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A Smart Safety Gadget Design to Avoid Accidents in Warehouse Environment

Muhammad Yaseen[1], Engr. Laeeq uz Zaman[1], Dr. Muhammad Khurram[1] and
Dr. Rana Noman Mubarak[2]

[1] Koshish Foundation Research Lab, Computer and Info. Systems Engineering Department, NED University of Engineering and Technology,
Karachi, 75290, Pakistan (mohammadyaseen13@gmail.com, laeeq2410@hotmail.com, mkhurrum@neduet.edu.pk)
[2] MTE Group,
Hamilton, New Zealand (rana@modtrans.co.nz)

Abstract: Warehouses are one of the most dangerous places to work because of sudden accidents caused by automated machinery and vehicles. Such accidents can be prevented by stopping the machinery or alerting the operator immediately when it is in close proximity of a worker. In this paper we present our design of a smart safety gadget that can avoid this problem to a greater extent. The device is triggered by an easily accessible emergency rope or switch. The gadget hosts an ultra-wide band (UWB) radio module for measuring distance between worker and machinery and generates an alert signal to stop the vehicle if calculated distance is less than a defined programmable value (e.g. 10m). Gadget also sends a distress signal to other workers within a 150m radius over range radio so that they can come to assistance of worker. This ranging and alert mechanism has been successfully implemented on the demonstrated prototype with ±0.3m maximum error.

Keywords: Smart Safety Gadget, RF system, Time-of-flight, Positioning algorithm, UWB positioning, RF localization.

I. INTRODUCTION

Safety of workers is a major concern for all organizations. Not only specialized bodies make laws for workplace safety but organizations too, take different measures to ensure the safety of their workers as it relates directly to the morale of workforce and hence productivity. A human causality is considered a damage to functioning and working environment of any organization. Companies also suffer financial loss in the form of lawsuits and claims by grieved employees.

The problem of worker safety becomes more critical in cases where the risk of potential accidents is higher. Warehouses are among such places and have a high rate of fatal injuries [1]. A considerable proportion of these accidents involve automated machinery and heavy lifting vehicles. Such accidents can be avoided if there is a reliable way to communicate the distress signal to machine and stop it immediately in case of danger. This communication can be achieved by utilizing robust wireless communication mechanism [2]. Apart from communication, ranging applications are also required on ground. It is also desirable to inform other workers in the area about the accident so that they can attend to the situation.

Ranging mechanism can be implemented through number of techniques. These techniques include GPS based positioning system [3]. Despite popular applications of GPS based ranging systems they underperform in indoor environments. Optical ranging systems [4] 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 obstacles. 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) [5], Time Difference of Arrival (TDOA) [6], Received Signal Strength Indication (RSSI) [7], Near Field Electromagnetic Ranging (NFER) [8] and Angle of Arrival (AOA) [9].

This paper utilizes the RF Time-of-Flight (TOF) method for ranging application. Rest of the paper has been organized as follows: Section II illustrates a typical application scenario of the proposed system. System design has been discussed in Section III. Section IV describes the ranging method and gadget roles in detail. Prototype has been described in Section V followed by testing results in Section VII. Section VII states the conclusion.

II. USE CASE SCENARIO

The following use case will illustrate the working of gadget and ranging mechanism. Consider a typical

