ECEN 403

Electrical Design Laboratory - Summer 2024

Senior Design Proposal
Hemaya: Non-invasive multi-sensor wearable wristband for fatigue prevention

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"On my honor, as an Aggie, I have neither given nor received unauthorized aid on this academic work."

Abstract

This project aims to raise the standards of health and wellness for Qatar construction workers who conduct physical hard work. We want to provide continuous tracking and warning by developing a wearable wristband with a multi-sensor system for fatigue recognition to minimize accidents and injuries on construction sites. Three distinct types of sensors will be used by the wristband to assess heart rate, tremors, and oxygen saturation levels. Since hosting the FIFA 2022 World Cup, the number of construction workers needed to complete various infrastructure and building projects nationwide has increased noticeably. Qatar continues to renovate and build the infrastructure required for the 2030 National Visions. It is highly significant because it can serve as a preventive measure to reduce the risk of severe health conditions and ensure safer working environments for employees. For construction workers, fatigue is a considerable risk because it can seriously affect both their physical and mental performance, increasing the likelihood of accidents and injuries at work. Because it impairs focus and affects reaction times, workers are more exposed to errors and dangerous circumstances at that time.

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1. Introduction

With advancements in engineering and architecture, a global rise in the construction of skyscrapers, towering structures, and bridges has been observed, resulting in a higher demand for construction workers. The fast rate of progress has required construction workers to operate at high speeds, negatively impacting their physical and mental well-being. Consistent attention to this issue is crucial to prevent serious harm, including fatalities, among construction workers. Scientific and technical principles in engineering are crucial not just for design and creation but also for ensuring the greatest possible protection of individuals. The aim of this project is to develop a non-invasive multi-sensor wearable wristband to detect fatigue in construction workers, with sensors primarily detecting oxygen saturation, heart rate, and tremor.

1.1 Motivation

Construction workers frequently encounter strenuous physical tasks, extended work shifts, and challenging weather conditions. These factors can result in considerable fatigue, which plays a significant role in workplace accidents and injuries. The presence of fatigue among construction workers not only jeopardizes the well-being of the individuals affected but also poses potential hazards to their colleagues and the overall safety of the construction site. Despite the progress made in safety protocols and equipment, fatigue continues to be a recurring problem that affects the well-being and efficiency of construction workers. The continuing problem highlights the pressing demand for creative solutions that can efficiently monitor and address worker fatigue, ultimately improving safety and minimizing the likelihood of accidents [1].

A recent study highlights the significance of closely monitoring physiological indicators to proactively address health problems associated with fatigue. An academic paper titled "Heat Stress Impacts on Cardiac Mortality in Nepali Migrant Workers in Qatar" sheds light on the significant health dangers linked to extended periods of intense heat and physically demanding work. The study revealed a concerning correlation between heat stress and an increased risk of cardiac-related mortality among workers, highlighting the urgent importance of ongoing health monitoring [2].

The motivation behind this project is to address this critical issue by developing a wearable wristband that employs a multi-sensor approach to detect fatigue in real time. The wristband aims to provide accurate and timely assessments of a worker's condition by integrating sensors to monitor oxygen saturation levels, heart rate, and hand tremor. This innovative solution will facilitate proactive fatigue management, enabling immediate action when needed. The main objective is to enhance safety, minimize the chances of accidents, and enhance the overall well-being of construction workers. This project aims to promote a safer and more efficient working environment in the construction industry by emphasizing the importance of worker alertness and capability. It seeks to foster a culture of health and safety among workers.

Our wearable wristband aims to address the challenges faced by construction workers by focusing on key physiological metrics like oxygen saturation, heart rate, and tremor. The research presented here highlights the importance and potential benefits of our proposed solution in improving worker safety and reducing the occurrence of fatal incidents related to fatigue.

1.2 Literature Review

Significant advancements have been made in the field of wearable technology for health monitoring over the past decade. Several research papers have investigated the capabilities of different sensors in identifying and addressing fatigue, especially in challenging work settings like construction. This literature review will explore important discoveries from recent research and emphasize the strengths and weaknesses of current methodologies.

