Development of a SafetyBelt for Construction Workers

FINAL PERFORMANCE REPORT

Research Organization: Technological Systems Research, Design & Education
126 Viscount Drive
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Project Title: Development of a SafetyBelt for Construction Workers
[SBIR Phase I Project]

Report Date: March 22, 1999

Principal Investigator: Dr Satish Mohan
Consultant: Dr Darold Wobschall

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Table of Contents

Page #

1. **List of Figures** ---------- **3**
2. **List of Tables** ---------- **3**
3. **Significant Findings** ---------- **4**
4. **Usefulness of Findings** ---------- **6**
5. **Abstract** ---------- **7**
6. **Project Report** ---------- **8**
7. **References** ---------- **19**
8. **Appendices** ---------- **20**
   - A: NIOSH Grant Office Advisor's letter of 06/08/98 21
   - B: Response to Questions/Suggestions in NIOSH GOA letter of 06/08/98 ... 24
   - C: NIOSH Grant Office Advisor 's letter of 12/04/98 26
   - D: Worker Acceptability Survey Questionnaire 31
9. **List of Possible Future Publications** ---------- **32**

1. List of Figures

Page #

FIGURE 1: RF Device Front View Photograph ---------- 9
FIGURE 2: Block Diagram of Safety Device with Radio Frequency Sensor ---------- 10
FIGURE 3: Circuit Diagram of the RF Device ---------- 10
FIGURE 4: Single Sensor Ultrasonic Safety Device Prototype ---------- 11
FIGURE 5: The Ultrasonic Transducer used in the Prototype MHW and ED Devices ---------- 12
FIGURE 6: Block Diagram of Safety Device with Single Ultrasonic Sensor ---------- 12
FIGURE 7: Transmit-Receive Cycle Waveforms of Ultrasonic Safety Device ---------- 13
FIGURE 8: Circuit Diagram of the Safety Device with Single Ultrasonic Sensor ---------- 14
FIGURE 9: Grant Office Advisor's Letter (first 2 pages) ---------- 15
FIGURE 10: Photograph of MHW Device with Single Sensor ---------- 18
FIGURE 11: Photograph of MHW Device with Three Sensors ---------- 18
FIGURE 12: Photograph of ED Device ---------- 18

2. List of Tables

Page #

TABLE 1: Key Personnel 8

3. Significant Findings

The specific aim of this SBIR (phase I) project was to examine the technical merit and feasibility of using ultrasonic or RF wave (radar) technology for developing electronic safety devices for construction workers, to eliminate the following two types of accidents:

(i) Struck-against, and Caught in/under/between equipment, and

(ii) Falls through floor, wall and roof openings, and from open-sided floors.

Significant findings of this research are listed below:

A. Feasibility of Electronic Devices in Preventing Construction Accidents

A_1: It is feasible to develop electronic devices to protect construction workers from:
(i) 'struck-by', 'struck-against', and 'caught in/under/ between' equipment; and
(ii) falls from roofs and open-sided floors.

A_2: It is not feasible to develop an electronic safety device to protect construction workers from falls through floors/walls/roofs openings due to the obstruction, in the ultrasonic wave transmission, created by the wide loads carried by workers.

B. Most Appropriate Technology

B_1: The ultrasonic technology is best suited for developing electronic safety devices for construction workers.

B_2: The RF wave (radar) technology was found to have the following limitations with regards to its use for the safety devices:

(i) The RF wave cannot measure short distances to any acceptable accuracy - short distance detection is needed for the safety devices.

(ii) The RF wave reflection is a function of the material of the reflected surface (e.g., metal surfaces echo the best). Typical construction equipment have a lot of rubber and glass material and could also be covered with mud. As a result, radar-based devices will be grossly inaccurate when doing calibrations due to the great variances in possible materials encountered, and equipment conditions.

(iii) The radar device would be more expensive, larger, and heavier than the ultrasonic device.

(iv) It has been documented in the literature that radar energy can cause blindness, sterility, and other health problems.

C. Safe Clear Distances

C_1: Safe clear distance for moving equipment was determined to be 30 feet, based on the equipment speeds of 4 ft/sec to 6 ft/sec, and the estimated perception-reaction time of an average worker as 5 secs.

C_2: Safe clear distance for falls from roof edge and from open-sided floors was determined to be 6 feet.

D. Acceptability of Electronic Safety Devices

(i) In a limited survey of 14 workers and supervisors, 93% said that they will use such devices if available. Several of them suggested more use of technology in safety. The safety director who conducted the worker acceptability survey commented as below:

'*I am the safety director for Lehigh Construction Group Inc. I have shown these two devices to some of the construction workers and supervisors on our staff. The response was very positive. Out of all the people interviewed, not one person said they would not use these devices. The workers agreed that the construction safety field needs to make better use of today's technology.*

Behavior based programs & attitude adjustments have improved the safety of our worksites a great deal. It is now time for technologically advanced devices such as these two units to take construction safety into the twenty-first century. I feel that with a little training these devices could drastically reduce the number of struck-by & fall related accidents'.

(ii) Presentations of the prototype safety devices were made to local and regional unions, construction companies, contractors' associations and one insurance company; all of them said, in unqualified terms, that they will buy and recommend the safety devices to their workers. In spite of the fact that the prototype devices were 3 times larger and heavier than the anticipated final product, no one gave any discouraging opinion about the devices

4. Usefulness of Findings

The findings of this project can be used in developing two electronic safety devices, using ultrasonic technology:

(i) A Moving Hazard Warning (MHW) device to prevent 'struck-by', 'struck-against', and 'caught in/under/between' construction equipment, and

(ii) An Edge Detector (ED) device to prevent falls from roofs and open-sided floors.

Ultrasonic sensors powered by small rechargeable batteries, and controlled by microchips can be packaged into the two (2) safety devices. Each safety device will be of the size of a pager, and can be built into the rear-side of the worker's tool-belt or waist-belt. Each of the two devices can have rings, which will slide into a rod built into the waist-belt; this mechanism will keep the sensors normal to the floor when the worker bends forward or backward. The devices will warn the worker via sound and/or vibration alarm whenever he/she is closer than a safe distance from the approaching equipment or from the edge of the roof or open-sided floors.

The above two accidents account for 18.9% of the construction accidents and cost the nation $ 981 million, annually.

At this time, any engineering controls, for preventing the accidents of the type listed above, do not exist. Assuming a 50% utilization of the developed products, the savings are estimated to be $ 490 million per year in the construction industry alone, besides saving 98 lives and 21,000 lost time injuries.

5. Abstract

This project has established the technical merit and feasibility of using ultrasonic technology in developing electronic safety devices, to protect construction workers from two of the major construction worksite accidents: (i) 'struck-by', 'struck-against', and 'caught in/under/between' equipment, and (ii) falls from roofs, and open-sided floors/platforms. These accidents account for 18.9% of the construction accidents and cost the nation $ 981 million annually. The devices will be built into the rear-side of the worker's tool-belt or waist-belt and warn the worker via sound and/or vibration alarm whenever he/she is closer than a safe distance from the approaching equipment or the edge of the roof/open-sided floors.

To determine the safety devices design parameters, the safe clear distances were determined in the early phase of this project. For safety against moving equipment, safe clear distance was estimated to be 30 feet; and for safety against falls from roof edges and from floors/platforms, the clear distance was estimated to be 6 feet. These safe clear distances were used in the design and testing of the prototypes.

Preliminary studies done prior to this project had examined the potential of all of the available technologies: ultrasonic, RF wave, laser, and infrared; and determined that only ultrasonic, and RF wave (radar) technologies can be used for the proposed safety devices. Prototype devices using each of the two technologies: ultrasonic, and RF wave, were then designed and assembled in this project, and were tested in the laboratory as well as in the field. These tests concluded that the ultrasonic technology is the appropriate technology for the safety devices. The RF wave technology was found to have several limitations: (i) it cannot measure short distances, as required in this project, to any acceptable accuracy, (ii) the RF wave reflection is a function of the material of the reflected surface, it will therefore give inaccurate measurements from construction equipments that have a lot of rubber and glass material and could also be covered with mud, (iii) the RF device would be more expensive, larger and heavier than the ultrasonic device, and (iv) it has been documented in the literature that radar energy can cause blindness, sterility and other serious health problems.