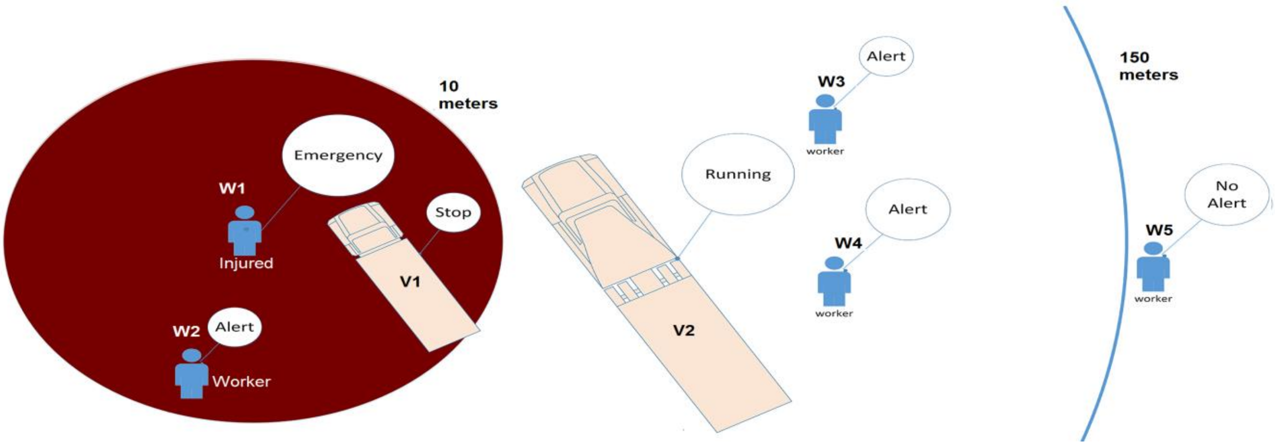

Fig. 1 Use-case scenario for smart safety gadget. Workers and Vehicles are equipped with the gadget

warehouse environment with two automated machines or vehicles V1 and V2, four workers W1 to W5 in the region of interest. Vehicles V1 and V2 are operating normally. Let's assume that worker W1 suffers an injury and is thus immobilized. He is unable to move out of the way or stop the approaching vehicle V1. More often than enough these kinds of situations lead to accidents and serious injuries.

To address this problem, we propose to equip workers and machines with smart safety gadgets. When faced with a potentially hazardous scenario worker will pull the string in the gadget, causing worker and vehicle device to compute distance between themselves. If the calculated distance is less than a predefined range, referred to as Critical Distance (CD) hereinafter, the device on the machine will generate a signal that can be used to bring it to halt. Simultaneously, worker's device will transmit a help message over the long range radio that will cause buzzers to sound an alarm on all worker devices, thereby alerting them of a potential accident.

The scenario after the worker has pulled the string has been depicted in Fig-1. Notice that vehicle V1, which was inside the critical range (10m in this case) has been stopped while V2 – that was outside the critical range - is still operational as it should be. Workers W2, W3 and W4 have been alerted by the long range radio. Worker W6 was outside the range (150m) of long range radio and hence has not been alerted.

III. SYSTEM DESIGN

A. System Overview

Two types of devices have been implemented. One is for the worker, called Worker's Device (WD) and the other is for automated machines, referred to as Vehicle's Device (VD). The functionality of WD includes: initiating range calculation when emergency rope is pulled, long range alert transmission/reception, sounding the buzzer, and battery monitoring. VD is responsible for final range calculation, generating signal in case range is less than programmed CR. VD also provides a USB serial interface to reconfigure CR. The block diagram of both devices is shown in Fig-2.

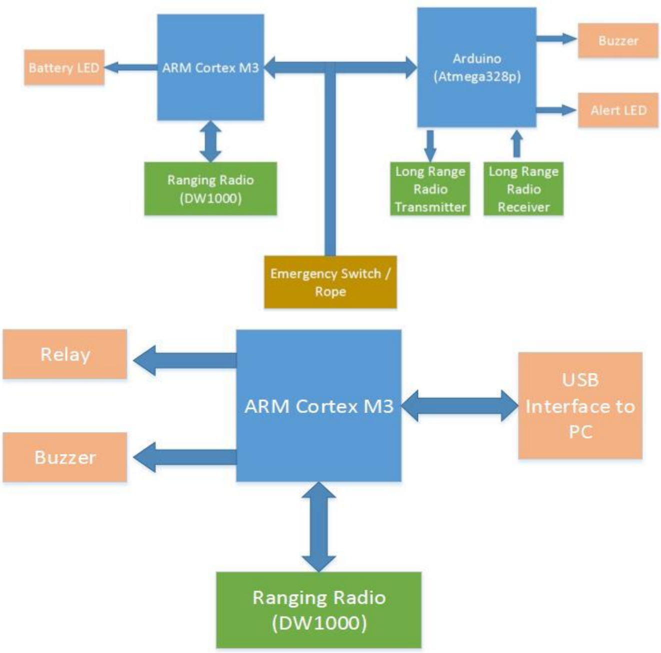

Fig. 2 Block diagram of Worker's device (above) and Vehicle's Device (below)

