ECEN 404

Electrical Design Laboratory - Fall 2024

Final Report

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.

Our project, 'Hemaya' , a non-invasive multi-sensor wearable wristband, generates a detailed report on crucial fatigue indicators, such as heart rate, blood oxygen levels, and oxygen saturation. These parameters will be consistently tracked using an app that will be developed in the upcoming semester. The project is aimed at construction workers, where monitoring these indicators is vital for ensuring a safe work environment. The wristband provides real-time measurements, allowing sufficient time for planning and response if any risks are detected.

The literature review contrasts our wristband with other similar products, highlighting its unique features. This comparison enabled us to refine our project to better align with the needs and preferences of our target demographic. The report also showcases public awareness of environmental hazards through a customer needs analysis, which involved surveying the general public for their opinions on our project. Additionally, we interviewed experts, including electrical engineers and professionals who manage construction workers. These interviews and surveys were conducted as part of our customer needs assessment to gather valuable insights. Also, the benchmarking assignment further confirms its effectiveness in addressing the initial problem statement, showcasing its societal contributions. These include improvements in safety, welfare, public health, and economic, cultural, social, and global impacts. Analyzing existing

solutions thoroughly compares various products, emphasizing our wristband's advantages in terms of functionalities, sensors, and constraints over competitors. Another assignment, functional modeling provides a detailed flow diagram and system analysis, elaborating on the upper-level model. The project's operations are thoroughly evaluated by examining the inputs and outputs of components and understanding their functionality through physical and wireless connectivity. Block diagrams are used to outline sub-functions and illustrate the energy flow within the wristband's system, offering a comprehensive analysis of its overall structure.

To provide a comprehensive understanding of the progress made by our project ‘Hemaya’, a timeline depicting completed and remaining tasks is presented, along with plans for concluding the report. In addition to presenting the system's designs and operation, complex engineering problems are addressed step-by-step. Technical standards are reviewed and analyzed, considering constraints such as safety, welfare, public health, and economic, cultural, social, and global impacts. Connections to ECEN courses are established and analyzed to relate the project to the relevant academic material.

Chapter 1: Literature Review and Customer Needs

1.1 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 [1].

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 [2].

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 [1].

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 [2].

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.

1.2 Customer Needs

This section aims to conduct a thorough study on customer needs for the senior design project ‘Hemaya’ , which is a non-invasive multi-sensor wearable wristband for fatigue prevention. This project focuses on construction workers as the target group. The main focus is on prioritizing the safety and well-being of construction workers and taking measures to prevent accidents caused by fatigue. Identifying and assessing the requirements and preferences of end-users is a crucial step in product development known as a customer needs analysis. This analysis involves collecting information directly from potential users and stakeholders to gain an understanding of their needs, expectations, and any challenges they encounter that the product aims to solve. Through this analysis, well-informed decisions can be made regarding the design and functionality of the product, ensuring it effectively meets the needs of the users.

A survey was conducted to gather the perspectives of customers on the wristband in order to determine their needs. In addition, a series of interviews were conducted with professionals in the field. These interviews focused on project-specific and technical inquiries. The insights and input gathered from these interviews will be incorporated into the implementation of the project. The data collected from both the survey and the interviews will be carefully analyzed to improve the design, components, and functionality of the wristband. The survey results and expert insights will inform the development of a fatigue detection solution that is efficient, durable, and user-friendly, specifically designed for construction workers. The project aims to develop a product that effectively promotes safety and productivity in the construction industry by understanding and addressing the demands and needs of construction workers. The findings from this extensive study are essential for informing the progress of 'Hemaya', guaranteeing that the wristband not only fulfills but exceeds the expectations of its users. Section 1.2 will provide an effective foundation for the project, outlining the analysis of customer needs and how it influences the overall design and implementation strategy. The questions of the survey and the interview will be found in the Appendix Section at the end of this report.

1.2.1 Methods

1.2.1.1 Survey Development and distribution

To explore the potential impact and acceptance of a non-invasive multi-sensor wearable wristband for fatigue prevention among construction workers, we designed a comprehensive survey. Utilizing SurveyMonkey [3], we created a survey that included a mix of general, technical, and project-specific questions. The survey aimed to capture diverse insights from professionals in occupational health and safety, particularly those with experience related to construction workers.

To assess the acceptability and potential impact of non-prosthetic wristbands for fatigue prevention in construction workers, we designed and distributed a survey using SurveyMonkey. The study focused on awareness of health risks from fatigue and willingness to adopt wearable technology.

Our objective was to determine the awareness of construction workers about the health risks associated with fatigue. This is important for understanding the perceived importance and acceptability of fatigue management tools.

1.2.1.2 Interviews

In addition to the survey, we conducted three in-depth interviews to gather qualitative insights:

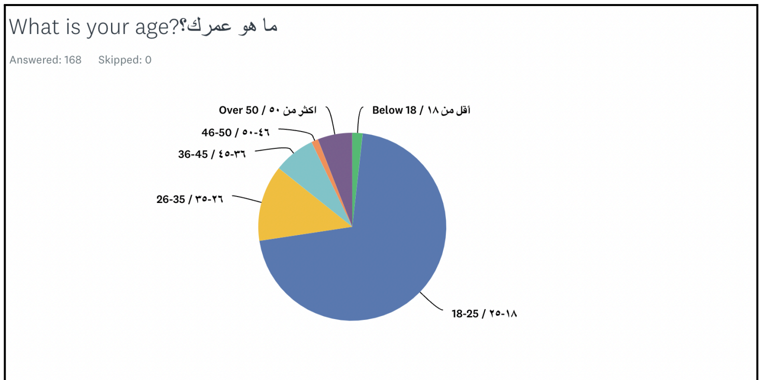
One University Interviews: Conducted with professors specializing in occupational health and safety, these interviews provided academic perspectives and insights into current research trends and technological advancements.

Two Industry Interviews: Conducted with representatives of two construction companies, these interviews offered practical industry insights and real-world experiences with fatigue management and wearable technology.

1.2.2 Customer Needs Analysis

In this part, the questions asked in the survey will be shown, along with the results figures. We highlighted the significance of surveying different audiences. We conducted ten different questions for our project. Then, we thoroughly analyzed the survey used to learn more about people's awareness and expectations about fatigue. The survey aimed to evaluate respondents' understanding and support of work-related fatigue.

Question 1: What is your age?



ANSWER CHOICES	RESPONSES	
Below 18 / أقل من ١٨	1.79%	3
18-25 / ١٨-٢٥	70.83%	119
26-35 / ٢٦-٣٥	13.10%	22
36-45 / ٣٦-٤٥	7.14%	12
46-50 / ٤٦-٥٠	1.19%	2
Over 50 / اكثر من ٥٠	5.95%	10
TOTAL		168

Figure 1:Pie chart of participant age distribution.

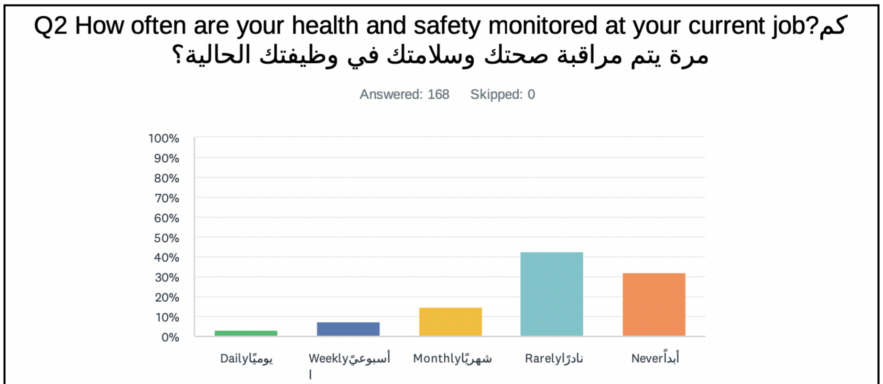
The survey's age group distribution indicates that young adults are overwhelmingly represented, with the 18–25 age group accounting for the greatest percentage of respondents (70.83%). This implies that a younger population was drawn to the poll, which may have been due to the survey's popularity among younger people or the relevance of the topic matter.

With 13.10% of responses, the age group of 26 to 35 comes in second place. This suggests that a considerable proportion of participants are in their late 20s and early 30s, indicating a wide range of life stages and experiences. With fewer responders in each age group after the older age categories, the distribution starts to drop off. The age group of 36–45 accounts for 7.14% of the responses, suggesting a decrease in the number of respondents in their mid–to late-thirties and early-forties. As one moves further along the age spectrum, just 1.19% and 5.95% of replies, respectively, are from the 46–50 age range and those over 50. This indicates that middle-aged and older people participate at a significantly lower rate than younger people.

The survey's overall findings point to a bias in favor of younger age groups, which may have an impact on the viewpoints and information acquired. Although this could offer insightful information about the views and behaviors of young adults, it is important to acknowledge the sample composition's limitations in terms of representing the larger population. Subsequent investigations may endeavor to broaden the range of participants in order to guarantee a more thorough comprehension of the topic matter throughout different age groups.

Question 2: How often are your Health and safety monitored at your current job?

The frequency of health and safety monitoring at present occupations survey uncovers alarming patterns about the degree of supervision in different types of workplaces. Notably, 42.86% of respondents said that health and safety inspections are infrequent at their places of employment, which is the most common response that suggests a lack of routine monitoring. This indicates a serious lack of protection for workers' health and safety, putting them at risk for dangers that may be avoided with more regular monitoring schedules.



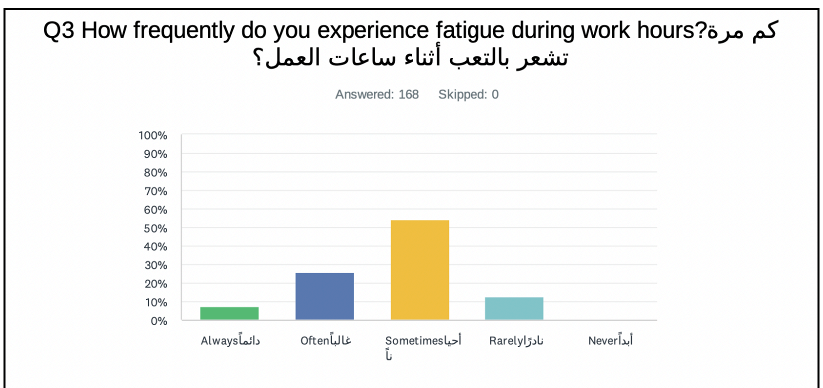
ANSWER CHOICES	RESPONSES	
Dailyيوميًا	2.98%	5
Weeklyأسبوعيًا	7.14%	12
Monthlyشهريًا	14.88%	25
Rarelyنادرًا	42.86%	72
Neverأبدًا	32.14%	54
TOTAL		168

Figure 2:Barchart of health and safety monitoring at current job.

