Smart Safety Belt Design to Avoid Accidents in Hazardous Industrial Environment

Muhammad Yaseen, Saad Qasim Khan, Muhammad Khurram and Rana N. Mubarak
Koshish Foundation Research Lab Department of Computer & Information Systems Engineering NED University of Engineering & Technology, Karachi-Pakistan

Article Info

Article history:

Received Jan 2, 2016
Revised Mar 23, 2016
Accepted Apr 11, 2016

Keyword:

Smart Safety
Belt Design
Avoid Accidents
Hazardous
Industrial Environment

ABSTRACT

Warehouse is one of the most dangerous places to work because of many potential dangers. The accidents caused by heavy vehicles result in serious injuries and even death. This paper proposes a solution to this problem. When a worker happens to be in any of such hazardous situations inside or outside workplace, he will press the emergency button (or pull a magnetic cord) placed in the smart safety belt which will not only stop the vehicles within 15 meters circle but also inform the workers within 250 meters circle through an indicator. In this technical paper, the outcome of first design phase has been reported. In the first design phase, we have successfully implemented a reliable and accurate ranging mechanism with ±0.3m maximum error. This ranging mechanism is based on wellknown RF Time-of-Flight (TOF) method. The maximum achievable transmit range of this solution is 300m.

Corresponding Author:

Muhammad Yaseen,
Koshish Foundation Research Lab
Department of Computer & Information Systems Engineering
NED University of Engineering & Technology, Karachi-Pakistan.
Email: www.kfrlab.com

1. INTRODUCTION

Safety of industrial worker, working in hazardous industrial environment is of major concern to many prosperous organizations. Different measures are taken by these organizations to increase the safety of their workers. A human causality within any industry is considered as a vital damage to functioning and working environment of any organization.

The scenario for hazardous environment can be understood from the following case study. Consider a worker that suddenly fell off within a warehouse area and become injured where heavy machinery is also being operated. In such harsh environment sometimes it is impossible to communicate with the heavy vehicle driver or crane operator. On the other side, heavy machine operator might not see such a person who is injured and he may not be visible through the driving chamber. This scenario may result in major accident which in turn may be avoided if panic signal is properly communicated from the effected employee to all the vehicles and peer workers in the warehouse. This sort of communication can be achieved by utilizing robust wireless communication mechanism [1]. Apart from communication, ranging applications are also required on ground.

Ranging mechanism can be implemented through number of techniques. These techniques include GPS based positioning system [2]. Despite of popular applications for GPS based ranging systems they underperform in indoor environments. Optical ranging systems [3] are also extensively employed for measurement of distance between transmitter and the target object. The problem with the optical ranging system is the presence of hindrance in the path between the optical transmitter and the target object. In target environment of a warehouse, it is nearly impossible to avoid all types of hindrances. RF based ranging mechanisms have also been implemented in the past. There are five major techniques for RF based ranging mechanism. These include Time-of-Flight (TOF) [4, 5], Time Difference of Arrival (TDOA) [6, 7], Received Signal Strength Indication (RSSI) [8], Near Field Electromagnetic Ranging (NFER) [9] and Angle of Arrival (AOA) [10, 11].

This paper utilizes the RF Time-of-Flight (TOF) method for ranging application. A system was designed to be placed within smart safety belt. This system is provided with a panic button which can be pressed by the worker under emergency. After pressing panic button by the worker, all the vehicles within the critical zone are forced to stop. The critical zone is defined within radius of 15 meters from the system where panic button has been pressed. System design has been discussed in Section II. Section III shed light on the algorithm utilized for system application. Section IV shows test results for both indoor and outdoor test environment. Section V state s the conclusion.