Wearable Technology and Fatigue Detection

The research study titled "Fatigue Monitoring Through Wearables: A State-of-the-Art Review" highlights the criticality of fatigue assessment within the field of occupational health and safety. Cognitive and motor performance are affected by fatigue, which increases the risk of injury and decreases productivity. Wearable systems present encouraging prospects for fatigue monitoring on account of their capacity to track biomedical signals in an unattended environment continuously and comfortably for extended durations. This capability is essential for the development of precise models for real-time fatigue monitoring.

A comprehensive analysis of scholarly literature starting from 2015, utilizing reputable databases such as Scopus and PubMed, uncovered sixty pertinent studies. Sensor data from motion (MOT), electroencephalogram (EEG), heart rate (HR), skin temperature (Tsk), and respiratory rate (RES) comprised the majority of the information utilized in these investigations. For fatigue detection, supervised machine learning models, particularly binary classification models, were frequently implemented. Although the models exhibited commendable performance, the evaluation brought attention to concerns regarding the quality of the data and the restricted practicality of the results. To improve the potential of sensors for fatigue quantification and to gain a deeper understanding of the relationship between physiological changes and fatigue [3].

Multi-Sensor Approaches

An effective approach to detecting driver fatigue is developed in the research titled "A Driver Fatigue Detection Method Based on Multi-Sensor Signals." The study utilizes signals collected from a Kinect 2.0 camera and a PPG pulse sensor. The multi-sensor method discussed in this study focuses on the transitional process of fatigue and its effects on training classifiers, a factor that is often neglected in conventional approaches. Data was collected from 15 groups through simulation experiments and underwent three main steps: feature extraction and fusion, sample labeling, and the creation of an SVM classifier. The method achieved an impressive 10-fold cross-validation accuracy of 90.10% and a test accuracy of 83.82%, showcasing its superior performance when compared to traditional single-sensor methods. The study emphasizes the effectiveness of multi-sensor systems in detecting fatigue by combining visual and physiological data, resulting in improved accuracy and reliability. This approach has proven to be highly beneficial in improving the safety and efficiency of fatigue detection systems in real-life situations [4].

1.3 Disadvantage of Literature’s Solutions

Despite the valuable insights provided by the existing literature on fatigue detection methodologies, this initiative seeks to address several significant drawbacks and gaps.

The research paper titled "Fatigue Monitoring Through Wearables: A State-of-the-Art Review" highlights various shortcomings in existing solutions. Although wearable systems indicate a

promise for continuous, non-intrusive fatigue monitoring, many studies have been conducted in controlled environments and have been of short duration, which limits their practicality in real-world situations. Furthermore, the data utilized in the development of fatigue detection models is frequently insufficient, which impacts their reliability. Despite the impressive performance of numerous models, especially those utilizing machine learning techniques, they encounter difficulties when faced with the unpredictable nature of real-world scenarios. Further investigation is necessary to enhance the precision and viability of wearable fatigue detection systems in everyday environments [3].

Similarly, the research paper titled "A Driver Fatigue Detection Method Based on Multi-Sensor Signals" brings attention to various limitations despite its promising approach. Firstly, many studies, including this one, are conducted in controlled environments, which may not accurately reflect real-world conditions, limiting their applicability. Furthermore, the use of certain sensors, such as the Kinect 2.0 camera and PPG pulse sensor, may pose challenges as their performance can be influenced by factors like lighting and sensor placement. In addition, the binary classification models employed may not fully capture the subtle development of fatigue. Although multi-sensor systems enhance accuracy, they also introduce challenges in terms of data fusion and real-time processing. Finally, it is crucial to address the issue of potential false positives or negatives, as this can have serious safety implications. To ensure the reliability of the technology in real-world scenarios, thorough field testing and validation are necessary [4].

Our project aims to address the drawbacks and create a wearable wristband that is non-invasive, comfortable, and accurate, adjusting specifically to the needs of construction workers.

1.4 Description of the proposed project

In this project, our group will develop a safety wristband that detects and tracks fatigue levels in construction workers. The wristband will measure oxygen saturation levels, heart rate, and tremors using two sensors. Typically, this is implemented by creating a connection to an Arduino microprocessor's input terminals. The collected data can be observed immediately on the app that will be built and connected by a wireless link to the Arduino. The Arduino board is equipped with a machine-learning algorithm that will be used to determine the construction worker's health

status. This project aims to create a healthier environment for construction workers by providing timely assistance when needed and continuously monitoring their fatigue levels. Doing so will help prevent dangerous situations and unwanted dangers, ultimately leading to a safer workplace because it may shield construction workers from working in hazardously unhealthy situations. Their quality of life will be improved, and a safer workplace will be provided.