The fact that 32.14% of respondents said they had never had their health and safety at work monitored is even more concerning. This finding presents grave questions regarding the enforcement of safety laws and the well-being of workers in these settings. It suggests that in order to safeguard employees from possible injury, safety procedures must be strictly enforced, and assistance is critically needed. Monthly monitoring was reported by 14.88% of respondents among the less common responses, whilst weekly monitoring was recorded by 7.14%. The most frequent and strict type of oversight, daily monitoring, was only reported by 2.98% of respondents. These numbers highlight how uncommon, thorough, and reliable monitoring procedures are in the workplaces that were examined.

Overall, the poll reveals a worrisome absence of routine health and safety oversight in many businesses, with a sizable percentage of participants reporting sporadic or nonexistent inspections. The need to put employee well-being first and the requirement for stronger enforcement of safety regulations across businesses are brought up by this. Resolving these issues is essential to protecting employees' general welfare, health, and safety in a variety of work environments.

Question 3: How frequently do you experience fatigue during work hours?



ANSWER CHOICES	RESPONSES	
Alwaysدائماً	7.14%	12
Oftenغالباً	25.60%	43
Sometimesأحياناً	54.17%	91
Rarelyنادرًا	12.50%	21
Neverأبداً	0.60%	1
TOTAL		168

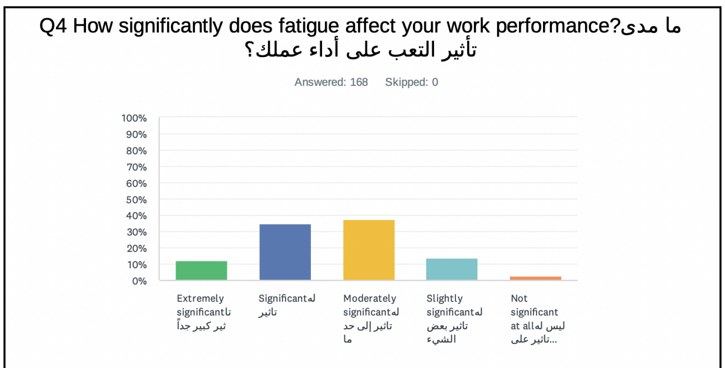
Figure 3:Barchart of experiencing fatigue during working hours

The survey's findings regarding fatigue during working hours are stark. A concerning 7.14% of participants reported constant fatigue, while a quarter, 25.60%, experienced it often. More than half, 54.17%, reported occasional fatigue, making this the most significant group. These numbers underscore the need for immediate action to address this prevalent issue in the workplace.

These numbers demonstrate that a significant percentage of those in work frequently struggle with fatigue, with the majority, 54.17%, reporting occasional fatigue; this group includes the most significant percentage of respondents. This suggests that although fatigue is occasional, it is frequent and impacts more than half of the employed population. More than a quarter, 25.60%, reported frequent fatigue. About 12.50% of respondents encounter this problem rarely, while a small percentage of 0.60% report never feeling tired at work.

It is essential to conduct surveys with diverse audiences to identify at-risk groups, realize the effects of distinct work settings, and develop specific wellness efforts. We can improve worker health and wellness by identifying patterns in the different levels of fatigue that different work functions or departments may display. These patterns can then be used to drive focused solutions. Furthermore, using these findings to guide policy changes relating to overall workplace efficiency and well-being would improve these.

Question 4: How significantly does fatigue affect your work performance?



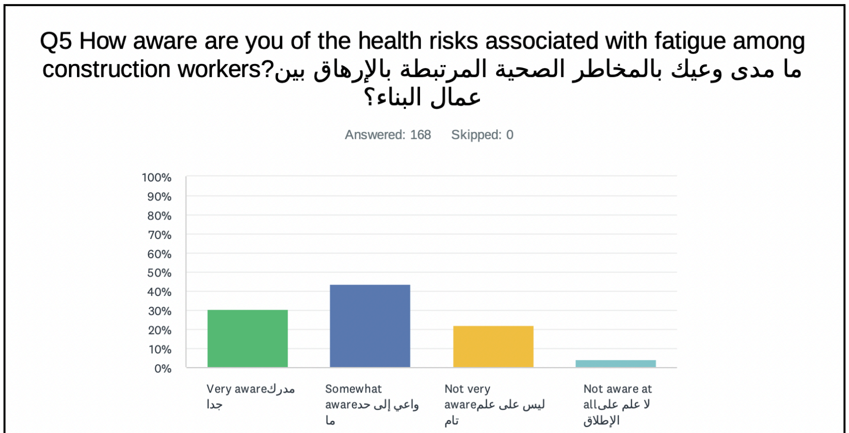
ANSWER CHOICES	RESPONSES	
Extremely significantتاثير كبير جداً	11.90%	20
Significantله تاثير	34.52%	58
Moderately significantله تاثير إلى حد ما	37.50%	63
Slightly significantله تاثير بعض الشيء	13.69%	23
Not significant at allليس له تاثير على الإطلاق	2.38%	4
TOTAL		168

Figure 4:Barchart of effectiveness of fatigue.

According to the figure, a central portion of workers report fatigue as either highly significant or significant to their work performance, indicating that fatigue is a severe issue for many. This is the largest group, with 63 respondents or 37.50%, having a moderate impact. This implies that even if their level of exhaustion may not be incapacitating, it nevertheless has an obvious effect on their job performance. According to 58 respondents, being tired has a big impact on their work. This implies that fatigue significantly affects workers in the workforce, which may result in decreased worker productivity and effectiveness as well as an increase in mistakes or accidents. All in all, we can see that only 4 responses out of 168, see that fatigue does not affect their work performance. Indicating how important and significant fatigue affects workers in general.

The study's findings are clear - fatigue significantly impacts work performance, with a substantial proportion of participants reporting moderate to severe effects. This underscores the urgent need for companies to prioritize employee well-being and implement effective fatigue management procedures. The results also highlight the necessity for tailored solutions and stricter regulations to manage fatigue across various work settings and positions. Addressing these concerns is crucial for ensuring the overall well-being, efficiency, and security of workers in the workplace.

Question 5: How aware are you of the health risks associated with fatigue among construction workers?



ANSWER CHOICES	RESPONSES	
Very awareمدرك جدا	30.36%	51
Somewhat awareواعي إلى حد ما	43.45%	73
Not very awareليس على علم تام	22.02%	37
Not aware at allلا علم على الإطلاق	4.17%	7
TOTAL		168

Figure 5:Awareness of the health risks associated with fatigue among construction workers

The aim of the study was to assess construction workers' awareness of fatigue-related health hazards, which is important to understand the importance of monitoring tools. Analysis of 168 responses indicated that most of the respondents were either "quite aware" (approximately 22.02%) or "somewhat aware" (approximately 43.45%) of this health hazard This reflects a high level of awareness of the importance of the matter. However, about 30.38% were "very aware," and about 4.17% were "not at all aware". This indicates that although the majority of respondents (60%) have at least some information about the health risks associated with fatigue, a significant percentage (40%) still have little to no knowledge This highlights the need for quality education and for awareness-raising projects in this area.

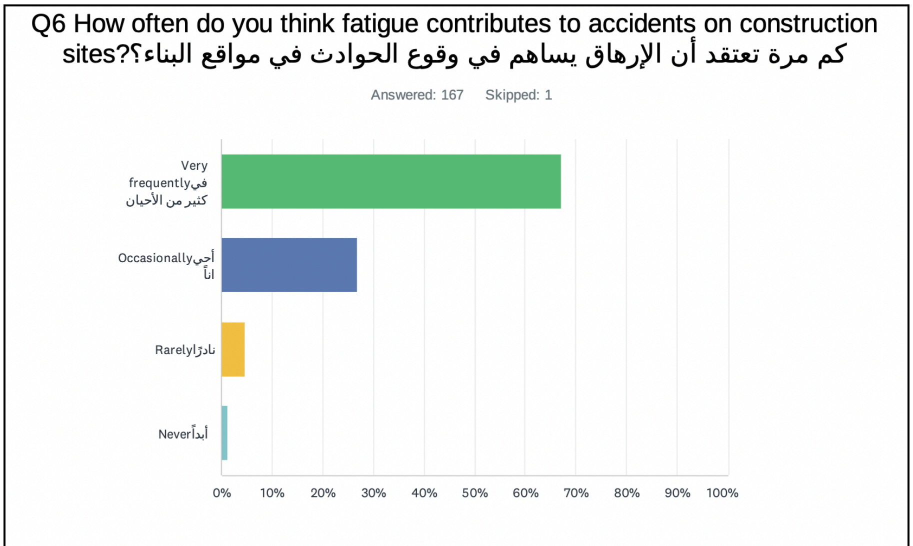
Survey responses also indicated that there is a strong belief that wristbands with multiple sensors can significantly improve safety and productivity among construction workers. Most people emphasized that monitoring vital signs such as heart rate, oxygen saturation, and vibration provides early warning of fatigue, prevents accidents, and improves overall performance Several people also said features such as real-time feedback and daily summary reports will be particularly useful.

When asked if they would consider using wearable wristbands that monitor vital signs to prevent accidents, the survey indicated a general openness to consideration The most common response was "Maybe or not," implying some uncertainty but not absolute denial. The absence of "definitely not" responses indicates positive attitudes toward the technology, with many respondents expressing a conditional interest or willingness to use the wristband

Tired workers tend to have lower alertness, slower reaction times, and poorer concentration, all of which can lead to accidents and injuries. Long working hours and demanding jobs in construction make them tired again. Therefore, it is important to examine the willingness to adopt such technologies to ensure safety and efficiency at construction sites.