B. Ranging Mechanism

In this project the mechanism to evaluate the distance between worker and vehicle is based on Ultra Wide Band (UWB) RF Time of Flight Two Way Ranging technique. UWB is becoming popular for short-range RF Communication [10]. The main reason behind utilization of UWB for ranging application is use of sub-nano seconds pulses for transmission which is considered to be more robust as compared to narrow band signals [11-12].

C. Time of Flight

Time of Flight (TOF) is a highly accurate method as compared to Received Signal Strength Indicator (RSSI) as a measure of distance which suffers from constructive and destructive interference in practical environments [13]. Decision to use TOF was further motivated by easy availability of supporting hardware (i.e. DW1000). TOF method of range calculation is shown in Fig. 3:

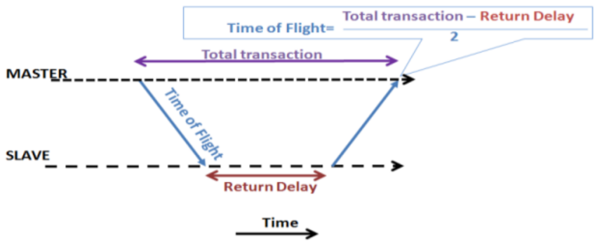

Fig. 3 Time of Flight Two way ranging method

IV. ALGORITHM

The DW1000 UWB module provides MAC and PHY support (e.g. time stamping, frame encoding and decoding) on top of which a highly accurate ranging method can be implemented. Ranging method used in this gadget has two different phases as described below:

A. Discovery Phase

Initially WD and VD are unpaired and unaware of each other. When the worker pushes the emergency button WD sends a Blink message that contains its own address, after which it listens for a Ranging Initiation response from VD. If it does not get one it sleeps for a period (default 1 second, can be changed) before Blinking again. The unpaired VD listens for WD Blink messages and pairs with the first WD it gets the Blink message from, and sends the Ranging Initiation message back to WD. Both WD and VD are now aware of each other and ready to exchange range messages. This concludes the Discovery Phase.

B. Ranging Phase

In this phase VD waits indefinitely for a poll message (a timeout can be implemented as well). WD sends a Poll message that is received by VD which then sends a Response message to WD. After receiving the Response message WD sends a Final message back to VD. Now VD can calculate distance between itself and the paired WD based on timing information contained in exchanged messages. The graphical representation of the scenario is shown in Fig. 4.

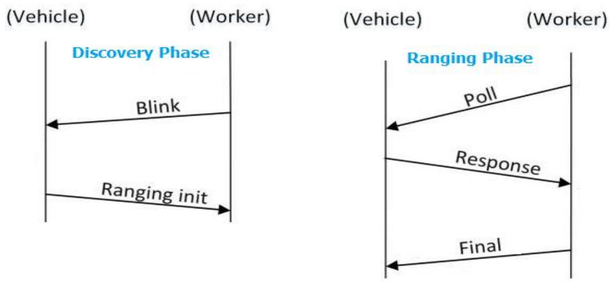

Fig. 4 Graphical representation of ranging timeline

C. Algorithm for Worker's device

Worker's device is in receiving mode under normal conditions and wakes up periodically to listen for alert messages from other workers. It switches to transmit mode when emergency button is pressed. A simplified code organization, omitting battery monitoring, is presented below:

1. If Emergency button pressed go to Procedure A.
Else if Alert received go to Procedure B.

Procedure A:
1. Send Alert message to all other workers in range using Long Range AM radio.
2. Turn on UWB transceiver.
3. Start ranging with the Vehicle's device.
4. Once ranging has concluded, stop alarm message broadcast and turn off AM radio.
5. Turn off UWB transceiver.
6. Return

Procedure B:
1. Toggle alert LED.
2. Sound the buzzer.
3. Repeat step 1-2 every 5 seconds until reset.