1.5 Description of the Prototype

The final prototype is a non-invasive wearable wristband designed for construction workers to detect fatigue using a multi-sensor approach. This innovative wristband integrates several sensors to provide comprehensive monitoring of the wearer's physiological state. Specifically, the sensors will track three critical indicators of fatigue: oxygen saturation, heart rate, and tremor. By continuously measuring these parameters, the wristband can accurately assess fatigue levels in real time, providing valuable insights and alerts to help prevent accidents and improve overall safety and well-being for construction workers.

1.6 Proposal’s Outline

The remaining parts of the proposal will cover and discuss the problem statement and the project's objective, and the methodology section will provide the phases of project execution, task division, the method the offered solution will be implemented, and the way the solution will be put together in the specified stages. Next up is the estimated budget required for its completion and justification, including the tools that will be utilized and their prices. In conclusion, assign a comprehensive timeline to ensure that all work is finished on time, and conclude our project proposal with a brief summary.

2. Problem Statement

The project aims to improve the health and welfare needs of Qatari construction workers by developing a wearable wristband with multiple sensors for fatigue monitoring. These efforts are necessary for the ongoing efforts in National Vision 2030 and the increasing demand for construction workers following the FIFA 2022 World Cup, construction workers are likely to be

overworked, which will affect their mental and physical health in a dangerous manner and will increase the risk of accidents and injuries.

However, several challenges need to be addressed to ensure the project's success:

i. Severe Climate: The high temperatures in Qatar limit the accuracy and efficiency of wearable sensors and increase operator fatigue.

ii. Network issues: Although continuous monitoring and data transfer is essential, timely alarms and real-time data analysis can prevent potential network issues. Examine your current alarm data to create a baseline and pinpoint your areas of concern.

iii. Delayed Institutional Review Board (IRB) approval: If the IRB takes longer to approve testing the model on real participants, the project may take longer to complete.

iv. Battery Life: The battery in the belt should be long enough to maintain operation in construction environments that do not require frequent recharging.

v. Wristband: The design of the wristband should be small, comfortable and stable for the users.

Addressing these challenges is essential to develop a reliable and effective fatigue recognition system that can significantly reduce the risk of severe health conditions and ensure safer working environments for construction workers in Qatar.

3. Objectives

- **Create a wearable wristband**: Create a multi-sensor wristband to track construction worker fatigue levels.
- **Enhance Worker Safety**: Reducing accidents and injuries on construction sites by installing ongoing tracking and warning systems to improve worker safety.

- **Deal with harsh weather conditions**: Make sure the wristband can withstand the extreme heat in Qatar and manage fatigue perfectly.
- **Ensure Reliable Connectivity**: To ensure reliable connectivity, provide a robust system that can maintain consistent data and instant analytics even with any connectivity issues.
- **Obtain IRB approval**: Obtain approval from the IRB to test the model in real-time.
- **Optimize Battery Life**: To maximize battery life, make sure the wristband has a long-lasting battery that can withstand many shifts of duty.
- **The Dimension**: design of the wristband should be small, comfortable and stable for the users.

4. Methodology

To increase the health and wellness needs of construction workers, wearable wristbands with a multi-sensor system for fatigue detection will be developed. This requires a complementary approach to real-time data implementation, advanced hardware and software development and testing. This describes the steps necessary to successfully complete the objective [5].

4.1 Hardware Development:

4.1.1. Sensor Input Data:

Measuring tremor, oxygen saturation, and heart rate using the triaxial accelerometer ADXL335 and heart-rate monitor and pulse oximeter biosensor MAX30102 by Analog Devices. These sensors provide accurate readings for these parameters, allowing for effective monitoring of physiological conditions.

4.1.2 Arduino Uno Rev4 microcontroller:

We will use a microcontroller board Arduino Uno Rev4 WiFi because it is affordable, easy to use, compatible with sensors, allows easy and effective access to a wearable wristband system EEMB Lithium Polymer Battery 5 V 2000mAh 103454 for powering the device, guaranteeing

continuity [6]. As they move to job sites, construction workers can keep an eye on their health and well-being with the help of this robust and reliable system [7].