Question 6: How often do you think fatigue contributes to accidents on construction sites?

The survey included a question that got to assess participants' views on the impact of fatigue on accidents at construction sites. A total of 167 responses were gathered to provide insights on this matter. According to the findings, a significant proportion of participants (67.07%) strongly believe that fatigue plays a major role in causing accidents at construction sites. The overwhelming majority emphasizes the importance of fatigue as a crucial factor in ensuring workplace safety in the construction industry. Another 26.95% of participants believe that fatigue sometimes plays a part in these accidents, highlighting the widespread agreement that fatigue is a significant factor in causing accidents.

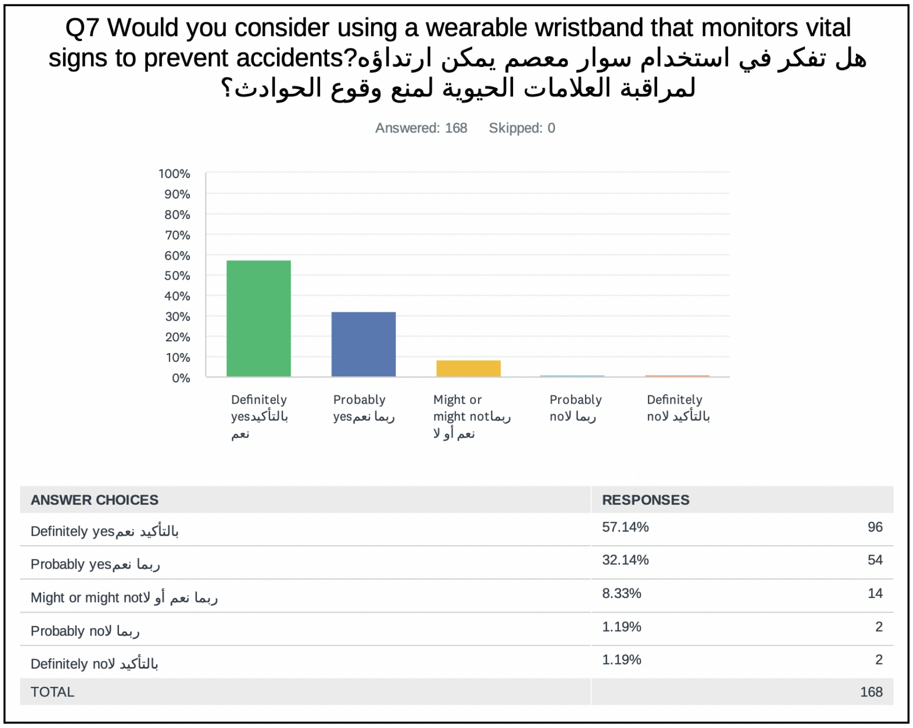


ANSWER CHOICES	RESPONSES	
Very frequentlyفي كثير من الأحيان	67.07%	112
Occasionallyأحياناً	26.95%	45
Rarelyنادرًا	4.79%	8
Neverأبداً	1.20%	2
TOTAL		167

Figure 6:Barchart of fatigue-related accidents on construction sites

Fatigue is thought to be a minor factor in accidents only by a small minority of responders (4.79%), and at most, 1.20% felt it never happened. The findings suggest a strong demand for practical strategies to address fatigue in the construction sector. The significant number of participants recognizing the influence of fatigue on accidents provides strong support for the ‘Hemaya’ project. This innovative initiative involves the creation of a non-intrusive wristband equipped with multiple sensors designed to identify and mitigate fatigue among construction workers. The survey findings highlight the significance of tackling fatigue in order to improve safety and decrease the occurrence of accidents at construction sites.

Question 7: Would you consider using a wearable wristband that monitors vital signs to prevent accidents?



ANSWER CHOICES	RESPONSES	
Definitely yesبالتأكيد نعم	57.14%	96
Probably yesربما نعم	32.14%	54
Might or might notربما نعم أو لا	8.33%	14
Probably noربما لا	1.19%	2
Definitely noبالتأكيد لا	1.19%	2
TOTAL		168

Figure 7:Percentage of people considering wearing a wristband

The survey indicated a general openness to using the wristband, with a significant number of respondents expressing interest in or conditional willingness to adopt the technology. Most respondents were open to the idea, with a significant number expressing interest or conditional willingness. The absence of "Definitely no" responses indicates general acceptance of the wearable wristband for monitoring vital signs.

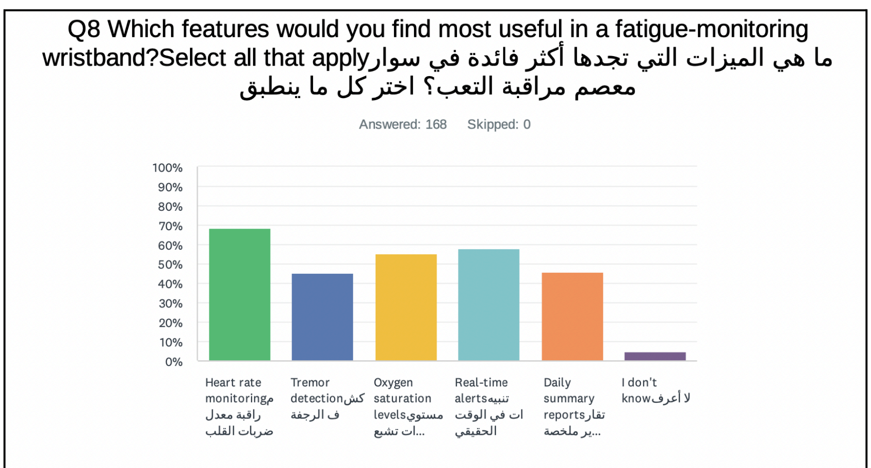
The survey provided five response options: Definitely yes, probably yes, Might or might not, probably no, and Definitely no. The percentage distribution of the responses was as follows:

- **Definitely yes:** A significant portion, around 25% of respondents, indicated a strong interest in using the wristband.
- **Probably yes:** Approximately 20% expressed a high likelihood of adopting the technology.

- Might or might not: The longest bar in the graph, representing around 40%, reflected some uncertainty or conditional interest.
- **Probably not:** About 15% were less inclined to consider using the wristband.
- **Definitely no:** No respondents selected this option, suggesting general openness to the concept.

The analysis of responses shows a favorable disposition towards the technology, with many respondents expressing interest or conditional willingness to use the wristband. This openness indicates a promising potential for improving safety and productivity through wearable fatigue monitoring. The survey results suggest that the multi-sensor wearable wristband is beneficial for workers, as there is both a high awareness of fatigue risks and a strong willingness to adopt such technology. This indicates a promising potential for improving safety and productivity through wearable fatigue monitoring.

Question 8: Which features would you find most useful in a fatigue-monitoring wristband?



ANSWER CHOICES	RESPONSES	
Heart rate monitoringمراقبة معدل ضربات القلب	68.45%	115
Tremor detectionكشف الرجفة	45.24%	76
Oxygen saturation levelsمستويات تشبع الأكسجين	55.36%	93
Real-time alertsتنبيهات في الوقت الحقيقي	57.74%	97
Daily summary reportsتقارير ملخصة يومية	45.83%	77
I don't knowلا أعرف	4.76%	8
Total Respondents: 168		

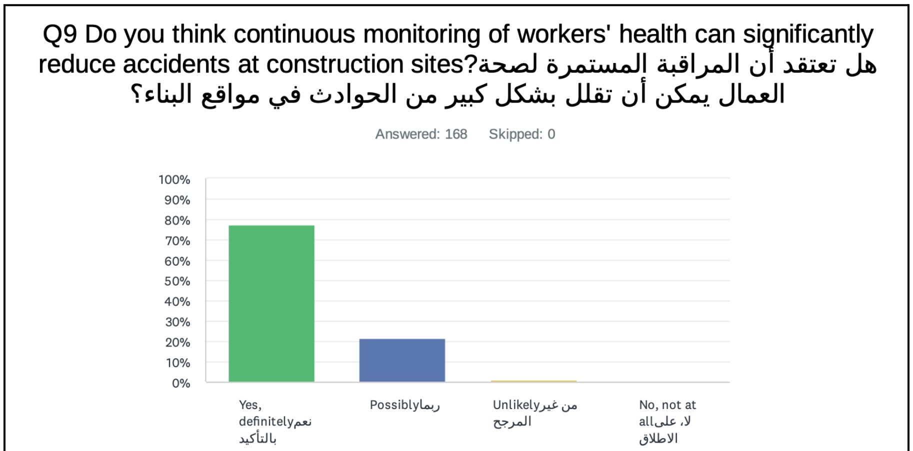
Figure 8:Barchart of most useful features in a fatigue-monitored wristband

The survey included a question that sought to determine the features that respondents found most valuable in a fatigue-monitoring wristband. A total of 168 responses were gathered for this question. The heart rate monitoring feature was highly valued, as indicated by 68.45% of the respondents. This emphasizes the importance of monitoring physiological signals that are closely linked to cardiovascular health, as they can serve as a valuable indicator of fatigue. 55.36% of respondents highly valued oxygen saturation levels, highlighting the significance of monitoring respiratory efficiency and overall well-being. A significant percentage of respondents find real-time alerts to be valuable, highlighting the importance of timely feedback in mitigating fatigue-related incidents. A significant number of respondents highly value tremor detection as it can indicate muscle fatigue and early signs of physical strain. Additionally, a considerable percentage of respondents appreciate daily summary reports as they offer comprehensive insights into fatigue levels and health trends on a daily basis.

A significant majority of respondents, 95.24%, demonstrated a clear understanding and appreciation of the benefits associated with these monitoring features, as only a small fraction, 4.76%, expressed uncertainty regarding their usefulness. The findings of this study indicate that the key functionalities of the ‘Hemaya’ wristband, including heart rate monitoring, oxygen saturation levels, and tremor detection, are highly compatible with the requirements and desires of the intended users. In addition, implementing real-time alerts and daily summary reports will greatly improve the wristband's ability to promote safety and well-being for construction workers. The survey results highlight the significance of these features in creating a functional and dependable fatigue-monitoring solution.

Question 9: Do you think continuous monitoring of workers’ health can significantly reduce accidents at construction sites?