Three prototypes using ultrasonic sensors were developed: (i) A Moving Hazard Warning (MHW) device with single ultrasonic sensor, (ii) A Moving Hazard Warning (MHW) device with three ultrasonic sensors, and (iii) An Edge Detector (ED) device with single ultrasonic sensor. These prototype devices were tested for: (i) the directionality of the device; (ii) the effect of the noise: acoustic, electrical, and high winds; (iii) signal attenuation through the worker's jacket or mud; (iv) calibration after being dropped or covered with mud; (v) possibility of system failures; (vi) battery life; (vii) effect of environment (rain and temperature extremes); and (viii) the physical dimensions and weight of the device. The prototypes performed satisfactorily on all of these test-items.

At this time any engineering controls for preventing the accidents of the type listed above do not exist. Assuming a 50% utilization of the developed products, the savings are estimated to be $490 million per year in the construction industry alone, besides saving 98 lives and 21,000 lost time injuries.

6. *Phase I* Project Report

Project Title: *Development of a SafetyBelt for Construction Workers.*
SBIR (NIOSH) Grant Number: 1 R 43 OH03497-01
Period: September 30, 1997 to October 31, 1998

The SBIR grant was awarded on September 29, 1997 for a 6-months period from 09/30/97 to 03/31/98. The funds, however, were not released because the project involved human subjects, therefore requiring prior approval by the Office for Protection from Research Risk (OPRR) of an assurance to comply with the requirements of 45 CFR 46 to protect human research subjects. An Institutional Review Board (IRB) was formed, and the application for Single Project Assurance (SPA) was made. The OPRR approved the Single Project Assurance as Assurance # S-14496-01, on December 9, 1997.. Two time extensions were, later, approved to 10/31/1998, and the Phase I project was completed on 10/31/1998.

Key Personnel

Three key persons worked on Phase I, as in Table 1.

TABLE 1: Key Personnel

Name	Title	Date of Service	Approx. No. of Hours
Satish Mohan	Principal Investigator	05/16/98-08/16/98	600 hours
Darold Wobschall	Consultant	04/01/98-08/31/98	60 hours
Computech Consultancy Services (Ashish Nath)	Contractor	09/07/98-10/31/98	320 hours

Specific Aims

The specific aim of the Phase I project was to build a prototype safety device for construction workers to eliminate the following two accident types:

(ii) Struck-against, and Caught in/under/between accidents, and
(ii) Falls through floor, wall and roof openings, and from open-sided floors.

Accomplishments of the Phase I Effort

The main tasks under *Phase I* were:

(a) Determining Safety Device Design Parameters
(b) Safety Device Assembly for Preliminary Testing
- Using Ultrasonic Sensor
- Using RF (Radar) Sensor

(c) Selection of the Most Appropriate Technology, and
(d) Technical Merit and Feasibility Report.

All of these tasks were completed successfully, as described below:

(a) Determining Safety Devices Design Parameters. The safety device design parameters included:

(i) Safe clear distance, which were determined to be 30 ft. for moving equipment, based on the equipment speeds of 4ft/sec to 6 ft/sec, and the perception-reaction time of average worker (5 sec.). For roof edges, the clear distance was determined to be 6 ft. These clear distances were used in the design of prototype devices.

(ii) Signal intensities and alarm type. Mini speakers, 0.2 watt power output, were used, they gave low sound in the construction environment. *Phase II* will further research on signal intensities. A field survey of workers, who tested the prototype devices, suggested using vibrator alarm for `struck-against' accidents, and sound alarm for `fall' accidents.

(b) Safety Device Assembly for Preliminary Testing. Two ultrasonic devices were assembled:

(i) *Moving Hazard Warning (MHW)* device, and
(ii) *Edge Detector (ED)* device

Both of these devices worked satisfactorily, as per design, in the lab as well as in the field. These devices are described in the next section.

One RF wave (radar) device was also assembled. The RF device worked satisfactorily in the laboratory against metal surface. In the field, it did not echo from equipment. A photo of the device, and its block diagram is given in Figure 1. The block diagram of the RF device is given in Figure 2, and the circuit diagram is shown in Figure 3.

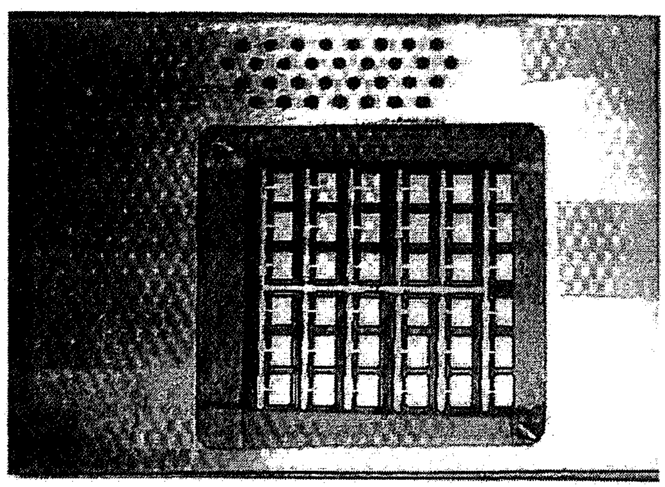


FIGURE 1: RF Device Front View Photograph

(c) Selection of the Most Appropriate Technology. Since the results of this task would decide the technology for phase II, a complete evaluation was done of the ultrasonic technology as well as the RF technology. The conclusions are given on page 2 of the GOA's letter in Figure 9 (page 16).