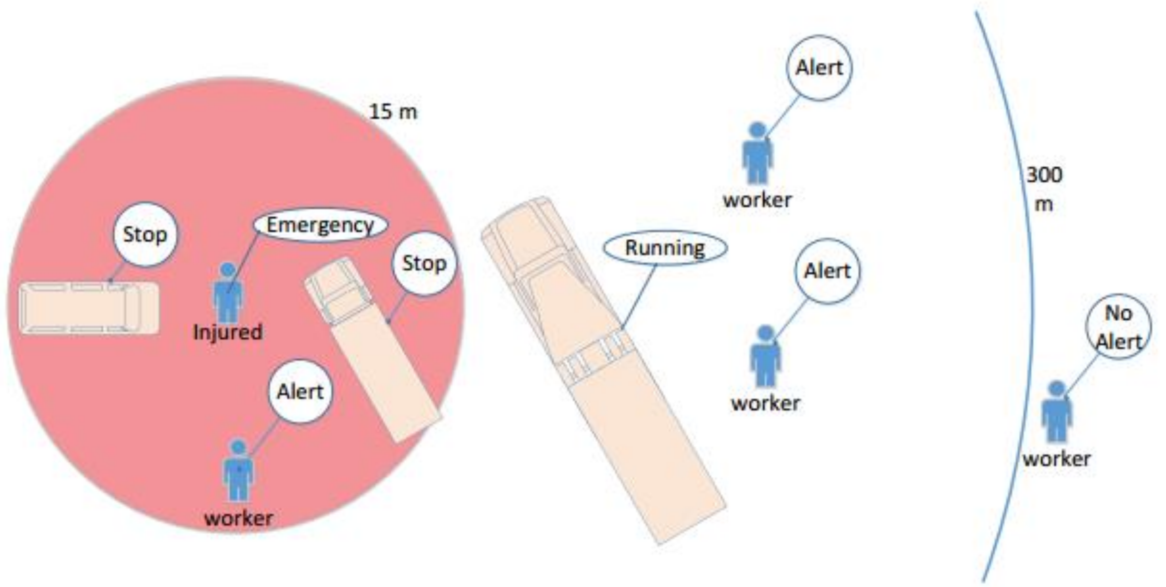

Figure 1. Possible application scenario

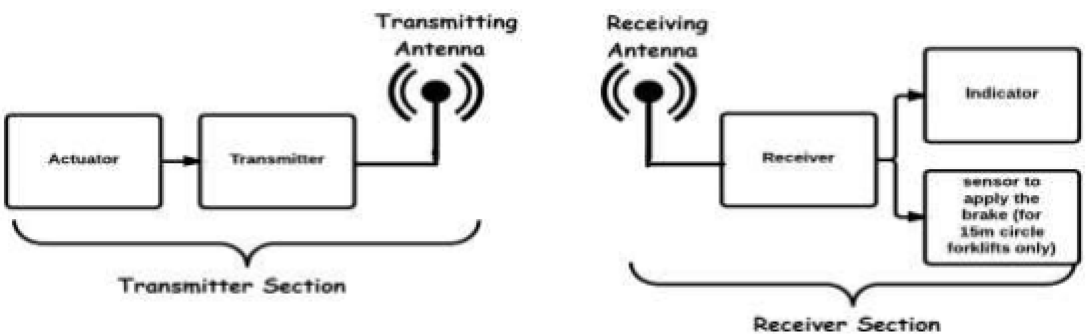

Figure 2. System Block Diagram

2. SYSTEM DESIGN

A. Environment

The possible environment for proposed system is depicted in Figure 1. Here an injured worker is shown in the center of red circle. Red circle with radius of 15 meters can be regarded as critical zone. There are three vehicles depicted where two vehicles are in the critical zone and one vehicle is outside the critical zone but within 300 meters where the UWB transceiver based system can communicate. The vehicles within the critical zone should be stopped to avoid any mishap. Whereas the one vehicle that is outside the critical region may receive an alert for an injured worker but may not be stopped.

Similarly colleagues of an injured worker are also depicted in Figure 1. There is one worker in the critical zone. Two workers are within 300 range. All these three workers will receive alert message for injured worker. Whereas one worker depicted outside the 300 meter range of UWB transceiver may not get any alert message. It is presumed that for this scenario it is suffice if only those workers get the alert message whom are within 300 meters range.

B. Ranging mechanism

Ultra Wide Band (UWB) is becoming popular for implementation of ranging mechanism [12]. The main reason behind utilization of UWB for ranging application is use of subnano seconds pulses for transmission which is considered to be more robust as compared to narrow band signals [13]. The system has two main sections; the transmitter (Tx) and receiver section (Rx) as shown in Figure 2. The transmitter section includes one RF transmitter and one acoustic signal generator, connected to an actuator. The panic call will be initiated by the threatened worker through a push button or a cord. While at the receiving end, the signals will be received by the RF antenna and acoustic sensors mounted on the belts or vehicles. Through the strength of the received RF signal or acoustic signal, the receiver controller section will decide whether the driver should only be alerted of an injured worker or the vehicle should also be stopped. The mechanism to evaluate the distance on the system is based on RFT OF mechanism which is discussed in the next subsection.