4.2 Software Development:

4.2.1 Programming with Arduino IDE:

Use the Arduino Uno Rev 4 WiFi IDE to generate firmware to optimize sensors, analyze data, and monitor power consumption in the wearable wristband system. The Arduino IDE provides a flexible programming environment for the Arduino microcontroller, enabling integrated component capabilities to communicate with sensors, processing collected data, and assuring high performance over long periods of construction workers of the job change [8].

4.2.2 Data Processing and Analysis:

Calibrate and integrate sensors in the wearable wristband system to ensure accurate data collection. Calibration techniques will be used to achieve the best accuracy and reliability in sensor readings. Additionally, the device will collect raw data collected by sensors before being uploaded to the cloud for further local analysis. This approach makes it possible to store and upload real-time data to the cloud for comprehensive health and wellness assessment of construction workers.

4.2.3 Arduino IoT Cloud:

Real-time data transfer and remote monitoring will be possible from the framework for IoT integration, allowing the wearable wristband and the cloud system to communicate seamlessly with each other. This integration will enable continuous monitoring of construction workers' health and welfare statistics and prompt intervention should fatigue-related problems arise. In addition, dashboard architecture will be used to enable data visualization [9] so that sensor data can be viewed. By helping to identify fatigue processes, these dashboards provide insightful information for early implementation and mitigation strategies on construction sites.

4.3 Machine Learning Algorithm:

4.3.1 Sensor and ML Algorithm:

This strategy seeks to maximize subsequent analysis by ensuring that the information is suitable for machine learning (ML) techniques, to clean and normalize during the data pretreatment stage, and by improving data quality and accuracy, increasing efficiency. Appropriate signs of fatigue will be gleaned from previously processed cases. These symptoms are important clues to identify patterns of fatigue in construction workers.

Subsequently, the labeled data will be used to train and test several machine learning models, such as random forest, support vector machines (SVM), and neural network (NN) models will have the ability to identify fatigue patterns accurately divided by this training method [10].

4.4 Application Development:

4.4.1 User Interface:

The goal of creating a user-friendly interface using a variety of tools and screen sizes will be a key strength in creating a flexible website for real-time fatigue tracking. This website will feature charts, graphs, and data visualizations, another detail to shine a light on the degree of fatigue faced by construction workers. Alarm systems will also be integrated into the website to immediately notify supervisors and medical professionals of any disturbing or abnormal conditions. Backend enhancements for the system will handle application data requests, handle user authentication to enable security, and provide communication between Arduino IoT cloud and systems for smooth data transactions. Providing better data management and connectivity, this backend monitors and analyzes health and wellness metrics for infrastructure construction workers.