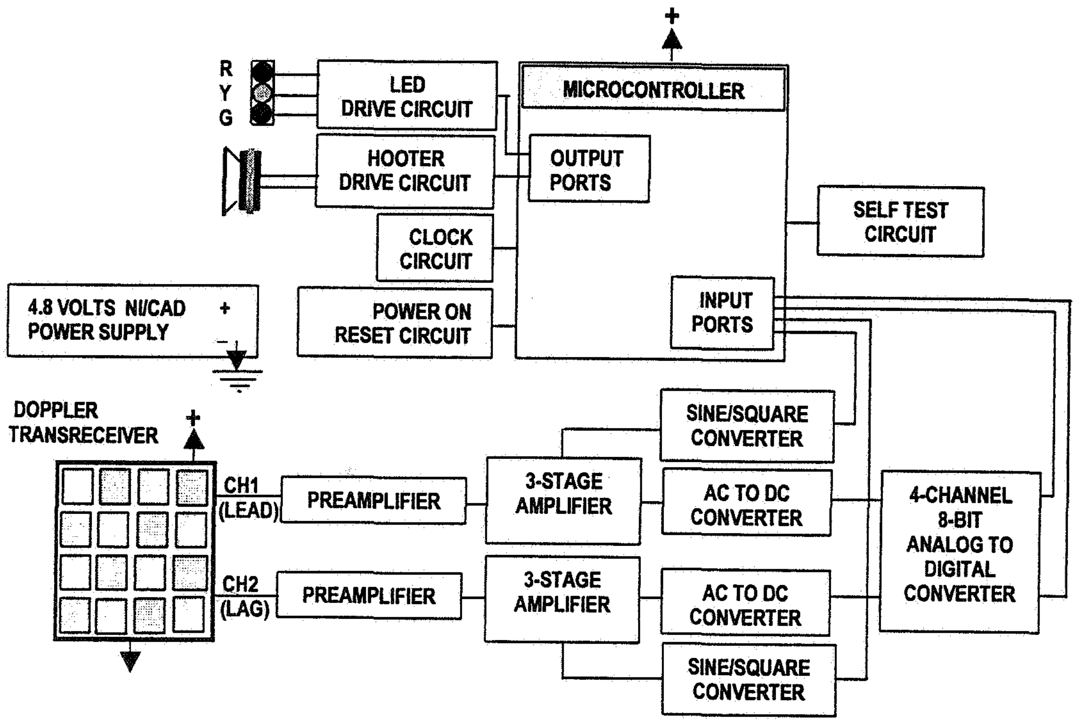


FIGURE 2: Block Diagram of Safety Device with Radio Frequency Sensor

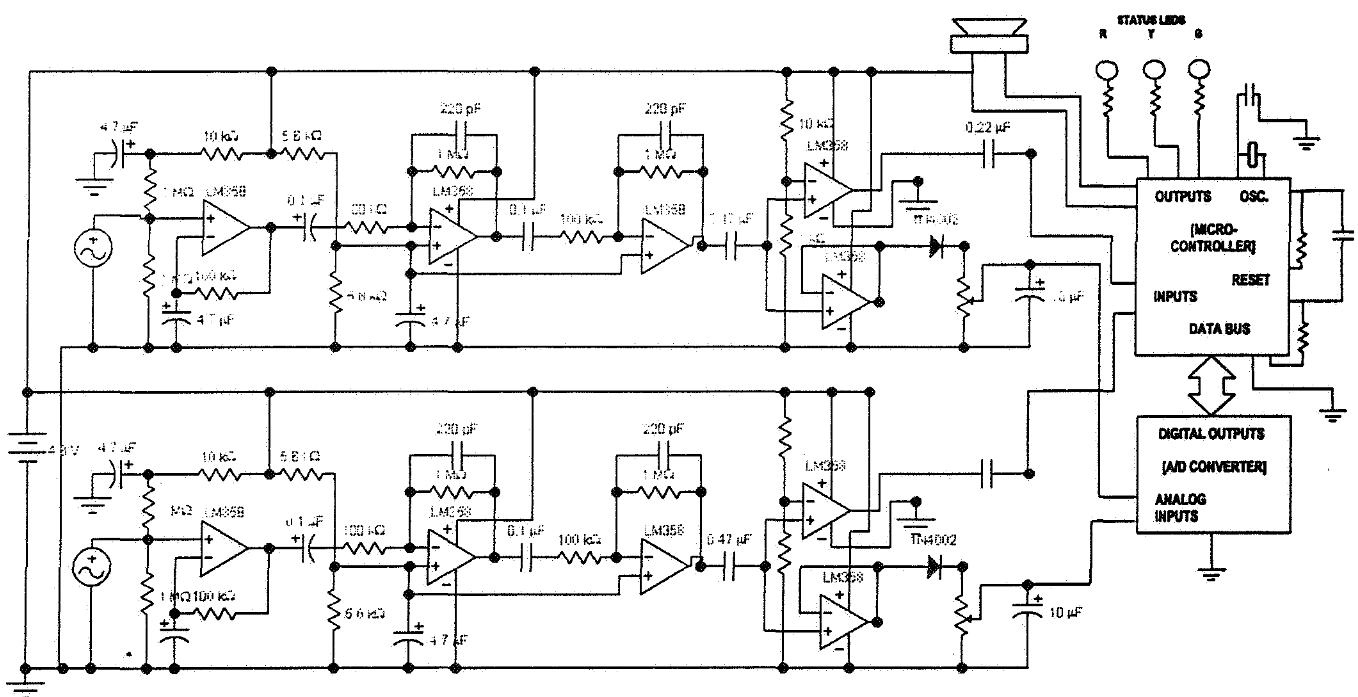


FIGURE 3: Circuit Diagram of the RF device

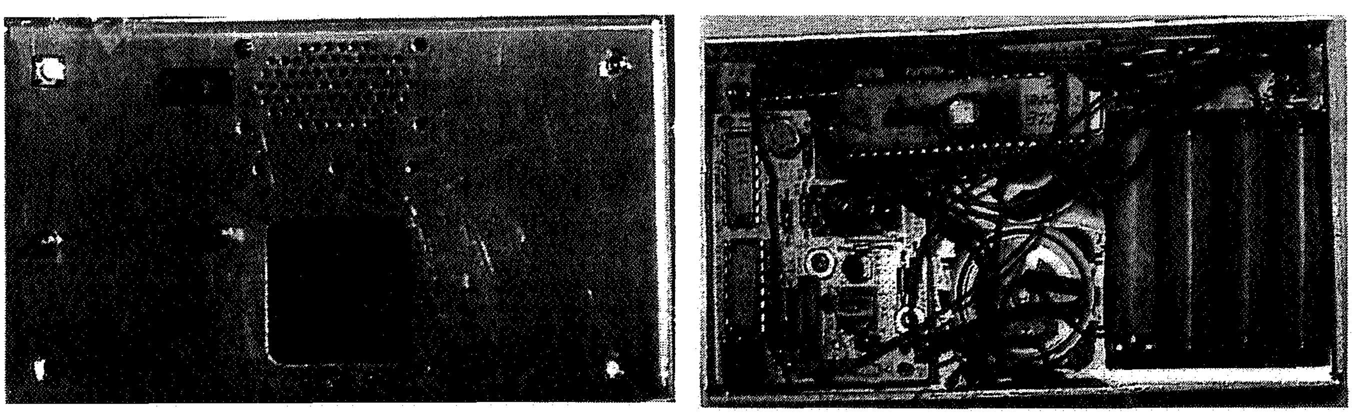
(d) Technical Merit and Feasibility Report. This project had a Grant Office Advisor (GOA): Dr. Gary L. Mowrey of the NIOSH Pittsburgh Research Laboratory (PRL), appointed vide Dr. Roy Fleming's letter of Feb. 02, 1998, to serve as an advisor to his office for reviewing and monitoring the project. Dr. Mowrey formed a 7-member advisory group from amongst the PRL scientists and engineers, who reviewed the products of this research on May 29, 1998 and on Nov. 20, 1998. During our May 29, 1998 presentation, nine items of concern were expressed and discussed and later communicated, in GOA's letter of June 8,1998 (Appendix-A, on page 21). We set to address those items, and resolved all of them as in the Table given in Appendix-B, on page 24. A presentation was then made to the GOA, on November 20, 1998. They expressed satisfaction, and all of us agreed that the ultrasonic technology can be successfully used to prevent targeted construction hazards. The GOA's letter of December 04, 1998, is attached in Appendix-C (page 26), and the first 2 pages of this letter that relate to Phase I are included in this section, as Figure 9 (page 15). A paragraph from page 2 of the GOA's letter, quoted below, states that - **the technical merit and feasibility of the proposed research has been established.**

"You have established to our satisfaction in your latest prototype ultrasonic devices, that most of these initial concerns have been resolved and that the Phase I portion of this project has been successfully completed. You have established the basic technical merit and feasibility of your ultrasonic research, and have shown that your prototypes can, at least in a controlled experimental field environment, be utilized for developing ultrasonic-based safety devices for construction workers."

Phase I Prototype Ultrasonic Safety Device Description

Two devices were assembled in this phase: (i) the Moving Hazard Warning (MHW) Device and (ii) The Edge Detector (ED) Device. Both of these safety devices comprise of the following five primary components. Phots of the single sensor MHW device, developed in phase I are shown in Fig. 4.

1. Ultrasonic Transducer
2. Transmitter-Receiver Circuit
3. Microcontroller
4. Power Supply, and
5. Audio-Visual Alarms.



(a) Exterior View (b) Interior View

Figure 4. Single Sensor Ultrasonic Safety Device Prototype

1. The Ultrasonic Sensor

The ultrasonic sensor functions both as a transmitter as well as a receiver. Phase I prototype used the sensor made by Polaroid Corporation. This sensor, when activated, emits a burst of 16 pulses at 49.4 kHz, in about 0.5 millisecond. It then waits to receive the echo from the object(s) reflecting the sound pulses. The dimensions of the transducer used in this project are: 1.33 in x 1.13 in x 0.64 in, as shown in Figure 5, below:

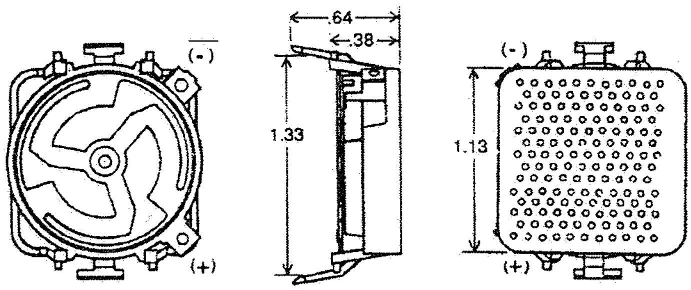


Figure 5. The Ultrasonic Transducer used in the Prototype MHW and ED Devices
[Source: Polaroid Corporation]

2. The Transmitter/Receiver Circuit

The transmitter-receiver circuit contains the electronics to control the transmitting and receiving of transducer. The `Range Card', shown in Figure 6 contains the transmitter-receiver circuit.