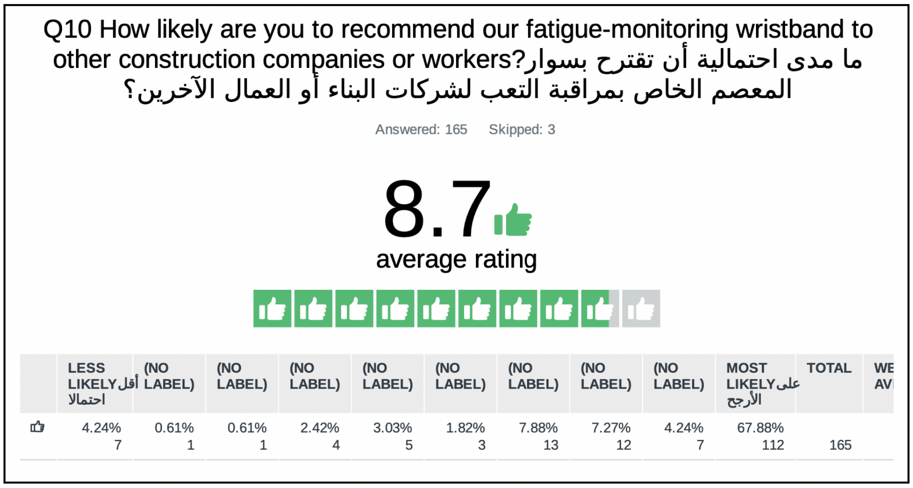
The survey results indicate a strong consensus among respondents on the effectiveness of continuous health monitoring in reducing accidents at construction sites. Out of 168 respondents, a significant majority of 77.38% firmly believe that such monitoring can indeed significantly decrease the occurrence of accidents. Another 21.43% think it is possible that continuous health monitoring might have a positive impact. Only a small fraction, 1.19%, are skeptical, considering it is unlikely to make a significant difference. Notably, no respondents (0%) believe that continuous health monitoring would have no impact at all. This data suggests that there is overwhelming support for the implementation of continuous health monitoring as a safety measure in construction environments, highlighting its perceived importance in promoting worker safety and accident prevention.



ANSWER CHOICES	RESPONSES	
Yes, definitelyنعم بالتأكيد	77.38%	130
Possiblyربما	21.43%	36
Unlikelyمن غير المرجح	1.19%	2
No, not at allلا، على الاطلاق	0.00%	0
TOTAL		168

Figure 9:Shows monitoring workers' health at construction sites

Question 10: How likely are you to recommend our fatigue-monitoring wristband to other construction companies or workers?



	LESS LIKELY أقل احتمالا	(NO LABEL)	(NO LABEL)	(NO LABEL)	(NO LABEL)	(NO LABEL)	(NO LABEL)	(NO LABEL)	(NO LABEL)	MOST LIKELY على الأرجح	TOTAL	WE AV
	4.24% 7	0.61% 1	0.61% 1	2.42% 4	3.03% 5	1.82% 3	7.88% 13	7.27% 12	4.24% 7	67.88% 112	165	

Figure 10:Indicates the recommendation for a fatigue-monitoring wristband

The figure presents the results of a survey question asking participants how likely they are to recommend a fatigue-monitoring wristband to other construction companies or workers. A total of 165 participants answered the question. The survey reveals an average rating of 8.7 out of 10, suggesting a strong inclination among respondents to recommend the wristband. This high average rating is visually supported by a series of thumbs-up icons, emphasizing the positive feedback. A detailed breakdown of the responses provides further insight into the survey results. The largest portion of respondents, 67.88%, rated the likelihood of recommending the wristband at the highest score of 10, denoted as "Most Likely." This significant majority highlights a strong endorsement. Conversely, the lowest score, labeled "Less Likely," was chosen by only 4.24% of respondents, reflecting minimal negative feedback. The remaining responses are distributed across the mid-range scores, with small percentages (ranging from 0.61% to 8.7%) scattered across intermediate labels. This distribution indicates that while a few respondents were more reserved in their recommendation, the overwhelming consensus is highly positive. The inclusion of dual-language text and detailed response metrics underscores the thoroughness of the survey and the broad support for the wristband's effectiveness in fatigue monitoring.

1.2.3 Surveys

1.2.3.1 Public Survey

According to the collected response from the public survey, there is a worrying trend of insufficient health and safety monitoring at work, especially on building sites. Younger adults predominate in survey responses, which may distort the results. Respondents acknowledge that fatigue is a common problem that negatively affects work performance and raises the possibility of accidents. On the other hand, wearable technological solutions are needed because the current monitoring techniques are insufficient. Respondents strongly support these technologies, especially wristbands that track vital indicators. Heart rate monitoring is emphasized as a top feature, which suggests that thorough health tracking is desired. In other words, continuous health monitoring is quite useful in preventing accidents. Overall, the survey indicates an average rating of 8.7 suggesting a strong tendency among respondents to recommend the wristband.

1.2.3.2 Professionals Survey

The interview conducted with the experts points to the urgent need for better occupational health and safety monitoring, especially in construction environments. Respondents strongly endorse wearable technology as a potential solution, with gadgets that track vital signs receiving particular support. One important function that many people want is heart rate monitoring, which suggests that there is a need for extensive health-tracking features. Professionals in the field agree, stressing the need to deal with fatigue-related problems and putting in place efficient monitoring systems. Meridian Constructions stresses the need for enhanced safety procedures while acknowledging the absence of formal fatigue tracking systems. In its proposal, Syook Technologies highlights the possibility of incorporating tracking devices into personal protective equipment and offers Internet of Things solutions for real-time tracking

Overall, the findings underscore how critical it is to address the risks associated with fatigue and how wearable technology can improve worker safety in a variety of sectors.

1.2.4 Experts Interviews

1.2.4.1 Dr. Erchin Serpedin's Interview

In a recent interview, Professor Erchin Sperdin, the Program Chair of Electrical and Computer Engineering at Texas A&M Qatar, highlighted the critical importance of keeping an eye on workers' heart rates, oxygen levels, and tremors in order to guarantee their safety in harsh conditions like Qatar. He admits to having an understanding of signal processing but not of certain medical thresholds. He emphasizes the value of wireless, portable sensors that can notify coworkers and other parties when vital indicators show signs of extreme exhaustion or potential health hazards. Dr. Serpedin emphasizes the necessity for practicality over complexity and supports gadgets that are straightforward, small, and durable. He also mentioned the difficulties in creating such hardware, such as the requirement for effective sensors and simple algorithms to handle the data. In addition, he also discusses future directions for wearable technology, speculating that increasingly sophisticated sensors would be able to forecast serious health occurrences like strokes. However, he issues a warning against designing wearables that are overly complicated or invasive. In particular, his vision calls for readily deployable sensors that strike a balance between user convenience and thorough monitoring, especially for demanding jobs and vulnerable populations.

1.2.4.2 Dr. Jim Ji's Interview

In the interview with Dr. Jim Ji, a Professor in the Electrical and Computer Engineering Department at Texas A&M, emphasized the potential of wearable technology as a reliable indication of exhaustion, with a focus on heart rate. Even though he is unsure if oxygen consumption and tremor detection are relevant to weariness, he emphasizes the need for more research. For implementation to be effective, practical factors like battery life and convenience of use are essential. To highlight the significance of timely notifications from wearable devices to avoid overexertion, Dr. Ji uses a personal story. He recognizes the difficulties in developing trustworthy wearable sensors, especially for blood pressure monitoring, and underlines the advancements made in wristband and smartwatch technology. Notwithstanding these difficulties, Dr. Ji believes that as technology advances, these tools will be a great help to people in a variety of professions, as well as construction workers, by reminding them to balance their activity levels and get enough sleep. In his final words, he emphasizes the potential of wearable technology to enhance safety and well-being while expressing hope for the project's success in expanding wearable technology for useful uses.

1.2.4.3 Architecture Kersten Chandy’s Interview

The company's dedication to occupational health and safety for construction workers is discussed by Kersten Chandy Mathew, a business development executive at Meridian Constructions Qatar. With a concentration on small- to medium-sized businesses' residential, commercial, and industrial projects, Meridian Constructions has been in business for almost 17 years. Mathew notes that exhaustion is a major problem, especially given the rigorous environment. He highlights that the organization places a high premium on protecting the health and safety of its employees, which includes offering necessities like shade and clean water. As for the methods used now to track weariness, Mathew notes that there isn't a formal system in place.

The sector frequently depends on unofficial queries concerning the welfare of its employees, which is insufficient and usually leads to people being overworked. This draws attention to a crucial weakness in the efficient management and tracking of fatigue. Mathew believes that a wearable wristband with many sensors for detecting weariness has a lot of potential applications. If the device's cost is acceptable, he believes it would greatly improve worker productivity and safety, in line with the company's dedication to worker well-being.

Finally, Mathew promotes the use of technology to track and evaluate worker weariness methodically. He emphasizes how crucial it is to have a formal structure in place that can gather and evaluate data in order to guarantee the welfare of employees. This viewpoint emphasizes how important it is for the construction sector to use cutting-edge technologies that can offer practical insights for enhancing health and safety outcomes, rather than continuing with antiquated techniques.

1.2.4.4 Samer Gadban's Interview

Syook Technologies' strategy and growth consultant, Samer Gadban, shares his knowledge of the company's IoT real-time location services, specifically its platform Insight. They highlight how their system is adaptable and can be used to map and track assets in a variety of settings, including manufacturing facilities, warehouses, and hospitals. Gadban emphasizes how important it is to monitor compliance, particularly in places like Qatar, where heat exhaustion and stress are common.

The interview emphasizes the crucial role of integrating hardware with their software platform to increase clientele. Gadban talks about the difficulties encountered, especially regarding battery durability and life in hard conditions such as building sites. Instead of depending only on wristbands, they suggest incorporating tracking devices inside personal protective equipment (PPE), which is a more seamless and useful approach.

Overall, Gadban effectively conveys Syook's emphasis on using cutting-edge IoT solutions to solve real-world problems while simultaneously recognizing realistic roadblocks and suggesting tactical adjustments. An overview of the company's technological prowess, market positioning, and innovative customer service methodology may be gained from the interview.

