Forklift Safety

Sensing the Dangers With Technology

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IN BRIEF

- **One common hazard in manufacturing environments is struck-by events between forklifts and pedestrian workers.**
- **This article reviews research conducted to evaluate the effectiveness of magnetic field proximity-sensing technology deployed in an active indoor manufacturing environment.**
- **The technology was used to assess multiple variables associated with the successful implementation and operation of magnetic field proximity on a forklift and pedestrian workers.**
- **Experimental results demonstrate the proximity-sensing system's ability to alert pedestrian workers and forklift operators when a hazardous proximity situation exists.**

The U.S. manufacturing industry constitutes 8.3% of the workforce, but experiences a higher percentage of workplace injuries (12.6%) and workplace fatalities (7.3%) (BLS, 2016). Manufacturing environments are often characterized by dynamic resources including interactions between mobile equipment and pedestrian workers. The hazardous work environment characteristic of manufacturing facilities is evident in the high ratios of workplace injuries and fatalities compared to other industrial sectors in the U.S. A common problem in this environment is struck-by incidents between forklifts and employees completing tasks on the ground surface (BLS, 2016).

Opportunity exists to decrease the number of injuries, illnesses and fatalities in manufacturing work environments. The authors identified a need to evaluate the capabilities of magnetic field sensing technology to alert manufacturing personnel when hazardous situations exists.

This article reviews an experimental evaluation of the effectiveness of magnetic field proximity-sensing technology deployed in an active indoor manufacturing environment. A test bed and experimental trials were created to assess the effectiveness of a select proximity-sensing system. The research scope involves hazardous proximity situations and conditions between forklifts and pedestrian workers in a manufacturing environments.

Experiments were created to assess multiple variables associated with the successful implementation and operation of magnetic field proximity sensors on a forklift and pedestrian workers in an active manufacturing facility. Metrics were used to evaluate the technology's effectiveness, including alert range, alert strategy, power source, cost and system complexity. Human-equipment interaction scenarios were created to assess the technology's effectiveness.

Proximity-Related Incidents in Manufacturing

The dynamic resources (e.g., mobile equipment, pedestrian workers) in manufacturing environments often produce human-equipment interactions (Godwin, Eger, Salmoni, et al., 2007). In 2014, 29% of

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work-related fatalities in manufacturing were caused by struck-by incidents in which a person was contacted by a piece of equipment or object (BLS, 2015), a decrease from 35% in 2013 (BLS, 2014).

More specifically, NIOSH (2001) estimates that at least 100 manufacturing employees are fatally injured annually in forklift struck-by incidents. It also is estimates that 35,000 employees are seriously injured each year after being struck by forklifts in manufacturing facilities (Marsh & Fosbroke, 2015; OSHA, 2016). When these events are nonfatal, employees typically experience crushing injuries of the foot or ankle (Hong, Nashi, Kuan, et al., 2015).

Magnetic Field Sensing

Magnetic fields are created from a generated field of electric charges that create electromagnetic fields (WHO, 1998). The strength of the electric current is strongest near the generating source and decreases as the distance from the source increases (Zhang, Zhang, Zhang, et al., 2007).

Magnetic sensors can indirectly measure direction, presence, rotation, current and angle through indirect disturbances in the magnetic field (Caruso, Bratland, Smith, et al., 1998). Industries that have benefited from the capabilities of low-frequency magnetic-field-sensing technology include biomedicine, tissue engineering, robotics and automotive (Zhang, et al., 2007). Minimal experimental evidence exists that demonstrates the impact of magnetic fields on human physiology and safe behavior (WHO, 1998).

Experiments & Results

A magnetic field proximity-sensing system was deployed on a forklift and a pedestrian worker to simulate hazardous proximity situations in the manufacturing environment. Experimental trials were designed to evaluate the system's effectiveness.

The trials simulated typical operating functions of manufacturing facilities including multiple combinations of static and mobile pedestrian workers and forklifts. Experimental trials were conducted in created test beds both indoors and outdoors. Aspects of previous research with sensing technology were used to develop these experimental trials (Marks & Teizer, 2013).

Magnetic Field Proximity-Sensing System

The selected magnetic field proximity-sensing system provides a wireless and rugged technology that can function indoors and outdoors. The generated magnetic field can be adjusted to calibrate the alert distance depending on the forklift's speed and function as well as the work environment.

The system communicates between two components, the equipment protection unit (EPU) and the personal protection unit (PPU) (Figure 1). The EPU is mounted atop the forklift to audibly and visually alert the operator during hazardous proximity situations. Each EPU costs approximately $1,000.