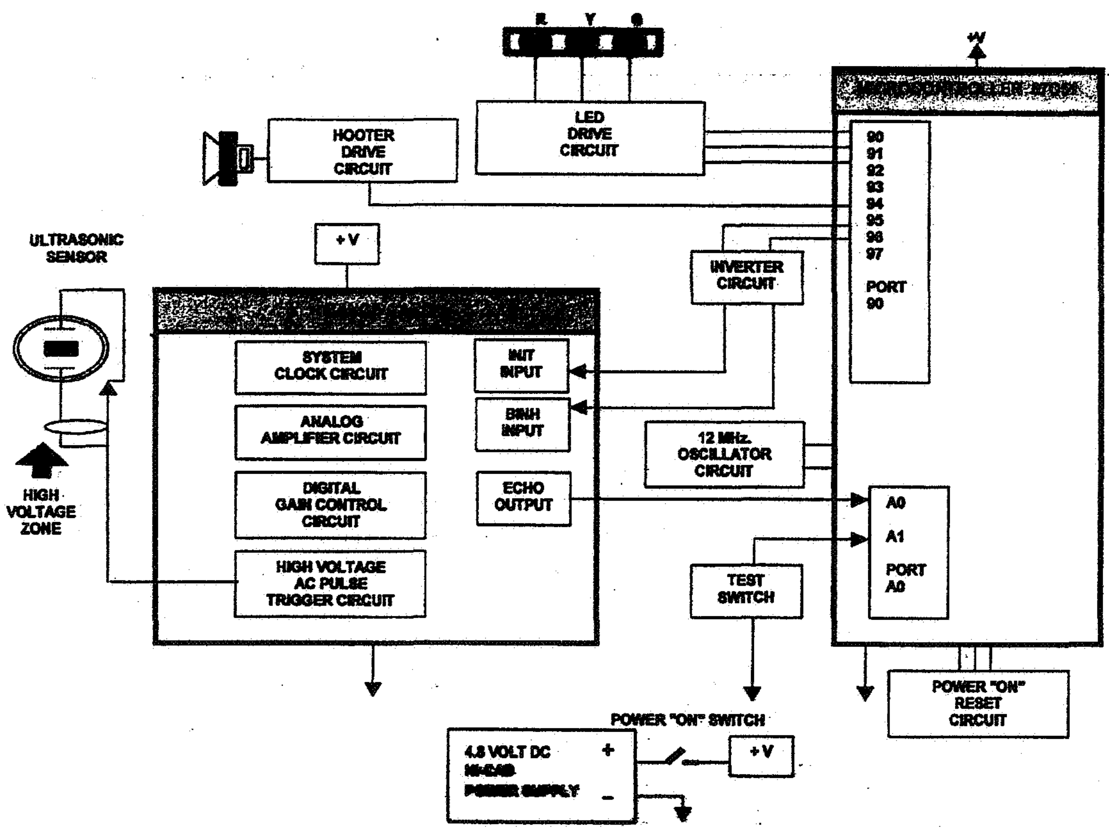


FIGURE 6: Block Diagram of Safety Device with Single Ultrasonic Sensor

Transmission starts with the Initiate (INIT) input from the microcontroller going high, when a burst of 16 pulses at 49.4 kHz are emitted in about 0.5 millisecond. At the end of the transmission, the transducer is put into idle mode for approximately 2.38 millisecond before it is switched over to receiver mode. This idle time, called blanking period, is used to eliminate the ringing sound of the electrostatic foil being detected as a return signal and prevents any detection of objects within 1.33 ft. (velocity of sound in air is approximately 1.11 ft/millisecond).

The system now waits for the return of the transmitted signal travelling at approximately 1.11 ft/ms, or 0.9 ms/ft. The reflected burst of sound pulses is received, amplified and converted to a high-logic-level ECHO input to the microcontroller. The time between the INIT input going high and ECHO output going high is proportional to the distance of the reflecting source from the transducer. This cycle is shown in Figure 7.

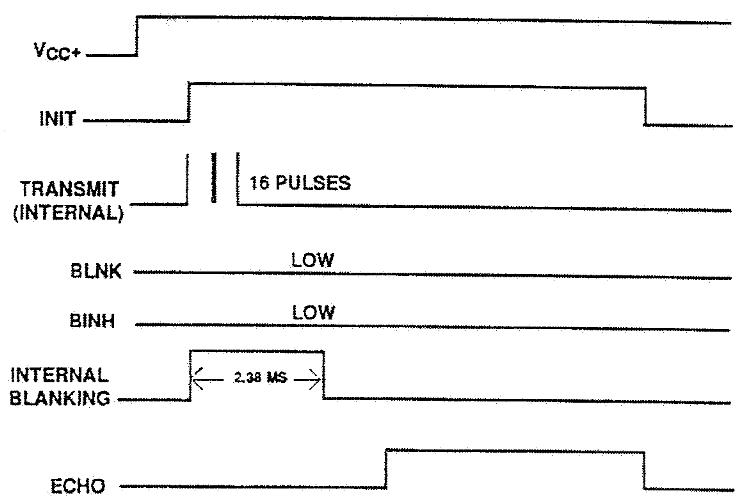


FIGURE 7: Transmit-Receive Cycle Waveforms of Ultrasonic Safety Device

3. The Microcontroller

The microcontroller computes the information obtained from the transmitter-receiver circuit and generates the alarm to warn against the approaching equipment within the danger zone. Figure 8 is the circuit diagram of the safety device using single ultrasonic sensor, where the interconnections between various components are shown. In this initial design phase, the danger zone is assumed to start at 30 feet from the worker. The basic computations done by the microcontroller include:

a. Generation of INIT and BLNK pulses at regular intervals,
b. Generation of variable frequency audio warning signal, and
c. Self-diagnostic tests for:
   - System malfunction, or Blocking of the transducer by mud, heavy clothing, or any other object(s).

4. The Power Supply

The power supply used in this has 4 x 1.2V Nickel Cadmium (Ni-Cad) AAA size batteries having a capacity of 650 mAh, and performed well. The maximum draw-down rate of the designed system required was 20 mA, and these batteries were able to provide the high surge current required to send ultrasonic bursts. The optimal size, weight, and the capacity of the power source will be determined in phase II of this project.

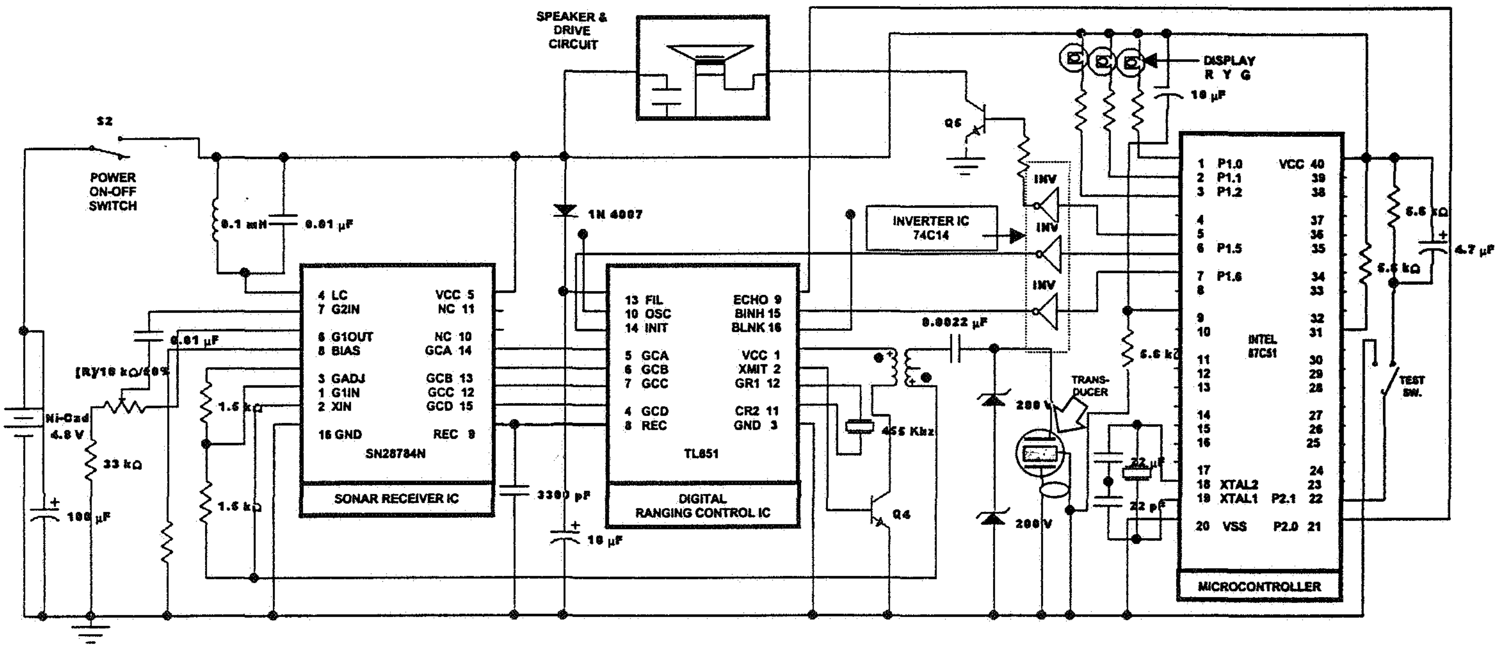


FIGURE 8: Circuit Diagram of the Safety Device with Single Ultrasonic Sensor

5. Audio-Visual Alarms

The warning system against approaching equipment is an audio alarm which generates a loud sound of varying frequency, increasing with the nearness of the approaching equipment. There is a different audio alarm in the form of a 'beep' sound which warns the user against malfunctioning of the unit. The visual indications in the form of red, yellow, and green LEDs are provided to check the status of the unit during testing mode.