Chapter 2: Benchmarking

Rapid advances in technology and construction have resulted in a surge in the building of high-rises, skyscrapers, and bridges globally, escalating the need for construction labor. This swift expansion necessitates meticulous planning, significantly impacting the physical and psychological health of workers. Addressing this issue is essential to preventing serious harm, including fatalities. This project aims to develop a non-invasive multi-sensor wristband called ‘Hemaya’ that monitors construction workers’ oxygen saturation, heart rate, and tremor to detect fatigue and locate them in real-time situation assessment [4].

Construction workers are exposed to intense physical labor, long working hours, and extreme weather conditions, resulting in high levels of fatigue, a leading cause of accidents and injuries at work despite improvements in safety measures and equipment, fatigue is an ongoing problem. Studies such as "Effect of Heat Stress on Cardiac Mortality in Nepalse Migrant Workers in Qatar" have highlighted the need for ongoing health monitoring due to the association between heat stress and increased worker mortality due to heart disease [5].

Wearable technology for healthcare has evolved dramatically over the past decade. Research shows that wearable systems can monitor fatigue by tracking medical symptoms consistently and being comfortable over time. Studies such as "Fatigue Monitoring Through Wearables: A State-of-the-Art Review" highlight the critical role fatigue monitoring plays in occupational health and safety. Wearable programs can monitor mental and physical performance affected by fatigue, increased risk of injury, and decreased productivity. However, existing solutions have limitations, such as testing in controlled environments and over short periods of time, limiting their practical application [6].

To address these challenges, Hemaya uses a multisensory approach to real-time fatigue detection by integrating sensors to monitor oxygen saturation levels, heart rate, and handshaking. This innovative solution aims to increase safety, reduce accidents, and improve the welfare of construction workers, promoting a safer and more efficient working environment.

The proposed wristband overcomes these limitations by integrating multiple sensors to measure oxygen saturation, heart rate, and hand tremor, ensuring a complete physiological evaluation. Using a machine learning algorithm implemented on an Arduino Uno R4 WiFi microcontroller will process the data collected by these sensors for real-time fatigue analysis. Collected data can be instantly viewed in the accompanying app, enabling fatigue to be quickly addressed and immediate action taken when needed.

Development includes a broad range of hardware and software components, data processing, analytics, and integration of machine learning. Hardware includes triaxial accelerometer ADXL335 and heart rate monitor pulse oximeter biosensor MAX30102, which connects the Arduino Uno R4 WiFi microcontroller. Software programmed through Arduino IDE will optimize sensor performance and monitor power consumption. The data collected by the sensors will be processed and analyzed, with real-time data transfer enabled by the Arduino Uno R4 WiFi module [7].

The project addresses a number of challenges, such as severe weather in Qatar, connectivity issues, delayed Institutional Review Board (IRB) approvals, and battery life optimization.

2.1 Existing Solutions

An abundance of commercial health-tracking wearable gadgets have been developed in response to the rising concern for general health. These devices are designed to measure health and fitness. Now available on the market are fitness bands and smartwatches that are able to monitor vital signs related to health. On the other hand, the construction workers that we intend to assist frequently do not have access to this equipment, mostly because of the expensive cost of these appliances. These devices are expensive because they have features like stylish designs, attractive aesthetics, and compact form factors. All of these aspects require substantial engineering, which drives up the expense of maintaining these devices.

Furthermore, in order to communicate data in real time, the majority of these items require a nearby smartphone. If they do not have a smartphone, they will have to wait to reconnect, which is counterproductive to our objective of real-time health tracking. Even while some of these devices do feature artificial intelligence algorithms that can determine the level of fatigue experienced by a worker, they are still out of reach for the demographic that we are trying to reach. Through the implementation of our project 'Hemaya', we intend to close this gap by providing a solution that is not only economical but also capable of detecting oxygen saturation, heart rate, and tremor in real time. This will make the solution accessible and practical for construction workers.

2.1.1 OURA Ring Generation 3

The Oura Ring Generation 3 is a smart wearable device designed to track various aspects of health and fitness, offering several advanced features. It provides comprehensive health tracking, including sleep monitoring (tracking deep, light, and REM sleep stages and providing a sleep score), activity tracking (monitoring daily activities, steps, and calories burned), and a readiness score that combines sleep, activity, and other metrics to indicate overall readiness for the day. The ring is equipped with advanced sensors for continuous heart rate monitoring, including resting heart rate and heart rate variability (HRV), as well as body temperature sensing to measure deviations and provide insights into health and recovery [8].

Figure 11:

2.1.2 Apple Watch Series 9

The Apple Watch Series 9 is a feature-rich smartwatch that offers a range of advanced functionalities to enhance health, fitness, and daily convenience. It includes comprehensive health monitoring capabilities such as heart rate tracking, ECG, blood oxygen measurement, and sleep tracking. The Series 9 introduces a more powerful S9 chip, ensuring smoother performance and longer battery life. It is also equipped with improved fitness tracking, including advanced workout metrics and personalized coaching. Additionally, the Apple Watch Series 9 provides robust connectivity options, such as cellular support, allowing users to stay connected even without their iPhones. The design remains sleek and customizable, with various bands and watch faces to suit individual styles [10] .

Figure 12:Picture of Apple Watch Series 9 [10]

2.1.3 Whoop 4.0

The WHOOP wearable is a tech fitness and wellness tracker created for athletes and health enthusiasts, providing a variety of functions. It constantly monitors heart rate and heart rate variability (HRV). Sleep patterns offer in depth insights into the users well being and fitness. With the WHOOP, users receive a recovery score based on sleep quality, intensity of activity and other factors to assist them in optimizing their training regimen and recovery process. Its strain coach feature offers guidance on maintaining exertion levels for peak performance while avoiding overtraining. The device also keeps tabs on rate and skin temperature to detect signs of potential illness or fatigue. Moreover, the WHOOP boasts a design for comfort and durability, along with a long battery life and automatic data synchronization, for hassle free continuous usage. The accompanying app provides analytics, personalized recommendations, and community support features to help users reach their health and fitness objectives effectively [11].

Figure 13:Picture of WHOOP watch [12]

2.1.4 Samsung's Galaxy Watch 5 Pro

The Samsung Galaxy Watch 5 Pro is a smartwatch made with a titanium case and a sapphire crystal display. It includes in-depth health tracking such as heart rate monitoring, ECG readings, and blood oxygen levels, along with sleep tracking and body composition measurements. The watch is equipped with GPS, route mapping, and various outdoor workout modes, delivering battery life and efficient performance while running Wear OS. It seamlessly connects to the Samsung ecosystem for receiving notifications, controlling home devices, and using Samsung Pay. Additionally, it offers personalized watch faces and interchangeable bands for customization [13].

Figure 14:Picture of Samsung Galaxy Watch 5 Pro [14]

2.2 Benchmarking Criteria

This section provides an overview of the main standards used to evaluate the 'Hemaya' project, which is a wristband equipped with multiple sensors that is aimed to identify fatigue in construction workers without the need for invasive methods. The benchmarking criteria cover a range of factors, such as public health, environmental effect, social and global impact, economic impact, welfare, cultural impact, and safety. Every criterion assesses the project's potential advantages and difficulties, guaranteeing a thorough evaluation of its efficacy and practicability in improving worker safety and well-being.

The 'Hemaya' project criteria emphasize the integration of advanced features to enhance worker safety.The system employs Wi-Fi and Bluetooth for smooth and uninterrupted connection, while relying on cloud storage for safe and secure data management. The device incorporates the monitoring of heart rate and SpO2 levels, together with the detection of tremors, in order to offer a thorough understanding of one's health. The device has a charging duration of 4-6 hours, ensuring minimal downtime. The device is mobile app compatible, enables IoT for improved functionality, and is compatible with various operating systems such as Apple iOS, Android, and web platforms, enabling widespread accessibility and usage.

2.2.1 Safety

Enhancing safety for construction workers is the primary objective of the ‘Hemaya’ project, which involves providing real-time fatigue monitoring. By detecting fatigue early, the wristband contributes to accident and injury prevention, thus promoting a safer working environment. Expert feedback emphasizes the crucial role of fatigue management in maintaining worker safety, further reinforcing the focus on safety. The ‘Hemaya’ wristband sets a new standard in occupational safety by showcasing the effectiveness of advanced health monitoring technologies in protecting workers.

2.2.2 Welfare

Continuous health monitoring, as implemented in the ‘Hemaya’ project, plays a crucial role in enhancing worker welfare. By actively monitoring the health of workers, this initiative aims to minimize workplace injuries and promote overall improvement in worker health. Comprehensive support for basic human needs is in line with the efforts of governments and organizations. The project aims to create a work environment that prioritizes worker safety and health, ultimately improving the overall quality of life for construction workers.

2.2.3 Public Health

The ‘Hemaya’ project aims to enhance public health by providing construction workers with a wristband that monitors vital indicators, including oxygen saturation, heart rate, and tremor. The device enhances the capability of preventing health-related issues, prolonging life, and promoting overall well-being through timely interventions by offering real-time fatigue detection. By adopting a proactive approach to health monitoring, workplace accidents and injuries can be significantly reduced, leading to a healthier workforce.

2.2.4 Social and global impact

The potential of the ‘Hemaya’ wristband to improve the health and safety of construction workers can create a significant social and global impact. Promoting a culture of proactive health management is achieved by raising awareness about the importance of health monitoring. Better working conditions and global inspiration can be achieved through the implementation of this technology. Furthermore, the importance of implementing enhanced safety measures is highlighted, urging industries across the globe to embrace more efficient health monitoring systems.

2.2.5 Cultural Impact

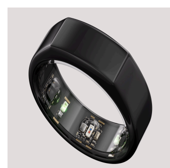
The potential of the ‘Hemaya’ Project to transform attitudes towards worker health and safety in the construction industry is significant in terms of its cultural impact. The project aims to foster a culture of safety and proactive health management by incorporating innovative health monitoring technology. These changes in culture can result in improved health practices, increased awareness, and a greater focus on safety standards, not just in Qatar but also in the construction industry worldwide. The project highlights the significance of worker health, promoting a more dedicated and compassionate approach to workplace safety.