The PPU, which measures 9 cm long, 7.5 cm wide and 2.5 cm deep (3.5 x 3 x 1 in.), weighs 32 g and costs approximately $100. It is worn on a pedestrian worker's safety vest or hard hat, and it provides vibratory and audible alerts when a forklift is nearby. Once the PPU deforms the magnetic field generated by the EPU, both units issue an alert.

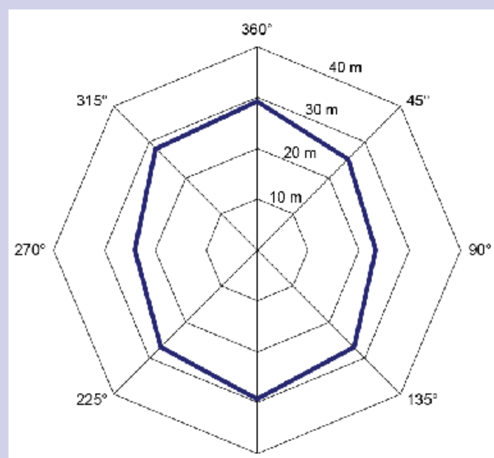
FIGURE 1

Magnetic Field Proximity-Sensing System Devices

Magnetic field proximity-sensing system devices including a) EPU mounted on a forklift and b) PPU placed on a pedestrian worker.

FIGURE 2

Average Alert Distance Range for Static Equipment & Mobile Worker



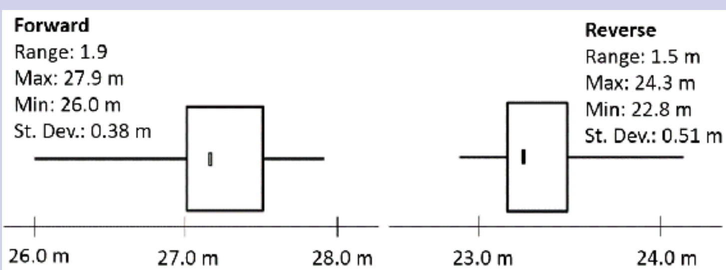
The selected system was found to be functional in rugged outdoor environments (Ruff, 2004; 2007). The low-frequency system deployed functions at 73 kHz from a power source generated from the PPU. The EPU contains a magnetic antenna that generates a magnetic field containing a ferrite core material powered by the system to generate a magnetic flux. Magnetic shells generated by the EPU are projected in a 3-D oval shape contributed to the magnet's polarity. A lithium-thionyl chloride battery powers the PPU. Each charge lasts approximately 72 hours. The batteries cost around $10.

Static Forklift & Mobile Pedestrian Worker Alert Distance

The first set of experimental trials was completed outdoors with clear weather conditions, minimal wind speed and a temperature of 70 °F (21 °C). For these trials, a paved surface with no obstructions was deployed as the testbed. For each trial, the alert distance was measured as the pedestrian worker advanced toward the static forklift from eight equidistant approach angles. The alert distance was measured 30 times for each of the eight approach paths. Manual methods were used to

FIGURE 3
Test Bed for Mobile Forklift & Static Pedestrian Worker

FIGURE 4
Results of the Mobile Forklift & Static Pedestrian Worker Experimental Trials



mark and measure the alert distance as the worker approached the static forklift at an average walking speed (2 m/s, or 4.5 mph).

These trials were designed to measure the alert distance range for the sensing system with minimal influence from other variables. These trials evaluated the system's effectiveness in detecting and alerting when a moving worker crossed into a precalibrated hazardous proximity zone. The PPU was placed in a pocket on the pedestrian's clothing and the EPU was mounted to the roof of the forklift cabin. Figure 2 (p. 37) presents the average alert distance from each approach path.

A statistical analysis was performed for each approach angle taken by the mobile worker; this encompassed 240 data points. The collected alert distances were mined for false negative readings and nuisance alerts. The following terms were used to analyze the collected data:

•False negative: An alert is not activated when the mobile worker is too close to the forklift.

•True negative: An alert is activated when the mobile worker is a safe distance from the forklift. Alert distances that are three times larger than the upper quartile value of length for each approach path of the sample. These are also called nuisance alerts.

The median alert distance for these trials was 26.9 m. The minimum and maximum alert distances were 23.1 m and 29.9 m, respectively (*SD* = 2.3). No false or true negative alerts occurred during this set of trials. All activated alerts were deemed true positives because a hazardous proximity situation existed between the pedestrian and the forklift.