C. Time of Flight

To provide the required functionality, Time of Flight (TOF) method is used. It is a highly accurate method as compare to the using received signal strength indicator (RSSI) as a measure of distance. TOF method of range calculation is shown in the following figure:

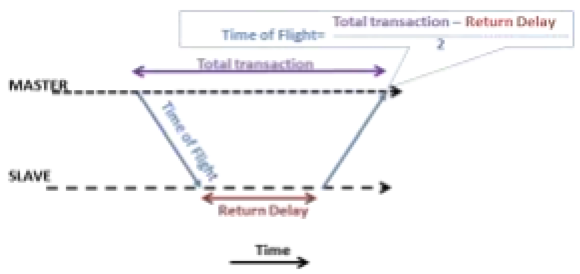

Figure 3. Time of Flight time domain representation

Above figure depicts the time-domain message transmission between the master and slave nodes. Total Transition (TT) represents the turnaround time for a packet that is transmitted from the master node and received back on the same node. Return Delay (RD) is the processing delay of a packet at the slave side. The TOF can be represented as

$$T.O.F = \frac{t_{TT} - t_{RD}}{2} \quad (1)$$

$$distance = T.O.F * speed\ of\ light \quad (2)$$

Here t_x represents the time of x. As soon as TOF is calculated, this delay information along with the speed of RF signal (speed of light) is used to compute the distance between the transmitter and the receiver.

3. ALGORITHM

The tag device is connected to the safety belt of the warehouse worker and anchor device is placed on all the vehicles in the warehouse. Initially the unpaired anchor and tag are not communicating with each other.

When the warehouse worker pushes the emergency button, the devices are in a discovery phase where the unpaired tag sends a Blink message that contains its own address, after which it listens for a Ranging Initiation response from an anchor. If it does not get one it sleeps for a period (default of 1 second) before blinking again. The unpaired anchor listens for tag blink messages. The anchor will then pair with first tag it gets the Blink message from, and send the Ranging Initiation message to exit from the Discovery Phase and enter Ranging Phase.

Once the anchor enters the Ranging phase it turns on its receiver and waits indefinitely for a poll message. The tag sends a Poll message with encryption key. Then anchor device receives the poll message, stores the encryption key and then sends a Response message to the tag device, after which the tag device encrypts the timing report and sends it through the Final message.

At the end of this exchange the anchor calculates the range to the tag. If the distance is less than 15 meters then the device will turn on the breaking system of the vehicle and stops it's moving. The graphical representation of the scenario is shown in Figure 4.

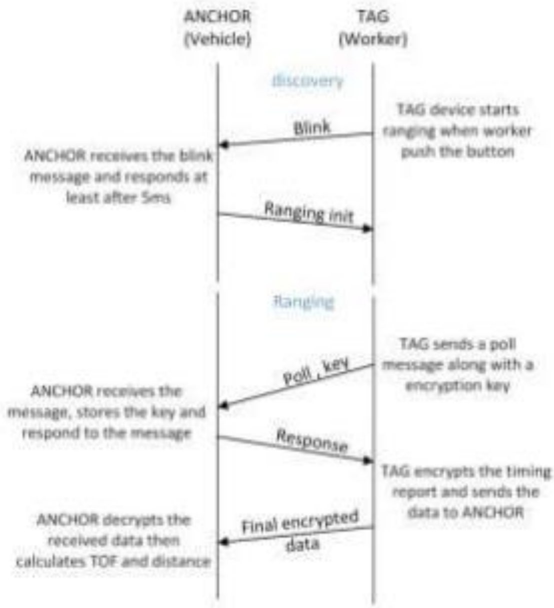

Figure 4. Discovery and Ranging phase message exchange

The complete algorithm for ranging and alert gadget is presented under two heading, algorithm for tag device placed inside the smart safety belt and for the anchor device placed inside the vehicle. Both algorithms are covered under separate headings as follow

A. Algorithm for Tag device

The tag device shall continuously check the emergency button. If the button is on, then it will start discovery. After receiving the start ranging message and sending acknowledgement, it will poll for ranging. Once ranging completed, it will wait for response message from other devices. It also sends alert message after each 5 or 10ms.