Alarm - Trigger Logic Software

The alarm trigger is the most critical consideration in the design of the system. The guiding principle has been to minimize false alarms, while covering all possible scenarios that warrant the warning. The alarm trigger logic is programmed to follow the under noted criteria; all of the criteria must be met for triggering the alarm device.

Movement: Equipment approaching the safety device.
(No alarm when an object is traveling away from the worker, or passing by)

Speed: Equipment moving between 4 and 6 ft./sec. speed
(This is to simulate the range of speeds of construction vehicles).

Range: The approaching equipment to be within 1.3 feet to 30 feet,

Uniformity: Equipment approaching should have uniform velocity. Minimal changes in velocity that are representative of construction vehicles are considered. Abrupt changes in velocity are not considered for alarm triggering, and

Frequency: The receiver is tuned only to echo pulses at 49.4 kHz.

DEPARTMENT OF HEALTH & HUMAN SERVICES   Public Health Service

Centers for Disease Control
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National Institute for Occupational
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December 4, 1998

Dr. Satish Mohan
Technological Systems Research
126 Viscount Drive
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Ref: NIOSH Grant 1 R43 OH03497-01 - Project Status Meeting

Dear Dr. Mohan:

Thank you for coming to the Pittsburgh Research Laboratory (PRL) on Nov. 20, 1998, and providing us with the current status regarding your project "Development of a Safetybelt for Construction Workers". An attendance list is provided in Enclosure A.

On your visit to PRL on May 29, 1998, you discussed and demonstrated your first-generation ultrasonic-based device. The NIOSH attendees assessed this device and provided a list of items to be considered in future research and development. These items were documented in a letter to you dated June 8, 1998 -- [*see Enclosure B for a copy of this letter*] and are briefly summarized below:

(1) What is the <u>directionality</u> of the ultrasonic device?
(2) What is the effect of <u>noise</u> on the device (e.g., ultrasonic, electrical)?
(3) How to address <u>signal attenuation</u> through a coat, jacket, and other obstructions?
(4) How will the worker be <u>warned</u> of danger – vibration, sound, light, etc.?
(5) How will the device be <u>calibrated</u> (after being dropped or covered with mud)?
(6) How can the device be considered <u>fail-safe</u> (periodic self-diagnosis)?
(7) What is the expected <u>battery life</u> (recharging intervals, low-battery check)?
(8) How does the <u>environment</u> (wind, rain, temperature extremes, etc.) affect the device?
(9) Have <u>physical considerations</u> (weight, dimensions, shape) been addressed?

At the Nov. 20 meeting, you mentioned that you had considered each of these issues and subsequently developed second-generation prototypes of the ultrasonic devices, which you successfully demonstrated to the NIOSH attendees:

FIGURE 9: Grant Office Advisor's Letter (first 2 pages)

Page 2 - Mr. Satish Mohan

(1) <u>Equipment warning safety device</u> for warning workers of approaching construction equipment, and
(2) Edge detector safety device for warning workers of floor/wall openings and roof/deck edges.

You have established to our satisfaction in your latest prototype ultrasonic devices, that most of these initial concerns have been resolved and that the Phase I portion of this project has been successfully completed. You have established the basic technical merit and feasibility of your ultrasonic research, and have shown that your prototypes can, at least in a controlled experimental field environment, be utilized for developing ultrasonic-based safety devices for construction workers.

In addition you presented a comparision between utilizing RF wave (radar) and ultrasonic technology for your application. Based on your research results, you concluded the following:

(1) The ultrasonic technology has the capability to address all of the concerns that the NIOSH group pointed out after your visit to PRL on May 29, 1998, and therefore appears to be an appropriate technology for the safety devices for the construction worker.

(2) The RF wave (radar) technology has been found to have the following limitations:

- The RF wave cannot measure short distances to any acceptable accuracy – short distance detection is needed for the device to work properly.

- The RF wave reflection is a function of the material of the reflected surface (e.g, metal surfaces echo the best). Typical construction equipment have a lot of rubber and glass material and could also be covered with mud. As a result, radar-based devices will be grossly inaccurate when doing calibrations due to the great variances in possible materials encountered and equipment conditions.

- The radar device would be more expensive, larger, and heavier than the ultrasonic device.

- It has been documented in the literature that radar energy can cause blindness, sterility, and other serious health problems.

The NIOSH attendees also agree that the RF wave (radar) technology does not appear to be a feasible alternative to pursue in the near-term.

In our opinion your ultrasonic-based device has the best chance for success (particularly the "Equipment Warning" device) and therefore merits further investigation, e.g., that this research project should be continued in a Phase II program.

FIGURE 9 (continued)

Prototype Safety Devices Developed in Phase I

Four (4) prototype safety devices were developed in Phase I:

Moving Hazard Warning Device with single ultrasonic sensor, (ii) Moving Hazard Warning Device with three ultrasonic sensors, (iii) Edge Detector Device with single ultrasonic sensor, and (iv) RF (radar) Device. The three ultrasonic devices are shown, and described in Figures 10, 11 and 12 on the next page, and the RF device is shown in Figure 1.

Changes in the Specific Aims of Phase I

Phase I Specific Aims included development of one (1) device to eliminate the following two accidents:

(i) Struck-against and Caught-in/under/between construction equipment, and
(ii) Falls through floor/wall/roof openings, and from open-sided floors.

During the prototype design and development, it was recognized that the safe clear distance for `struck-against' accidents was 30 ft. against 10 ft. for `falls through openings', and 6 ft. for `open-sided floors'. Also, the coverage angle for each of the three accident types were different: 180° for `struck-against' and `falls through openings', and 90° or less for `falls from open-sided floors'.

Also, in the *phase I* proposal, the choice of technology: ultrasonic or RF wave (radar) was not made. The RF waves can penetrate through construction loads such as: plywood or dry wall panels. It was, therefore contemplated that if RF technology is used, the safety device, when attached to the front of the waist-belt will detect floor/wall openings, and when attached to the rear of the waist-belt will detect approaching equipment as well as the floor/roof edges.

During our presentations of the *Phase I* research to NIOSH Grants Office advisory group, we concluded that using ultrasonic technology was best-suited for the task in hand. This necessitated location of the safety device in the front of the hard-hat to avoid wide construction loads such as plywood obstructing the ultrasonic waves. The above developments required that we develop three different safety devices, two built into the rear of the waist-belt and one into the front of the hard-hat. The location of the safety device in the hard-hat was not considered practical because of the bending and horizontal rotation of the neck in many different ways. The NIOSH Grants Office Advisor, in their December 4, 1998 letter on page 3 (Appendix-C), has now advised us to focus efforts primarily on one specific application, namely 'warning workers of approaching construction equipment'. We, however, are confident that we can develop two safety devices during *Phase II*, to eliminate the following accident types, and we are proposing the two devices for completion in Phase II.

(i) A *Moving Hazard Warning (MHW)* Device to prevent struck-against, and caught-in/under/between construction equipment, and
(ii) An *Edge Detector (ED)* Device to prevent falls from roofs, and open-sided floors.