2.2.6 Economic Impact

In terms of cost, the ‘Hemaya’ wristband offers an affordable solution for monitoring the health of construction workers. The wristband has the potential to generate significant savings in healthcare and accident-related costs by minimizing the need for frequent medical check-ups and reducing the risk of fatigue-related accidents. Long-term economic benefits can help offset the initial investment in these devices. These benefits include lower healthcare expenses and increased worker productivity. This economic advantage makes the project attractive to employers and stakeholders in the construction industry.

2.3 Benchmarking Table

Table 1 below compares our prototype to the existing solutions in the market discussed in **Section 2.1**.

Features	**Hemaya (Our product)**	**Whoop 4.0** [15-17] 	**OURA Ring Generation 3** [18-20] 	**Apple Watch Series 9** [21] 	**Samsung's Galaxy Watch 5 Pro** [22-24] 
Cost	$99.95	$239.00 + renew subscription $30/month.	$299.00	$399.00	$499.00
Wi-Fi	Yes	No	No	Yes	Yes
Cellular	No	No	No	Yes	Yes
Bluetooth	Yes	Yes	Yes	Yes	Yes
Cloud Storage	Yes	Yes	Yes	Yes	Yes
Battery Life	We don't have any information	5 Days	4-7 days	18 hours	3 days
Charging time	4-6 hours	2 hours	20-80 minutes	Up to 80% charge in about 45 minutes	2 hours
Product	Approximately	0.25 Pounds /	4 - 6 grams	39.0 grams	46.49 grams

Weight	0.301 kg	0.11 kg	(depending on ring size)		
Heart rate and SPO2 Monitor	Yes	Yes	Yes	Yes	Yes
Tremor Monitor	Yes	No	Yes	Yes	Yes
Sleep Tracking	No	Yes	Yes	Yes	Yes
Water Resistance	No	Yes	Yes	Yes	Yes
Mobile App Compatibility	Yes	Yes	Yes	Yes	Yes
IoT Support	Yes	No	Yes	Yes	Yes
Operating System Compatibility	Apple iOS, Android, website	Apple iOS, Android	Apple iOS, Android	Apple iOS	Android
Warranty	We don't have any information	1 year	1 year	1 year	1 year

Table 1: Shows the comparison of the benchmarking wearable devices.

2.4 Benchmarking Study and Analysis

2.4.1 Summary of Findings

Based on a thorough analysis of existing market solutions and different criteria, it is clear that our safety wristband offers significant advantages. Our wristband, in contrast to more common consumer goods like the Apple Watch Series 9 or OURA Ring Generation 3, is designed for the difficult conditions and demands of construction work. It guarantees immediate alerts and avoids errors brought on by fatigued workers. Additionally, our product is more cost-effective and promotes the welfare, public health, and safety of construction workers who operate in hazardous conditions. Compared to other products, our wristbands are more affordable.

Furthermore, its ability to function wirelessly by connecting to an app enhances its functionality and ensures continuous monitoring and accurate readings. The OURA Ring Generation 3 is the closest competitor in terms of features. Still, it is much more expensive (from approximately $300 up to $600) than our more affordable safety wristband (approximately $99.95).

2.4.2 Changes that will be done to Initial Project Design

Despite our best efforts to create a highly functional and efficient product, it needed certain modifications based on the equipment and tools it was to be used with. The first modification is replacing the existing 3.7-volt battery with a 6-volt rechargeable one. The 6-volt battery will improve our product's overall efficiency and reliability by offering a more steady and long-lasting power source. This modification makes the device more user-friendly and efficient by ensuring it can run for extended periods without frequently needing recharging. In addition, we will purchase a pre-made wristband rather than making a DIY one. This method will save time and money since pre-made wristbands have already been created and may be tested for comfort and durability. We can concentrate our attention on other important product features, including ensuring users receive a comfortable and high-quality wristband. Lastly, we will use the Arduino UNO R4 Wi-Fi instead of the Nano ESP32 since it is incompatible with our sensors and has limited cloud integration. Even though the Nano ESP32 was recommended as it's smaller, the Arduino UNO R4 WiFi provides strong cloud integration capabilities and compatibility with our sensors. With this modification, the development process will go more smoothly, increase data transmission efficiency, and guarantee cloud service connectivity. The Arduino UNO R4 WiFi combines the processing power and exciting new peripherals of the RA4M1 microcontroller from Renesas with the wireless connectivity power of the ESP32-S3 from Espressif. Our solution will thus be more reliable and adaptable, fulfilling the exacting requirements for modern health system functionality.

Chapter 3: Functional Modeling

3.1 Upper Level Modeling

Figure 15 illustrates the upper functional modeling diagram which outlines a system designed to monitor and evaluate fatigue levels. The prime components of the designed system consist of two sensors. The first sensor is the pulse oximeter MAX30102 which measures the heart rate and the SpO2 (blood oxygen saturation). The second sensor is the ADXL335 accelerometer which will measure the tremor levels. The sensors and the 6V rechargeable battery will be connected to the Arduino Uno R4 WiFi microcontroller to collect real-time data and upload them to the cloud for further analysis. This is where the Machine Learning part comes into play. The ML model will evaluate the data and compare it to the predetermined threshold set for each of the parameters used. If the SpO2 level was below 95% the model will indicate fatigue. In addition, for the heart rate the threshold will be calculated considering the users age. Based on the calculated threshold it will indicate if there is fatigue. Similarly with the tremor if it is detected to be between 10 to 20 Hz and amplitude then the model will flag fatigue. Furthermore, 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 mobile application for real-time fatigue monitoring. The application will provide charts, graphs and visualizations of the analysis of the fatigue levels detected. An alarm system will also be integrated with the mobile application to send an alert to immediately notify the supervisor in case of any fatigue detections.

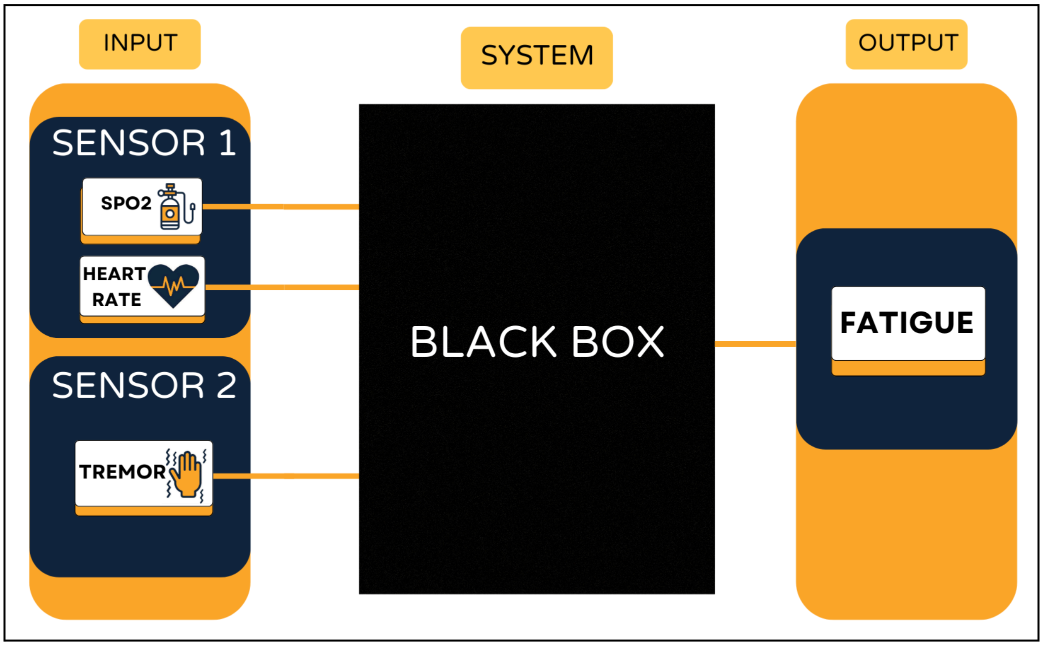


Figure 15:Upper-Level Functional Modeling Diagram

3.2 Detailed Functional Modeling

3.2.1 Full Functional Modeling Diagram

A wearable wristband-based fatigue monitoring system is shown in the diagram in **Figure 16**. First, sensors such as the ADXL335 accelerometer for tremor detection and the MAX30102 for heart rate and oxygen saturation are used. An Arduino Uno R4 WiFi gathers and transmits data to a cloud platform for processing. Before being analyzed using machine learning models against predetermined thresholds for SpO2, heart rate, and tremor levels, the data is subjected to validation, noise filtering, and standardization. Workers and supervisors are notified when weariness is identified by an app that is connected to the system. This allows for prompt intervention based on real-time health data.