Mobile Forklift & Static Pedestrian Worker

The second set of experimental trials evaluated the system's effectiveness on a simulated static pedestrian worker and a moving forklift. The same outdoor test bed was used for these experiments (Figure 3).

The forklift approached the static pedestrian worker in a straight path in the forward and reverse direction at approximately 3.7 mph (6 kph). The forklift operator stopped when he was alerted and then the research team measured the alert distance from the front of the forklift to the static pedestrian worker. Thirty trials were completed in each travel direction and no false negative alerts were experienced indicating that 100% of the readings were true positive alert readings. Figure 4 presents a summary of the analyzed results from these trials. Both the range and *SD* are slightly larger when the forklift travels in the reverse direction, which can be attributed to the EPU mounting location. The range value presented represents the difference between the highest recorded alert distance and lowest recorded alert distance for each set of trials.

Static Obstructed PPU Line-of-Sight With Mobile Forklift

The final set of experimental trials assessed the sensing system's ability to detect hazardous proximity situations while the communication line-of-sight between the EPU and PPU was obstructed. A test bed was created inside the maintenance room of an active manufacturing facility. In these trials, the PPU was placed in a static location while the forklift approached in a similar manner as in the earlier trials; this was repeated 30 times for each forklift travel direction. Figure 5 shows a photo of the test bed created for these trials.

The forklift approached the obstructed PPU in a straight path in the forward and reverse direction at about 3.7 mph (6 kph). The forklift operator stopped when he was alerted and the research team measured the alert distance from the front of the forklift to the perpendicular horizontal distance to the PPU.

No false negative alerts were recorded during these trials, indicating that 100% of the readings were true positive readings. Figure 6 presents box plots of both the forward and reverse travel direction experimental trials. The range and *SD* are also provided for each set of trials. The difference between the measurements for the forklift traveling forward and in reverse is negligible.

Conclusions

Existing safety practices are limited in preventing dangerous human-equipment interactions between pedestrian workers and forklifts. One can understand this by observing current practices or reviewing current safety statistics in manufacturing (BLS, 2014; 2015). This research aimed to evaluate the effectiveness of magnetic field proximity-sensing technology in an active indoor manufacturing environment. Three unique sets of experimental trials were conducted to assess various metrics related to overall effectiveness of the technology. Results indicate that this technology can alert forklift operators and pedestrian workers when a hazardous proximity situation exists. All alerts recorded were true positives meaning the alert was only activated when a hazardous proximity situation was present.

The researchers conclude that implementing and maintaining proximity-sensing technologies in manufacturing environments can alert employees to hazardous situations. These devices can be placed on all company employees and equipment, mounted on select equipment, or provided only to visitors or people unfamiliar with the work environment. Providing an alert to a potential hazard gives individuals a chance to retreat from the hazard before an incident occurs.

A few limitations are worth noting. The major limitation of the technology is the learning curve to transition an entire manufacturing site to its use. Furthermore, a company would need to make a significant investment to implement these devices. As with any new safety policy or technology, employees would need time to understand the system's capabilities. The experimental trials found no evidence that work environment factors (e.g., dust, wind, location of PPU on worker) affected the system's functional abilities.

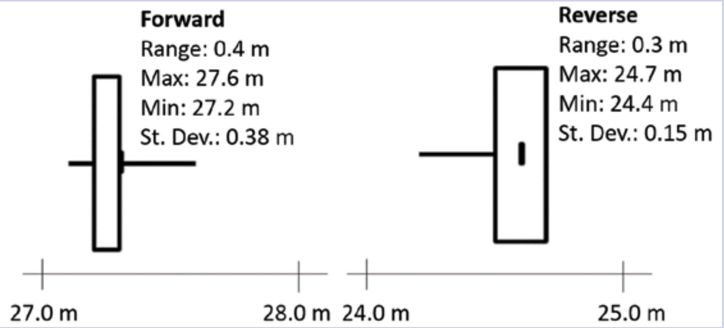
The findings from this research can guide efforts to install similar technology into active manufacturing environments to eliminate struck-by incidents between pedestrian employees and equipment. A company wishing to implement such a system should identify hazardous proximity situations in its current manufacturing environment, then conduct a pilot study in which EPU and PPU components are installed on equipment and pedestrian workers in a specific hazard location. Management can then conduct periodic informal surveys of equipment operators and pedestrian employees to assess their perceptions of the system. Based on results from the pilot study, the devices can be more accurately calibrated and deployed in other parts of the facility. **PS**

FIGURE 5

Indoor Test Bed for Mobile Forklift & Obstructed PPU

FIGURE 6

Results of the Mobile Forklift & Static Obstructed PPU



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