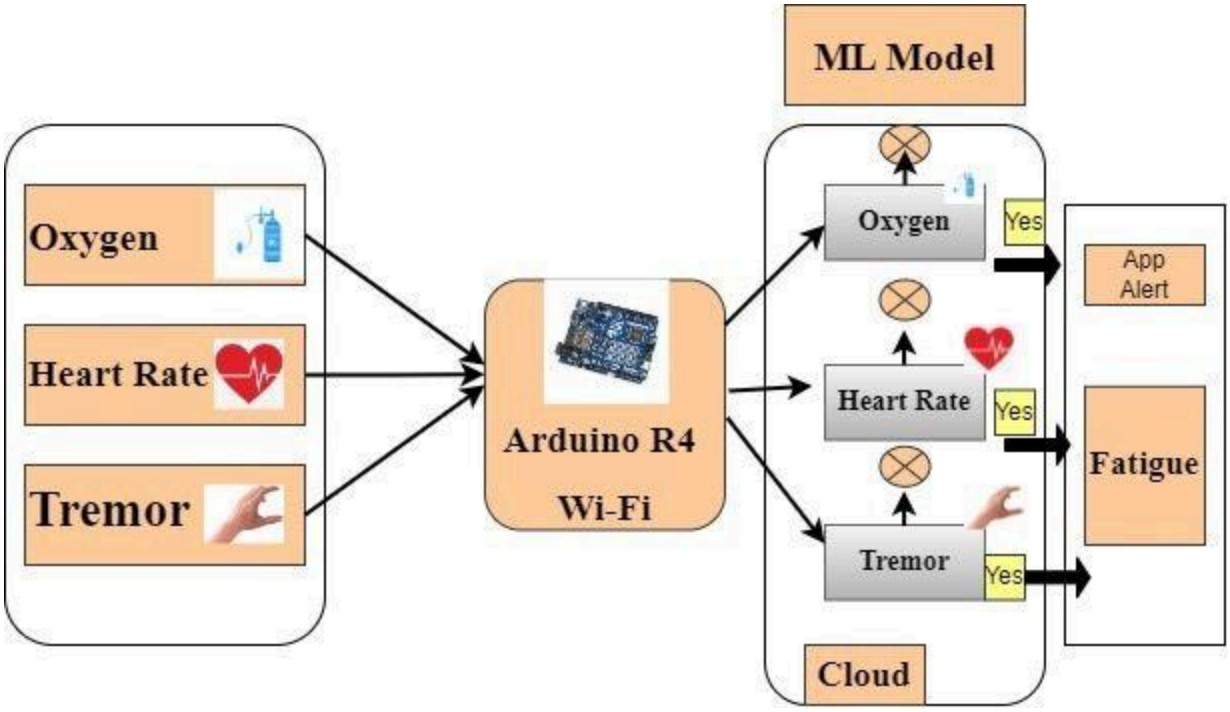


Figure 1: Block Diagram of Hardware Components.

4.5 Project Stages and Task Breakdown:

Phase 1: Requirements Analysis and Design: This phase will establish clearly defined requirements and specifications to ensure alignment with project objectives. In addition, architectures for software and hardware will be created to provide a foundation for further phases of development.

Phase 2: Hardware Development: This phase will involve acquiring a sensor and an Arduino microprocessor to build a wearable fingerprint prototype [11]. System integration and assembly of individual sensors are essential to ensure proper operation.

Phase 3: Software development: The primary focus here is writing and testing software for collecting sensor data, which is important for accurate data collection. Documentation for data analysis and model optimization is essential for data generation and machine learning modeling. Additionally, the Arduino IoT Cloud system enables efficient data storage.

Phase 4: Integration and Testing: The sensors must be integrated with the Arduino microcontroller. Testing data will transfer to the Arduino IoT Cloud to ensure connectivity. ML

model training requires data from a preliminary field test, which contributes to an accurate fatigue analysis.

Phase 5: Training and Model Validation: In this phase, the machine learning model will be trained on the collected data to accurately identify the fatigue pattern. Its reliability and generalizability are ensured through validation against other data sets. Improvements in model implementation make it more suitable for real-time applications.

Phase 6: Building the Website will improve usability and accessibility by creating a front-end user interface. This will allow stakeholders to better manage fatigue levels to ensure proper data handling and use. Real-time updates will be created to integrate the Arduino IoT Cloud for timely decisions.

Phase 7: Comprehensive testing and implementation: System performance will be validated under real-world settings through extensive field testing in realistic construction environments. The test results will indicate changes that need to be made to improve system performance. Finally, the implementation of real-time monitoring and alarm systems will ensure that the health and wellness needs of construction workers will continue to evolve.

4.6 Final Solution Assembly:

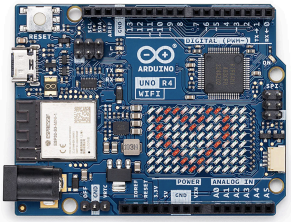
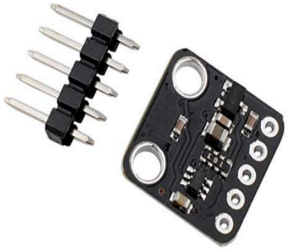
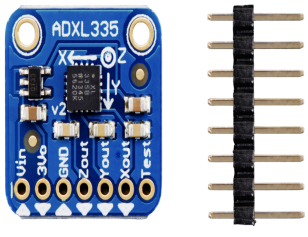
All objects created in the previous steps will be added to the final solution. The wearable wristband will continue to collect sensor data, which will be analyzed locally by the Arduino microprocessor and then sent to the cloud. Real-time data analysis will be performed using an ML algorithm, and the results will be displayed on an intuitive web page. Proper testing assures effectiveness and reliability in controlling risks associated with construction worker fatigue.