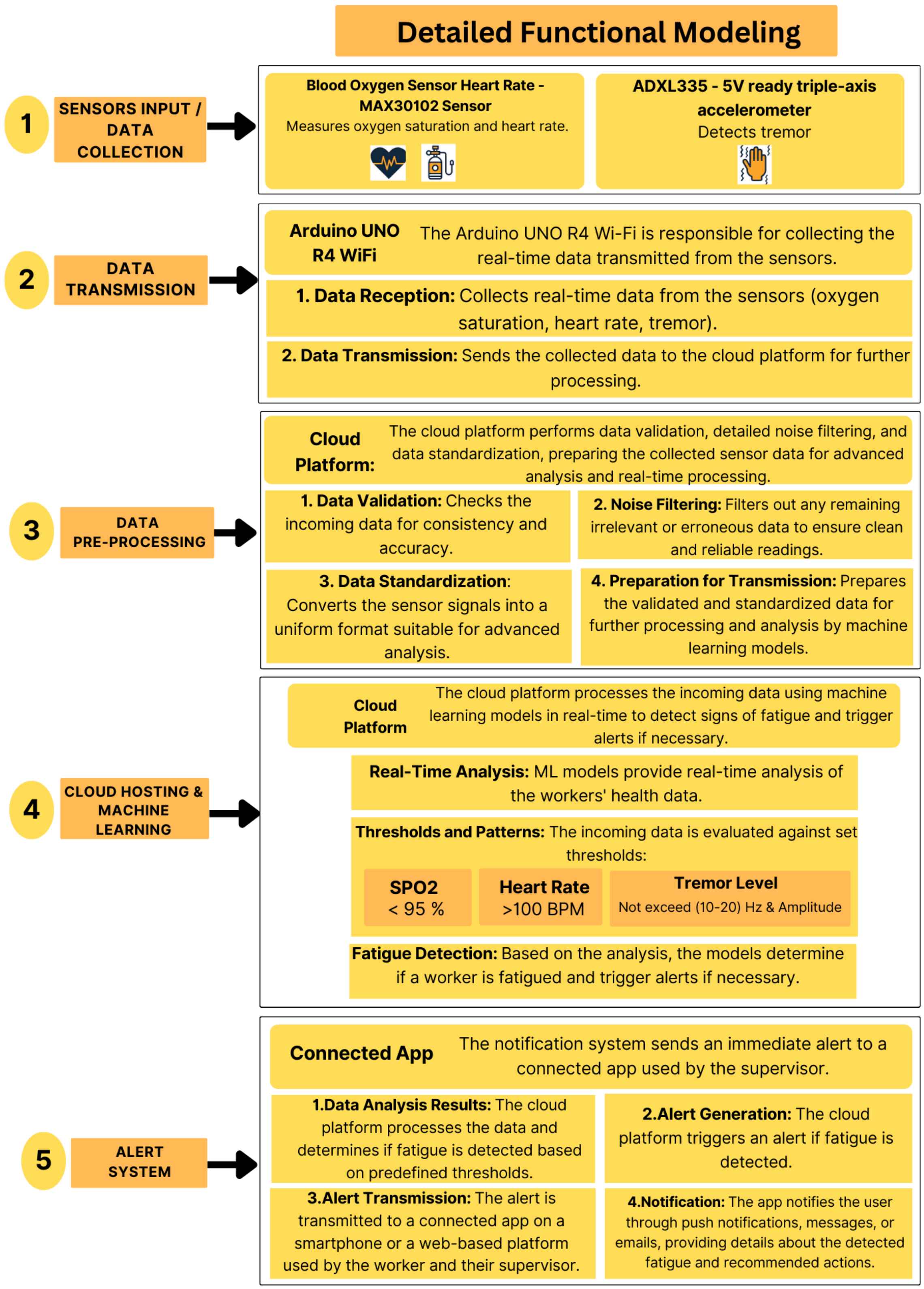


Figure 16:Functions Detailed Description

3.2.2 Function 1: Sensors Input / Data Collection

This process includes utilizing sensors to gather information from employees. The sensors referenced are the Blood Oxygen Sensor Heart Rate Click GY MAX30102 Sensor, which can measure blood oxygen saturation and heart rate, and the ADXL335. 5V ready triple-axis accelerometer, which detects tremors or involuntary movements indicating fatigue.

3.2.3 Function 2: Data Transmission

The Arduino Uno R4 WiFi microcontroller functions as the central hub for collecting data from the sensors. It acquires and organizes sensor data, converting raw readings into usable values such as oxygen saturation percentages. This preparation ensures that the data is ready for further analysis and processing.

3.2.4 Function 3: Data Pre-Processing

After gathering the data, the Cloud Platform continues pre-processing it. This includes verifying the data to confirm its reliability, preparing it to eliminate any irregularities, and removing any noise to guarantee the data's precision. This stage is essential to ensure the analysis's dependability.

3.2.5 Function 4: Cloud Hosting and Machine Learning

Within the cloud platform, machine learning models will analyze the data to detect signs of fatigue. These models will learn to recognize fatigue by examining patterns in oxygen saturation, heart rate, and tremor levels. For example, a drop in oxygen saturation below 95% may indicate fatigue in the worker. The threshold for heart rate will be calculated based on the user's age [25]. A significant increase in heart rate during strenuous activity, approaching or surpassing their age-adjusted threshold, could indicate strain and potential fatigue [26]. Additionally, tremor levels, considering both amplitude and frequency, exceeding 10-20 Hz may indicate muscle tiredness or neurological concerns [27].

3.2.6 Function 5: Alert System

The last feature is the system, which activates when the machine learning models identify fatigue using set limits. Notifications are transmitted via a linked app to both the worker and the supervisor. This quick alert enables action to avoid accidents or additional health concerns caused by fatigue.

3.3 Analysis and Evaluation of Assignment

The assignment exemplifies a thorough strategy for tackling the important problem of worker weariness in the construction sector. By emphasizing the growing need for construction workers because of worldwide improvements in engineering and design, the introduction successfully sets the scene [28]. Workers' physical and mental health have been found to suffer because of this fast-paced work environment [29]. To ensure worker safety and well-being, the introduction, therefore, emphasizes the vital need for creative methods to detect and manage tiredness.

Additionally, the introduction highlights the importance of scientific and technological concepts in engineering, not only for the purpose of planning and building buildings but also for the purpose of protecting the workers who create them [30]. The project's importance and urgency in the contemporary industrial setting are highlighted by this dual focus. The research intends to solve these urgent problems by recommending a non-invasive multi-sensor wearable wristband that can monitor vital physiological indicators in real-time, including heart rate, oxygen saturation, and tremor [31]. This proactive strategy demonstrates a careful integration of technical innovation with occupational health and safety requirements, with the goal of preventing accidents and improving the general health of construction workers.
The project's aims are in line with more general objectives to support the construction industry's transition to a safer and more productive work environment. This gives the other portions of the assignment a strong basis.

We have identified and applied the essential design changes or improvements by closely analyzing our non-invasive multi-sensor wearable wristband system after working through the functional modeling assignment. The systematic division of the execution process into primary and supplementary functions makes it easier to error-check related components together before integration. This systematic technique simplifies the development process while improving each module's dependability. Through a thorough analysis of every element, we have ensured that our design is reliable and effective. This evaluation will help us improve our prototype and finally accomplish our objective of developing a wearable wristband that effectively decreases fatigue among construction workers.

Chapter 4: System Overview

4.1 Detailed System Design

This project uses a complex mix of sensors, microcontrollers, and cloud-based machine learning algorithms to track and analyze construction worker fatigue This comprehensive system design demonstrates the potential for engineering, physics, and mathematics imagination has been used to identify, develop, and solve the challenges of complex engineering [32].

Sensor Integration

Pulse Oximeter MAX30102:

The pulse oximeter MAX30102 sensor was chosen because of its ability to monitor heart rate and SpO2 or oxygen saturation. These metrics are important markers of an employee's physical condition. Photoplethysmography (PPG) is the measurement of a sensor's

by measuring changes in light absorption due to blood flow. Light is transmitted to the skin. This information is important to identify potential indicators of fatigue given that changes in heart rate and oxygen saturation can indicate physiological stress [33] .

ADXL335 Accelerometer:

By detecting the accelerating force in three axes (X, Y, Z), the ADXL335 accelerometer is used to determine the vibration. These three-dimensional measurements are important to record subtle movements and vibrations that may indicate fatigue or stress. Data from the accelerometer are analyzed to detect characteristic oscillations and remove the noise. Signal processing techniques such as numerical modeling, filtering and Fourier transforms are used to efficiently analyze vibration data [34].

Data transmission

Microcontroller - Arduino Uno R4 WiFi:

The main focus of data collection is the Arduino Uno R4 WiFi microcontroller. It was chosen for its wireless communication capabilities, robustness and ease of use. For real-time data collection, the microcontroller communicates with the MAX30102 and ADXL335 sensors via I2C and analog inputs. The precise timing and synchronization required for integration ensures that both sensors collect accurate data. Preprocessing is done on the collected data to make it ready to be cleaned and sent to the cloud [35].

Cloud Integration and Machine Learning

Cloud Platform for Storage and Processing:

The cloud platform stores and processes the collected data. It provides the computing power and scalable storage options necessary for real-time data analysis. The Arduino Uno R4 uses secure communication channels to transfer data from Wi-Fi to the cloud. In addition, machine learning models for fatigue analysis are deployed on the cloud platform [36].

Machine Learning Algorithm:

A machine learning algorithm has been developed to evaluate sensor data in real time and detect fatigue based on predefined parameters. The labeled examples of fatigued and non-fatigued conditions are added to the historical data on which the system has been trained. The model receives information from the extracted parameters, including heart rate variability, oxygen saturation, and vibration amplitude. Methods such as logistic regression, support vector machines, and neural networks can be used according to the accuracy and robustness required. When fatigue is detected, the model immediately notifies the worker based on its continuous analysis of the incoming events and changes the worker's fatigue status detected [37].

Problem Identification and Solution

These devices solve a complex technological problem: they accurately and unobtrusively monitor the fatigue of construction workers. The combination of the ADXL335 and

MAX30102 sensors provide a wealth of motion and body information. Sophisticated real-time analytics are made possible by cloud platforms and machine learning algorithms, while Arduino Uno R4 WiFi promises efficient data collection and transfer. Fusing concepts Provides effective fatigue management solutions [38].

4.2 Technical Standards and Constraints

Technical Standard Conformity in Biomedical and Wearable Biomedical Technologies Research

Conformity with technical standards related to biomedical research and wearable technologies is ensured both for user safety and efficacy in relation to regulatory adherence. Research that involves human subjects is seriously looked into by institutional review boards to ensure that it's up to ethical standards and relates to FDA regulations. The well-being of participants will top the list when they critically review the research with a mechanism that the results thereof will also be valid [39]. The ISO 1000 sets the standards that build the base of the recommended use of the SI units and the promotion of uniformity to give clear papers in different scientific and technical publications [40]. This is to regular data collection, interpretation, and communication that will facilitate constant collaboration and innovation.

Wearable Technical Standards

It is very important that the standards set be followed to avoid risks and to make the wearable medical devices reliable and safe:

IEC 60601-1-11: This specifies essential performance and safety requirements for medical electrical equipment used in home healthcare environments, thereby protecting patients and users from diverse risks [41].

IEC 60601-6: Focuses on user-friendliness of medical electrical equipment, which in turn reduces the likelihood of user errors significantly and improves the overall user experience, which is indeed substantial in medical settings [42].

ISO 10993 guarantees the biocompatibility of all the medical devices, ensuring that they do not in any way harm or bring adverse reactions when they come into contact with the human body. This means that they should have tests for potential toxicity, irritation, and sensitization, to ensure patient safety throughout the entire course of use, as stipulated in [43].