Each of the two devices will be built into the rear of the workers' waist-belt. The *Phase II* will now include two safety devices, against one proposed in *Phase I*. **This change in scope has made us to change the project title to reflect the products of the project, the Phase II title will be:**
'Electronic Safety Devices for Construction Workers'

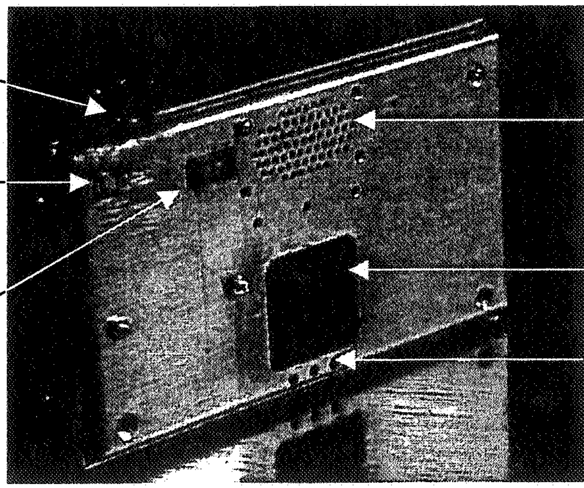

Figure 10: Photograph of MHW Device with Single Sensor

Figure 10 is the photograph of the Moving Hazard Warning (MHD) device with single sensor. This device is 5¼"x 3" x 3/4"in dimension and weighs 7½ oz. The single sensor unit has a beam width of 36° and it can detect objects up to 35ft. The electronic circuit operates at 4.8 VDC and consumes approximately 20mA current, except for short (0.5ms) period of time when it transmits ultrasonic pulses (at 49.3 kHz, five times in one second) at 2.5Amps/400VAC.

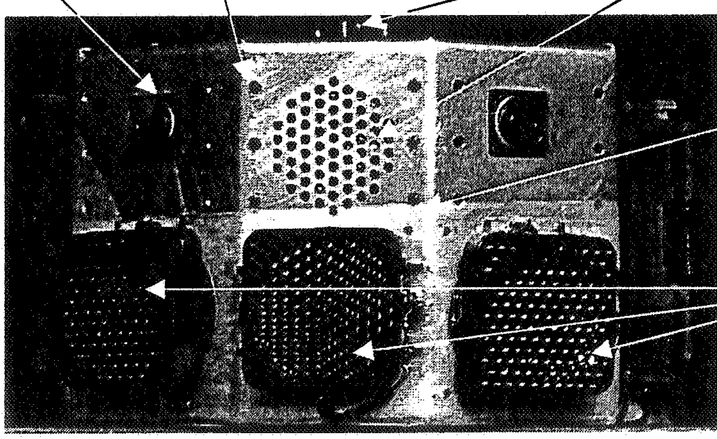

Figure 11: Photograph of MHW Device with Three Sensors

Figure 11 shows the Moving Hazard Warning (MHW) device with three sensors. The three sensors provide approx. 110° coverage angle. This device is 5" long, 2¾ inch high and has a depth of 2¼" in the middle length to 1½" at the two ends, the weight is 12 oz. The next phase MHW device will have a convex sensor to provide 180° beam width. The electronics and other features are similar to the single sensor MHW device. The final weight and size of the devices is estimated to be 1/2 to 1/3 of the present size and weight.

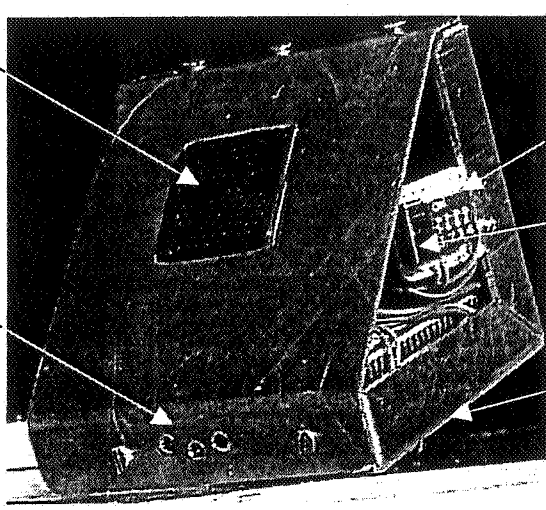

Figure 12: Photograph of ED Device

Figure 12 is the photograph of the Edge detector (ED) device, which incorporates one ultrasonic sensor. The sensor is installed at 45° to horizontal so that it faces the ground at an angle. The ED device weighs 8 oz and has a triangular cross section: 3" x 3" x 3½". The electronics is similar to that of the single sensor MHW. It has an additional program switch, by which the safe distance from the edge can be programmed.

7. References

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8. Appendices

A: NIOSH Grant Office Advisor's letter of 06/08/98

B: Response to Questions/Suggestions in NIOSH GOA letter of 06/08/98

C: NIOSH Grant Office Advisor's letter of 12/04/98

D: Worker Acceptability Survey Questionnaire

DEPARTMENT OF HEALTH & HUMAN SERVICES

Public Health Service

Centers for Disease Control
and Prevention (CDC)
National Institute for Occupational
Safety and Health
Pittsburgh Research Laboratory
P.O. Box 18070
Pittsburgh, PA 15236-0070

June 8, 1998

Dr. Satish Mohan, Ph.D.
Technological Systems Research
126 Viscount Drive
Williamsville, New York 14221

Dear Dr. Mohan:

Thank you for coming to the Pittsburgh Research Laboratory (PRL) on May 29, 1998 and discussing your NIOSH-sponsored project "Development of a Safetybelt for Construction Workers" with several of the NIOSH researchers here. It appears that your "smart" ultrasonic-based device has the potential for warning construction workers of approaching equipment.

For your records, the attendees present at this meeting and demonstration were:

John Breslin
Arthur J. Hudson
William D. Mayercheck
Gary L. Mowrey (GOA)
Michael J. Pazuchanics
William H. Schiffbauer
George H. Schnakenberg

A summary list of issues that should be addressed, based on the discussions at our meeting is provided below.

- **Directionality** of the sensor - define/determine as much as possible

- **Noise** - how is the sensor affected by
  - other ultrasonic noises (e.g., compressed air, steam, air leakage, air brakes, ...),
  - electrical noise (2-way radios, cell phones, power tools, power lines, ...),
  - lightning (both ultrasonic and electrical noise), wind, etc.

- **Signal attenuation** - Consideration of clothing masking the transmitted and/or received ultrasonic signal (e.g., jacket or coat over sensor)
  - Will the worker be careful to make sure that the sensor is not covered by any outer garments/coveralls/clothing
  - suggestion: maybe put it on the outside of a highly-visible vest like what the highway construction workers wear

- **Warning device(s)** - Consider what warning device(s) should be used, e.g., vibration, sound, light, etc.
  - Where should the warning devices be located on the worker so that s(he) will still be able to do their jobs

- **Calibration** - how will the unit be calibrated/tested?
  - will the worker be able to easily test it himself, particularly after the sensor is possibly damaged from an impact or caked with dust/mud/water
  - maybe have a manual self-test button

- **Fail-safe** - how to make the unit fail-safe without annoying the worker?
  - an automatic/periodic beep may bother the worker
  - how will the device inform the worker that it is not working properly? e.g., bad connection/cable, faulty/dirty sensor, replace battery

- **Battery life** - how often will the battery typically have to be replaced? How does the worker know when the battery needs replaced?

- **Environmental Factors** - How will the sensor cope with
  - Dust & mud
  - Water & rain
  - Temperature extremes (operating temperature range)

- **Physical considerations** -
  - How small can it be made (including batteries)? (weight and size?)
  - Consider minimizing/eliminating bothersome cables as much as practical, e.g., (wireless telemetry between ultrasonic device and warning device)
  - The final case design of the unit should be impact, dust, and water resistant
  - How rugged can it be made, particularly if it is tossed on a concrete surface?

This prototype device needs to be taken to several active construction sites to help ascertain the directionality sensitivity of the sensor and how it responds (or doesn't respond) to the typical background environmental noises (both electrical and ultrasonic) associated with each field site. At the field site, other issues not yet addressed may become apparent. Additionally, one-on-one discussions with the workers who would actually be wearing this device should also be done, which should provide much valuable insight into the pros & cons of this device.

From a human engineering perspective, the difficult issue of ascertaining that all human "spotters" of heavy construction equipment will be equipped each time with a fully-functional "safetybelt" needs to be addressed. It is likely, based on human nature, that the "spotters" will not necessarily take the time to protect themselves with this device.

Despite all the above concerns, you do have a potentially useful device that should prove valuable to at least certain sectors of the construction industry. How wide-spread this device might depend on how many of the above issues can be adequately addressed.

Thank you again for coming to PRL and we wish you continued success with your project. Please keep me informed of any significant findings/milestones/problems. I will pass this information on to the other researchers interested in your work.