C. Algorithm for Vehicle's device

Vehicle's device periodically checks for Blink messages from worker's device. Simplified code flow is as under:

1. Periodically wake up and listen for Blink messages.
2. If Blink message received, start ranging with the Worker's device.
3. Calculate distance.
4. If distance is less than the Critical Range (e.g. 10m), go to procedure A, else go to step 1.

Procedure A:
1. Generate a signal to stop the vehicle (e.g. by signalling the actuator to apply breaks).
2. Sound the buzzer to alert the operator.
3. Continue till system reset.

V. PROTOTYPE IMPLEMENTATION

The prototype was implemented as follows: VD comprised of an STM32F105 Cortex M3 based micro-controller (which hosted main application software and ranging algorithm) and DW1000 UWB radio module. WD additionally contained an Atmega328p chip interfaced with Long Range Amplitude Modulation (AM) radio. WD is battery powered and indicates the status of battery via an LED while VD is powered directly from the supply available on the host machine. Fig. 5 showcases the developed prototypes.

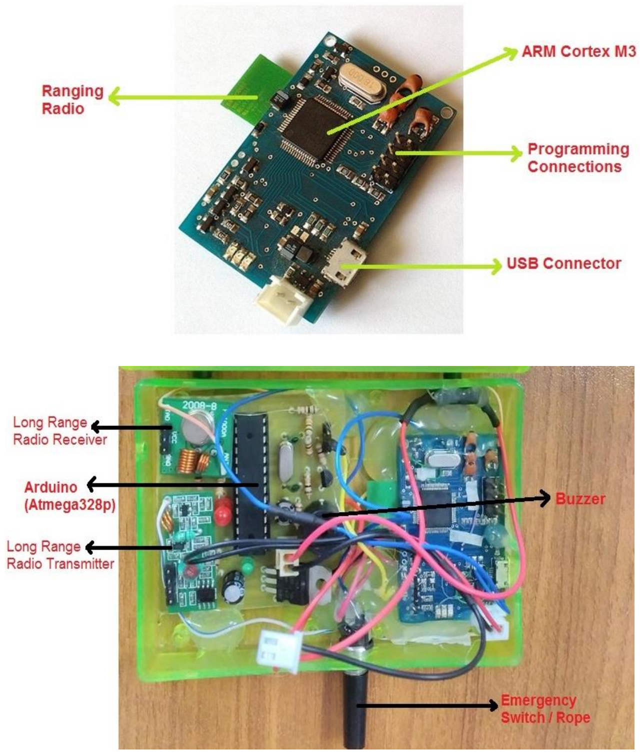

Fig. 5 PCB of Vehicle's device (above) and boxed Worker's Device (below)

VI. RESULTS

Tests on the implemented prototype were conducted in both indoor and outdoor environment. The results for these tests have been stated under.

A. Indoor Testing

The designed gadget was tested in lab environment operated by a battery. At different known distances (1 to 15 meters) the emergency rope on WD was pulled and halt signal was checked. VD was able to correctly generate the halt signal and sound the buzzer when calculated distance was less than CR.

B. Outdoor Testing

The gadget was also tested in outdoor environment at NED University to verify the operation of long range radio. Tests were carried out in corridor and open air environment. The radio achieved a maximum range of 70m when operated with an 8V battery at 1000bps data rate without external antenna. The range is expected to increase considerably when operated with a 12V battery and antenna.

All the tests conform to the requirement of this project with maximum error of ±0.3m.

VII. CONCLUSION

In this paper a working prototype of a smart safety gadget for warehouse workers was developed. The gadget has been tested with several critical distance values from 1 to 15 meters in both indoor and outdoor environments. The ranging an alert system will ensure the reduction in the accidental injuries and fatality rate in the warehouses. Range finding mechanism has been developed using RF TOF Two Way Ranging method with worst case error in measurement of ±0.3m. The response time of the prototype is 150ms. The prototype is programmable and its firmware can be updated to comply with any additional requirements. The size of the gadget can also be reduced up to 1/3rd of its current size.

As future work, we plan to add programmable long range radios and intelligent power management to provide longer battery life.

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