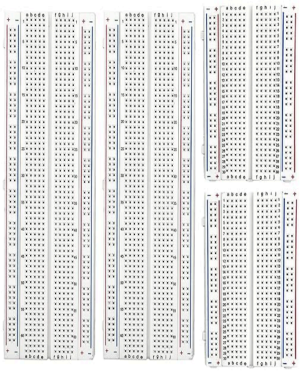
5. Estimated Budget and Justification

For the research aspect of our project, we will use accessible resources from trustworthy databases, guaranteeing a comprehensive groundwork for our project development. Our resources will be gathered from journals, articles, books, and papers. These resources will be accessed through the Qatar National Library Database (QNL), TAMU-Q Library Database, and IEEE Xplore website. These extensive resources will provide us with the essential academic

information to guide our project development, testing, and validation process. Therefore, we will not need a budget allocation for the research phase since everything is already accessible.

Our project comprises the development of a wearable wristband that detects and monitors fatigue. **Table 1** provides a financial summary of the components required to build the wristband. Considering the delicate nature of the sensitive components used to build this project, such as the sensors, additional component units will be ordered in case some equipment is defective throughout the building process. We ended up with a price of approximately $537.97, which is within the budget range provided by TAMUQ.

Component Name	Image	Quantity	Price per unit	Links
Arduino UNO R4 WiFi [12]		4	$27.50	Arduino
Blood Oxygen Sensor Heart Rate Click GY-MAX30102 Sensor Optical Heart-Rate Monitor Module for Arduino [13]		4	$15.00	Amazon
ADXL335 - 5V ready triple-axis accelerometer (+-3g analog out) [14]		4	$15.49	Adafruit

Blomiky 6V 2200mAh Ni-MH 5 AA Rechargeable Battery [15]		4	$14.99	Amazon
Breadboard [16]		3	$9.99	Amazon
Jumper Wires [17]		3	$9.99	Amazon
Elastic Band [18]		2	$12.99	Amazon

Velcro Straps [19]		2	$9.99	Amazon
Fabric Glue [20]		2	$9.99	Amazon
Small Zipper Pouch [21]		1	$9.99	Amazon
Sewing Kit [22]		1	$6.36	Amazon
BISON STRAP Nylon Watch Bands [23]		4	$6.99	Amazon

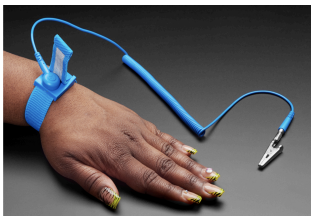
Barton Watch Bands [24]		4	$14.99	Amazon
iFixit Anti-Static Wrist Strap [25]		2	$7.95	Adafruit
Total price	**Approximately $537.97**			

Table 1: Components to be used to build wristband fatigue prevention.

6. Project Timeline

This graph represents our project timeline, outlining key milestones and deadlines to ensure our goals are met efficiently. By adhering to this timeline, we can systematically track our progress and make timely adjustments to stay on schedule.

Project Start	23/05/2024

	Task Completed	**Senior Project Timeline Chart**						
	Task in Progress	**Hemaya: Non-invasive multi-sensor wearable wristband for fatigue prevention**						
	Task Remaining	**May**		**June**			**July**	
Weeks		**3**	**4**	**1**	**2**	**4**	**1**	**2**
Tasks								
Project Proposal								
Team Agreement								

Project Website							
Customer Needs Study							
Project Video							
Benchmarking							
Functional Modeling							
Concept Generation							
Progress Presentation							
Final Presentation							
Final Report							

7. Conclusion

We believe that the implementation and development of the non-invasive wearable wristband with a multi-sensor system for fatigue prevention will mark a significant milestone in reducing accidents and injuries and improving the safety and well-being of construction workers during construction sites. This advanced technology of the wristband device is able to provide real-time feedback on fatigue levels through the sensors provided within the device. The proposed system will precisely monitor and evaluate the physical signals of the construction worker using the hardware's advanced sensors, such as the heart rate, oxygen level, and tremor. The wristband will continuously monitor their vital parameters. The software will be designed to collect raw data and upload it to the cloud for further analysis. Then it will alert the supervisor in case of any fatigue detection. Moreover, the final prototype of this project will include all the listed

components in the device to enhance the safety of the working environment and the overall productivity of the construction workers during their duty under some circumstances.

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