Sincerely yours,

Dr. Gary L. Mowrey
Grants Office Advisor, 1 R43 OH03497-01
Mining Injury Prevention Branch
Pittsburgh Research Laboratory

Ultrasonic Device:
Response to Questions/Suggestions in NIOSH, PRL's June 8, 1998 Letter

Question/Suggestions	Answers/Comments
1. Directionality of the Sensor	
(i) Beam width ?	(i) Beam width = 36^0, final design will cover the whole rear view, i.e., 180^0.
(ii) Equipment approaching	(ii) Excellent protection: reflection up to 141^0 at 5 ft to 7^0 at angle to the device ? Adequate for safe approach
2. Noise Analysis	
(i) Ultrasonic (acoustic) noises,	(i) Acoustic (ultrasonic) noises have no effect,
(ii) Electrical noise & lightning,	(ii) Electrical noise has no effect,
(iii) Wind.	(iii) Wind @ 33-38 mph fluctuated the echo approx. 2-3 ms, corresponding to 1.1-1.7 ft. Can be taken care of in the software.
3. Signal Attenuation	
(i) Worker's jacket masking the sensor	(i) The device will sound an alarm 6 sec. (adjustable) after the sensor is blocked by a jacket, mud, or any other obstruction.
4. Warning Device	
(i) Type of warning device [Vibration, sound or light]	(i) A limited study indicated vibration to be more effective. The responsiveness will be thoroughly studied for vibration/sound signals in phase II.
(ii) Location of the device on the worker's body.	(ii) At this time, we are working on the following device locations: (a) Rear side of waist-belt for safety against approaching equipment: (b) Rear side of waist-belt for safety from roof/high elevation falls; (c) Front of hard-hat for fall into floor/wall openings.
5. Calibration	
(i) After impact or mud coating	(i) The device, now, has a self-check button.
6. Fail-safe	
(i) False alarms are annoying	(i) Possibility of false alarms is minimal, as only the friendly objects are detected but do not trigger alarm.

(ii) Device's failure to function	(ii) A separate circuit powered by a coin battery will constantly check against device failures, including low battery power, and trigger an alarm.

7. Battery Life

(i) Replacement intervals	(i) At this time, we are working on a one-week battery life. The safety device consumes approximately 20 mA, thus a battery with 1 Ah will provide 50 hrs worth of life. Ni-Cad, and Alkaline batteries of 1 Ah are available Some lithium batteries go up to 10 Ah.
(ii) Low battery checks	(ii) As in 6(ii) above.

8. Environmental Factors

Sensor's functionality while in:

(i) Mud	(i) Mud on the sensor will trigger an alarm as in 3(i) above. Dust effect could not be tested, presumably will be less than rain.
(ii) Water and rain	(ii) Rain gives a feeble, temporary echo lasting for short time, will never trigger an alarm
(iii) Temperature extremes	(iii) The transducer has an operating range of - 20^0 F to +160^0 F, covers all regions within USA.

9. **Physical Considerations**

(i) Size and weight	(i) The device after field testing, is estimated to be miniaturized to about 4"x2"x1/2" size, weighing about 6 oz.
(ii) Minimize bothersome cables	(ii) The finished device will be a single unit, all components connected internally.
(iii) Case should be impact, dust resistant	(iii) The device will be enclosed in a dust and water resistant box.
(iv) Rugged design	(iv) The box will be padded on the edges/corners, and profiled to hit the edges only, after a fall.

DEPARTMENT OF HEALTH & HUMAN SERVICES

Public Health Service

Centers for Disease Control
and Prevention (CDC)
National Institute for Occupational
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P.O. Box 18070
Pittsburgh, PA 15236-0070

December 4, 1998

Dr. Satish Mohan
Technological Systems Research
126 Viscount Drive
Williamsville, New York 14221

Ref: NIOSH Grant 1 R43 OH03497-01 - Project Status Meeting

Dear Dr. Mohan:

Thank you for coming to the Pittsburgh Research Laboratory (PRL) on Nov. 20, 1998, and providing us with the current status regarding your project "Development of a Safetybelt for Construction Workers". An attendance list is provided in Enclosure A.

On your visit to PRL on May 29, 1998, you discussed and demonstrated your first-generation ultrasonic-based device. The NIOSH attendees assessed this device and provided a list of items to be considered in future research and development. These items were documented in a letter to you dated June 8, 1998 -- [*see Enclosure B for a copy of this letter*] and are briefly summarized below:

(1) What is the **directionality** of the ultrasonic device?
(2) What is the effect of **noise** on the device (e.g., ultrasonic, electrical)?
(3) How to address **signal attenuation** through a coat, jacket, and other obstructions?
(4) How will the worker be **warned** of danger – vibration, sound, light, etc.?
(5) How will the device be **calibrated** (after being dropped or covered with mud)?
(6) How can the device be considered **fail-safe** (periodic self-diagnosis)?
(7) What is the expected **battery life** (recharging intervals, low-battery check)?
(8) How does the **environment** (wind, rain, temperature extremes, etc.) affect the device?
(9) Have **physical considerations** (weight, dimensions, shape) been addressed?

At the Nov. 20 meeting, you mentioned that you had considered each of these issues and subsequently developed second-generation prototypes of the ultrasonic devices, which you successfully demonstrated to the NIOSH attendees:

(1) **Equipment warning safety device** for warning workers of approaching construction equipment, and
(2) Edge detector safety device for warning workers of floor/wall openings and roof/deck edges.

You have established to our satisfaction in your latest prototype ultrasonic devices, that most of these initial concerns have been resolved and that the Phase I portion of this project has been successfully completed. You have established the basic technical merit and feasibility of your ultrasonic research, and have shown that your prototypes can, at least in a controlled experimental field environment, be utilized for developing ultrasonic-based safety devices for construction workers.

In addition you presented a comparision between utilizing RF wave (radar) and ultrasonic technology for your application. Based on your research results, you concluded the following:

(1) The ultrasonic technology has the capability to address all of the concerns that the NIOSH group pointed out after your visit to PRL on May 29, 1998, and therefore appears to be an appropriate technology for the safety devices for the construction worker.

(2) The RF wave (radar) technology has been found to have the following limitations:

- The RF wave cannot measure short distances to any acceptable accuracy – short distance detection is needed for the device to work properly.
- The RF wave reflection is a function of the material of the reflected surface (e.g, metal surfaces echo the best). Typical construction equipment have a lot of rubber and glass material and could also be covered with mud. As a result, radar-based devices will be grossly inaccurate when doing calibrations due to the great variances in possible materials encountered and equipment conditions.
- The radar device would be more expensive, larger, and heavier than the ultrasonic device.
- It has been documented in the literature that radar energy can cause blindness, sterility, and other serious health problems.

The NIOSH attendees also agree that the RF wave (radar) technology does not appear to be a feasible alternative to pursue in the near-term.

In our opinion your ultrasonic-based device has the best chance for success (particularly the "Equipment Warning" device) and therefore merits further investigation, e.g., that this research project should be continued in a Phase II program.

Based on your findings, another series of suggestions and issues have been raised by the attendees and are recommended to be addressed in a Phase II portion of the project.

1. **Use ultrasonic technology** [as noted above] since it appears to have the greatest likelihood of near-term success (as compared to radar or other available technologies). RF wave (radar) technology may be potentially useful in the future, but it would require considerable additional research effort (both time and money).
2. **Focus efforts primarily on one specific application**, namely, warning worker of approaching construction equipment.
3. The device should be **ergonomically evaluated** for its intended use in the construction industry, e.g., how it will interface between the human worker and the surrounding environment. For the device to be effective in most construction site environments, and to be acceptable to most construction workers, ergonomic evaluations including the following should be performed:
   - Location of the device on the worker's body: waist-belt, hard hat, or other place.
   - Shape/profile of the device to match the contour of the worker's body part and/or the waist-belt, hard hat, etc.
   - Attachment of the device in the worker's belt or hard hat such that the body motions do not effect the hazard detection by the device. [careful here in that if the worker turns around and faces the approaching vehicle, he sees it and thus the alarm need not continue to detect it.]
   - Determine appropriate warning [annunciating] device(s) for the worker.
   - Audible alarm (if that is chosen) must be sufficiently loud (>90 dB) to warn worker of approaching hazard.
   - The physical size of the device should be as small and light-weight as practical.
4. **Discussions with workers**: General discussions with construction workers (the ones who would be wearing this device) should be done and their inputs considered in additional refinement of the device while it is still in a prototype stage.
5. **Keep cost low** as possible (ideally, >$50.00/unit). Companies and/or individuals will not buy it if the cost is unreasonable.
6. **Battery life** must be sufficient for at least 12 continuous hours (one shift) or 60 hours (one week) of operation in **cold** weather.
7. **Construction site testing**: The device needs to be taken to several active construction sites to better ascertain the directionality sensitivity of the sensor in regards to various types of construction equipment approaching at various angles and velocities.
8. **Susceptibility to false alarms** from on-site construction noises (both electrical and ultrasonic) needs to be determined. For example, if the operator gets a false alarm from behind him, he may take his eyes off the operation that would otherwise require his full attention for optimum safety. How the device responds (or doesn't respond) to typical background environmental noises (both electrical and ultrasonic) associated with each construction site.

