipment is most effective in a marine construction setting

Overall, the most effective equipment combination when all tests were considered was the Smartrac R6 tags and the Far Field reader with a success rate of 92%. However, this equipment combination was surpassed by the Omni-ID tag and Mini-Guardrail reader combination when the tags were worn on hardhats. The equipment combination of Smartrac R6 tags and Mini-Guardrail reader proved to be ineffective. This equipment combination was tested prior to deployment in the field and appeared to work. However, as noted in the field observations, this combination had insufficient range to register any readings.

CONCLUSIONS

RFID technology has shown to be an effective tool for contractors to track material and equipment movement across a construction jobsite. The research described in this paper has shown that RFID technology may also provide benefit in the marine construction arena as a safety measure.

Much more research is needed to discern the true effectiveness of RFID technology as a safety measure beyond what was presented in the paper, as the experiments conducted by the researchers were only conducted on one vessel, over a short amount of time (i.e. two days), and with only five construction personnel. Future studies should be conducted over a longer period of time, and with more crewmembers participating. Only one type of RFID tag technology (i.e. passive) was tested by the researchers. Future research should also include the testing of semi-passive and active tags to discern if different technologies provide different results. Finally, future research should be conducted on different types of vessels and in differing weather conditions to determine how those factors may affect the use of the RFID equipment.

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