If an alert message is received from any other worker, it will turn on the jackets alert LED, Vibrator motor and buzzer for one second and then rechecks if the emergency is handled. The algorithm for tag device is as follow

1) Interrupt Service Routine to check for Button pressed or Alert received. If Button pressed goto procedure A. Else if Alert received goto procedure B.

Procedure A:

2) Turn on UWB transceiver.
3) Send Alarm message to all peer nodes.
4) Response received? If no then goto step 3 otherwise proceed to next step.
5) Calculate distance using TOF between the tag and all anchor devices.
6) Alert handled? If yes proceed to next step otherwise goto step 3.

7) Stop Alarm message broadcast
8) Turn off UWB transceiver
9) Return

Procedure B:
2) Turn on vibrator.
3) Turn on alert LEDs.
4) Turn on Buzzer.
5) Repeat step 2-4 for 1 second.
6) Return

B. Algorithm for Anchor device

Anchor will wait for blink signal from tag device installed in the smart safety belt, after it gets the blink message; it calculates the distance to individual vehicles. If distance of any vehicle is less than 15m, it will stop that particular vehicle through actuators. Then it will decline responding for next blink till one second. The complete for Anchor device is as under
1) Initialize Anchor device.
2) Increment counter.
3) Blink received? If yes proceed to next step otherwise goto step 3.
4) Delay counter.
5) Send ranging message.
6) Wait for poll
7) Get poll request.
8) Generate response for tag device
9) Receive Final encryption data from tag device.
10) Calculate distance
11) Distance is less than 15 meters? If yes goto procedure A else goto step 6 with (1) millisecond delay.

Procedure A:
12) Signal actuator to apply breaks.
13) Wait for response from system.
14) Alert handled? If yes then goto step 6 with anchor system reset else goto step 13.

4. RESULTS

Tests on the proposed RF based ranging device were conducted in both indoor and outdoor environment. The results for these tests are stated section wise as under

A. Indoor testing:

The designed gadget has been tested in the indoor office environment operated by a battery. For different known distances (1 to 15 meters) the measurements were taken using the developed gadget. The system was tested with operation through walls and different types of equipment around. The results demonstrate an accuracy of 99.27% at 15 meters distance. The graphical illustration of the test results are presented in Figure 5.

B. Outdoor testing:

The designed gadget has also been tested in outdoor environment. For the dataset presented here, a vehicle parking space was selected. The results demonstrate an accuracy of 99.33% at 15 meters distance. The graphical illustration of the test results are presented in Figure 6.

All the tests that were conducted in indoor and outdoor environments using the proposed system confirms to the requirement of this project with maximum error of ±0.3 m.

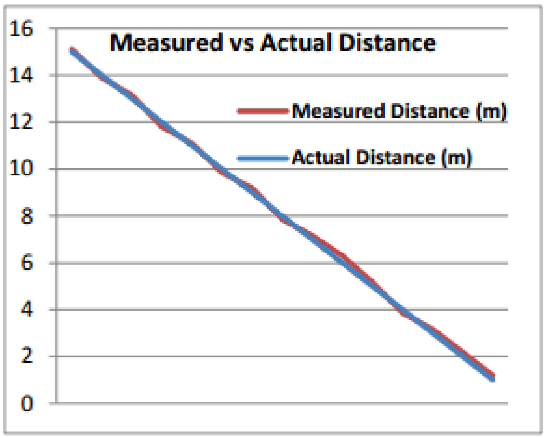

Figure 5. Comparison of Measured Vs Actual Distance (Indoor)