9. **Ruggedness testing**: The sensor, circuits, and other components (e.g., speaker, vibrator, switches, etc.) should be drop tested to ensure that the device is sufficiently ruggedized for use at construction sites. Also consider using high-grade and/or MIL-spec components, particularly for critical components in the device. Whatever components are used, the final prototype device should be subjected to full temperature, humidity, and vibration testing according to ANSI or MIL-spec standards since it is safety equipment.
10. **Device degradation consideration**: Some researchers have noticed with continued use that the ultrasonic pulses eventually crystallize the solder joints of the sensor and could thereby make the device fail or become intermittant.

Thank you again for visiting PRL and also for bringing Dr. Darold Wobschall (Sensor Plus) and Mr. Ashish Nath (Electrical Engineer) with you. I wish you continued success in developing your ultrasonic devices. Please continue to keep me informed of any significant developments and/or problems and I will forward this information to other PRL personnel interested in your work.

Sincerely yours,

Dr. Gary L. Mowrey
Electrical Engineer
Grants Office Advisor - 1/R43 OH03497-01
Mining Injury Prevention Branch
Pittsburgh Research Laboratory

2 Enclosures

Enclosure A: List of Attendees
Project Status Meeting
"Development of a Safetybelt for Construction Workers"
Nov. 20, 1998, NIOSH-PRL, Pittsburgh, PA

The Grantee attendees present at this meeting were:

Satish Mohan, Principal Investigator (Technological Systems Research,Williamsville, NY)

Darold Wobschall, Consultant (Sensor Plus, Amherst, NY)

Ashish Nath, Contractor (Computech Consultancy Services, Toronto, Canada)

The NIOSH-PRL attendees present at this meeting were:

John Breslin

Arthur J. Hudson

William D. Mayercheck

Gary L. Mowrey (Grants Office Advisor)

Michael J. Pazuchanics

William H. Schiffbauer

George H. Schnakenberg

Development of A SafetyBelt for Construction Workers
Worker Acceptability Study

1. (a) Have you ever been struck-by or caught-in construction equipment ? **Yes** ____ **No** ____
   (b) Have you ever seen any one struck-by or caught-in construction equipment ? **Yes** ____ **No** ____

2. (a) Have you ever fallen from a deck or roof ? **Yes** ____ **No** ____
   (b) Have you ever seen any one fall from a deck or roof ? **Yes** ____ **No** ____

3. (a) Have you ever fallen into a wall or floor opening ? **Yes** ____ **No** ____
   (b) Have you ever seen any one fall into a wall or floor opening ? **Yes** ____ **No** ____

4. ***A safety device (as shown here) for warning against equipment approaching from behind is being developed. This device, the size of a beeper, will be hooked to the waist-belt and alarm when any equipment approaches from behind.***

   (a) Do you see any problem in this device being used by workers ? **Yes** ____ **No** ____
   If 'Yes' please Explain ....
   ....
   (b) Would you use this device for your safety ? **Yes** ____ **No** ____
   If 'Yes' please Explain ....
   ....
   (c) In what ways do you think the device can fail ? ....
   ....
   (d) What alarm mode will be most effective ? **Sound** ____ **Vibration** ____ **Both** ____

5. ***A safety device for warning against approaching an opening or a roof/deck edge is being developed. This device will detect the edge of an opening from 10 ft. and alarm the worker.***

   (a) Do you see any problem in this device being used by workers ? **Yes** ____ **No** ____
   If 'Yes' please Explain ....
   ....
   (b) Would you use this device for your safety ? **Yes** ____ **No** ____
   If 'Yes' please Explain ....
   ....
   (c) In what ways do you think the device can fail ? ....
   ....
   (d) What alarm mode will be most effective ? **Sound** ____ **Vibration** ____ **Both** ____

6. **Any other comments on the devices** ....
   ....
   ....

Interviewee Name ....
Profession ....
Years on the job ....

9. List of Possible Future Publications

The following publications are planned in the future, after the patents for the electronic devices are registered. Patent process will begin soon after the Phase II project is approved.

1. *Development of a SafetyBelt for Construction Workers.*

2. *Effectiveness of Engineering Controls in Protecting Workers on Construction Worksites.*

3. *An Electronic Device for Safety Against Falls from Roofs and Open Floors*

4. *An Electronic Device for Safety Against Struck-by, Struck-against and Caught in/under/between Equipment.*

Memorandum

Date: March 26, 2001

From: Roy M. Fleming, Sc.D., Director, Research Grants Program RMF
Office of Extramural Programs, NIOSH, D30

Subject: Final Report Submitted for Entry into NTIS for Grant 1 R43 OH003497-01.

To: William D. Bennett
Data Systems Team, Information Resources Branch, EID, NIOSH, P03/C18

The attached final report has been received from the principal investigator on the subject NIOSH grant. If this document is forwarded to the National Technical Information Service, please let us know when a document number is known so that we can inform anyone who inquires about this final report.

Any publications that are included with this report are highlighted on the list below.

Attachment
cc: Sherri Diana, EID, P03/C13

List of Publications - None

Title: Electronic Safety Devices for Construction Workers
Investigator: Satish B. Mohan, Ph.D.
Affiliation: Technological Systems Research, Design & Education
City & State: Williamsville, NY
Telephone: (716) 689-4025
Award Number: 1 R43 OH003497-01
Start & End Date: 9/30/1997–10/31/1998
Total Project Cost: $99,700
Program Area: Control Technology
Key Words:

Abstract:
This project has established the technical merit and feasibility of using ultrasonic technology in developing electronic safety devices, to protect construction workers from two of the major construction worksite accidents: (i) "struck-by", "struck-against", end "caught in/under/between" equipment, and (ii) falls from roofs, and open-sided floors/platforms. These accidents account for 18.9% of the construction accidents and cost the nation $981 million annually. The devices will be built into the rear-side of the worker's tool-belt or waist-belt and warn the worker via sound and/or vibration alarm whenever he/she is closer than a safe distance from the approaching equipment or the edge of the roof/open-sided floors.

To determine the safety devices design parameters, the safe clear distances were determined in the early phase of this project. For safety against moving equipment, safe clear distance was estimated lo be 30 feet: and for safety against falls from roof edges and from floors/platforms, the clear distance was estimated to be 6 feet. These safe clear distances were used in the design and testing of the prototypes.

Preliminary studies done prior to this project had examined the potential of all of the available technologies: ultrasonic, RF wave, laser, and infrared; and determined that only ultrasonic, and RF wave (radar) technologies can be used for the proposed safety devices. Prototype devices using each of the two technologies: ultrasonic, and RF wave, were then designed and assembled in this project, and were tested in the laboratory as well as in the field. These tests concluded that the ultrasonic technology is the appropriate technology for the safety devices. The RF wave technology was found to have several limitations: (i) it cannot measure short distances, as required in this project, to any acceptable accuracy, (ii) the RF wave reflection is a function of the material of the reflected surface, it will therefore give inaccurate measurements from construction equipments that have a lot of rubber and glass material and could also be covered with mud. (iii) the RF device would be more expensive, larger and heavier than the ultrasonic device. and (iv) it has been documented in the literature that radar energy can cause blindness, sterility and other serious health problems.

Three prototypes using ultrasonic sensors were developed: (i) A Moving Hazard Warning (MHW) device with single ultrasonic sensor, (ii) A Moving Hazard Warning (MHW) device with three ultrasonic sensors, and (iii) An Edge Detector (ED) device with single

ultrasonic sensor. These prototype devices were tested for: (i) the directionality of the device; (ii) the effect of the noise: acoustic, electrical, and high winds; (iii) signal attenuation through the worker's jacket or mud; (iv) calibration after being dropped or covered with mud; (v) possibility of system failures; (vi) battery life; (vii) effect of environment (rain and temperature extremes); and (viii) the physical dimensions and weight of the device. The prototypes performed satisfactorily on all of these test-items.

At this time any engineering controls for preventing the accidents of the type listed above do not exist. Assuming a 50% utilization of the developed products, the savings are estimated to be $490 million per year in the construction industry alone, besides saving 98 lives and 21,000 lost time injuries.

Publications

No publications to date.