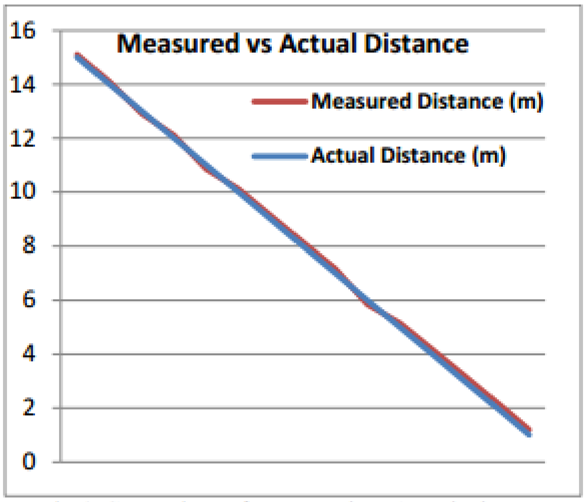

Figure 6. Comparison of Measured Vs Actual Distance (Outdoor)

5. CONCLUSION

In phase-I of the project, a ranging prototype mechanism have been studied and a gadget is developed for smart safety belt with 98% accuracy at 15 meters. It will be an efficient, cost effective and reliable system that will ensure the reduction in the accidental injury and fatality rate in the warehouses. Range finding mechanism has been developed using RF signal TOF method with worst case error in measurement of ±0.3m. Working prototype has been implemented and tested in realtime. The response time of the prototype is 150ms. Its size/board area is 2.5 sq. inches. The working prototype is completely programmable. Its firmware can be updated to include encryption in the gadget. The size of the gadget can also be reduced upto 1/3rd of its current size.

As the future work for this project, in phase II, the software will be modified to reduce the response time for the data transmission. Further the encryption algorithm on the timing information will be implemented for reliable communication between the peers.

REFERENCES

[1] G. Mao and B. Fidan, "Localization Algorithms and Strategies for Wireless Sensor Networks", Information Science Reference, pp. 526, 2009.

[2] E. D. Kaplan, Understanding GPS: principles and applications. Boston: Artech House, 1996.

[3] Amann, Markus-Christian, et al. "Laser ranging: a critical review of usual techniques for distance measurement", Optical engineering, 40.1 : 10-19, 2001.

[4] T.C. Karalar and J. Rabaey, "An RF ToF Based Ranging Implementation for Sensor Networks", *IEEE International Communications Conference*, University of California, Berkeley, vol 7, pp. 3347-3352, Jun 2006.

[5] S. Lanzisera, D.T. Lin, K.S.J. Pister, "RF Time of Flight Ranging for Wireless Sensor Network Localization", Intelligent Solutions in Embedded Systems, 2006 International Workshop, p1-12, 30-30 June, 2006.

[6] R.J. Fontana, S.J. Gunderson, "Ultra-wideband precision asset location system", *IEEE Conference on Ultra Wideband Systems and Technologies*, pp. 147- 150, May 2002.

[7] R.J. Fontana, E. Richley, J. Barney, "Commercialization of an ultra wideband precision asset location system", Ultra Wideband Systems and Technologies, *2003 IEEE Conference*, p369-373, 16-19 Nov, 2003.

[8] X. Li, "Performance study of RSS-based location estimation techniques for wireless sensor Networks", Military Communications Conference, 2005. MILCOM 2005. *IEEE*, p1064-1068, Vol.2, 17-20 Oct, 2005.

[9] H.G. Schantz, "*A real-time location system using near-eld electromagnetic ranging*", Antennas and Propagation Society International Symposium, 2007 IEEE, p3792-3795, 9-15 June, 2007.

[10] R. Peng, M.L. Sichitiu, "Angle of Arrival Localization for Wireless Sensor Networks", Sensor and Ad Hoc Communications and Networks, 2006. SECON '06. *2006 3rd Annual IEEE Communications Society*, p374-382, 28 Sept, 2006.

[11] P. Rong, M.L. Sichitiu, "Angle of Arrival Localization for Wireless Sensor Networks", Sensor and Ad Hoc Communications and Networks, 2006. SECON '06. *2006 3rd Annual IEEE Communications Society*, pp. 374-382, Sept 2006.

[12] Low, Z.N., et al. "Pulse detection algorithm for lineof-sight (LOS) UWB ranging applications", Antennas and Wireless Propagation Letters, *IEEE*, 4 pp: 63-67, 2005.

[13] J. Foerster, "Channel Modeling Sub-Committee", *IEEE*, Piscataway, NJ, P802.15-02/490r1-SG3a, Final Rep., Mar. 2003.