For wearable technologies, networking and WiFi standards (IEEE 802.11) are also vital, especially for real-time data transfers and cloud-based analyses [44]. WiFi, which stands for wireless fidelity, is a critical technology in wireless local area networks for wearables. This, therefore, translates to a need for this standard for constant monitoring health data to provide interventions timely.

Barriers and Vulnerabilities of Wearable Technology

Several problems and risks of wearable technologies include:

Long Life: Wearable technologies constantly require long operational times because of constant monitoring, so their power management innovations are of key importance.

Incorrect Placement: Misplacement of sensors can distort data, so if there is a need for proper health monitoring, exact sensor placement should be carefully coordinated [45].

Resistance: This technology must be resistant to weather conditions such as moisture, dust, and large temperature gradients, especially when used outdoors [46].

Networking and Wi-Fi: For good wireless communication, reliable and secure data transmission is needed in real time for efficient cloud-based analysis. The challenge is the provision of good Wi-Fi connectivity, particularly in regions with bad network infrastructures [47].

Sample Implementation

This work combines several sensor standards and technologies to efficiently and accurately monitor fatigue among construction workers. These constructions include:

Monitoring of Heart Rate and SpO2: The MAX30102 is a pulse oximeter capable of measuring some important vital signs; thus, useful information is manufactured [48].

Vibration and Speed Measurement: The accelerometer ADXL335 reads the level of the vibration and speed, which represent signs of fatigue [49].

Sensor Data Collection and Transmission: Arduino Uno R4 WiFi microcontroller collects data in real time from the sensor and transmits the data to the cloud to analyze it. The data collected in real time is analyzed from a machine learning algorithm set to predict fatigue based on predetermined criteria. All the machine learning models, which are used in research work, are stored and run over a cloud platform that takes care of efficient data storage and its analysis [50].

Technical standards and associated constraints and risk-management techniques actually work as drivers for increased improvement in quality, safety, and reliability of improved devices within the areas of biomedical research and wearable technology. Regulatory standards assure ethics in the procedures of research; technical standards and the subsequent risk management strategies themselves contribute toward building technically robust and effective wearable medicating technologies. These efforts together drive innovation in healthcare and are at the forefront of exciting changes that are leading to better patient outcomes within an increasingly technologically integrated and advanced global community.

4.3 Relativity to ECEN Courses

During our academic journey at Texas A&M University Qatar, we have gained a comprehensive understanding of engineering knowledge and practical skills through a curriculum designed to prepare students to tackle real world problems. We completed numerous courses that aided us with the foundational knowledge and skills required to efficiently carry out our senior design project of a non-invasive multi-sensor wearable wristband for fatigue prevention. The main courses that have significantly contributed to our project are the following: ECEN 210, ECEN 214, ECEN 446, and ECEN 449.

ECEN 210 a Computer Programming and Algorithms course which introduced us to C/C++ during our sophomore year. This course focused on the fundamentals of the C language such as modular programming and functions; arrays and matrices; pointers and strings; simple data structures; searching, sorting, and numerical algorithms [51]. The project relies heavily on the C language as a base for the Arduino Integrated Development Environment (IDE) we are employing and programming the sensors to allow us to collect real-time data. In addition, ECEN 214 is a Electrical Circuit Theory course which provided us with a comprehensive understanding and covered the essential topics related to electrical circuits such as, circuit laws, network reduction, nodal analysis, and mesh analysis; energy storage elements [51]. The practical skills learned in ECEN 214 will help us design and implement circuits that seamlessly integrate and function successfully between our sensors and Arduino UNO board.

The ECEN 446 Information Theory, Inference and Learning Algorithms course provides essential concepts and techniques that are invaluable for implementing the machine learning algorithm in our safety wristband project. Specifically, knowledge gained from neural networks and support vector machines will be pivotal in developing the algorithm to assess the health status of construction workers using sensor data. Clustering methods will aid in categorizing different levels of fatigue by identifying similar patterns in oxygen saturation levels, heart rate, and tremor measurements. Maximum likelihood estimation will refine model parameters to optimize health status predictions based on collected data. Monte Carlo methods and important sampling techniques will enhance probabilistic analysis and improve model performance across diverse conditions [51]. Additionally, applying data compression strategies will be critical for efficiently managing and transmitting large volumes of sensor data to the Arduino microprocessor via wireless connectivity. By integrating these advanced machine learning and statistical inference techniques from the course, our project aims to enhance workplace safety and productivity by accurately monitoring and assessing construction workers' health status in real-time.

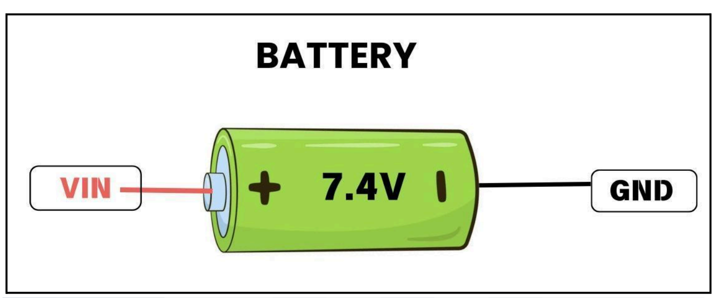
Similarly, ECEN 449 Microprocessor Systems Design course will play a crucial role in implementing key aspects of our safety wristband project, with a strong focus on integrating microprocessor and Arduino functionalities. The course's instruction on microprocessors and single board computer hardware will assist in designing an effective interface between the sensors and the Arduino microprocessor, ensuring efficient data collection from oxygen saturation levels, heart rate, and tremor sensors. Understanding chip select equations for memory board design and mastering interfacing protocols like serial and parallel I/O will streamline the integration of these sensors with the Arduino [51]. Additionally, knowledge of ROM, static and dynamic RAM circuits will be pivotal for optimizing data storage and processing capabilities on the Arduino, facilitating real-time monitoring of construction workers' health status. Proficiency in assembly language programming, gained through the course, will enable the efficient implementation of the machine-learning algorithm on the Arduino, ensuring precise assessment of fatigue levels. By applying these advanced concepts and techniques, our project aims to develop a robust safety wristband that enhances workplace safety by continuously monitoring and tracking fatigue levels among construction workers.

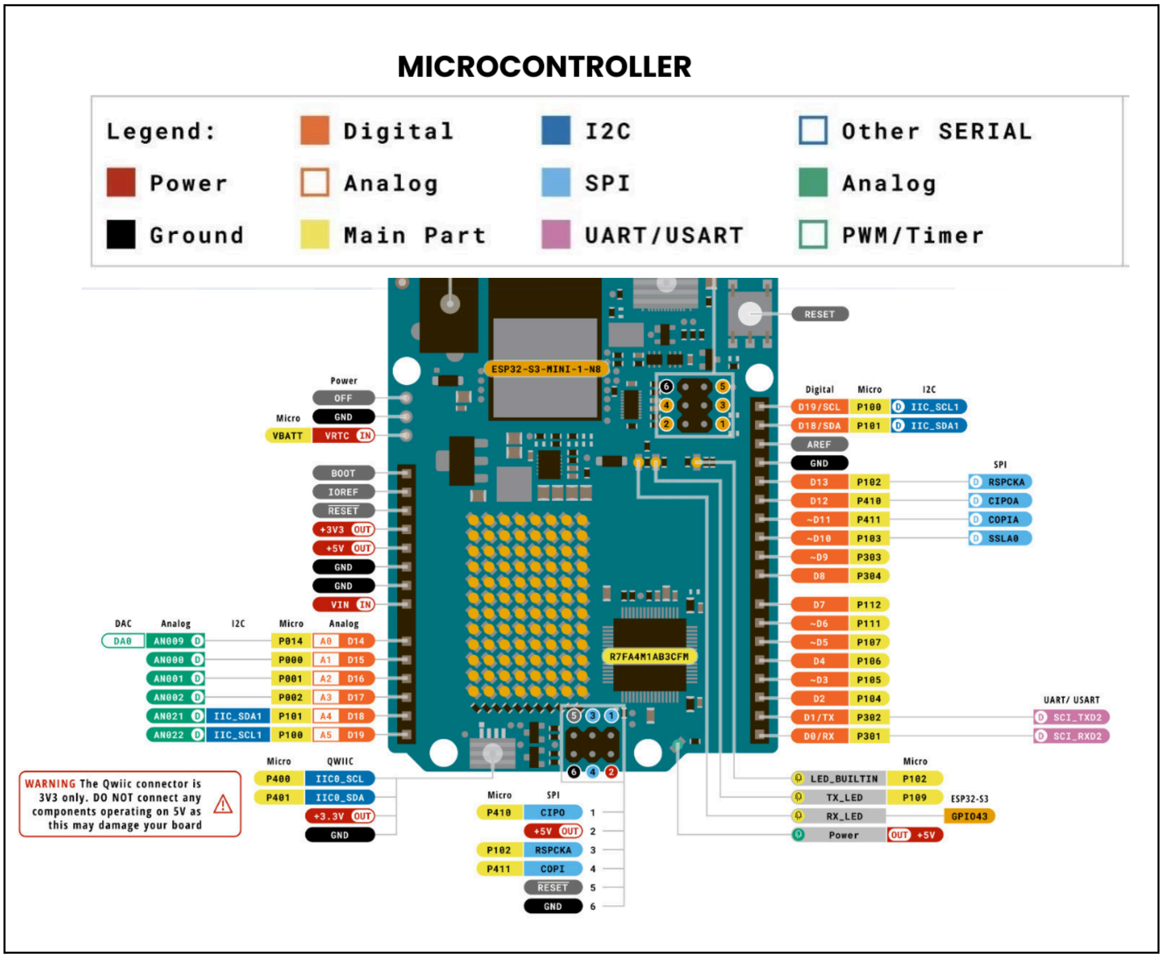
Chapter 5 : Simulation & Prototyping Analysis

5.1 Simulation ,Visual Prototyping , and Analysis

5.1.1 Hardware Setup

The following figures show the system's hardware configuration setup includes a 7.4V battery, an Arduino Uno R4 WiFi microcontroller, and two essential sensors: the MAX30102 and ADXL335. The battery provides power to the Arduino by linking its positive terminal to the Vin pin and its negative terminal to a GND pin, providing steady power distribution to the entire system. The MAX30102 sensor, utilized for monitoring SpO2 and heart rate, is interfaced with the Arduino through the I2C communication protocol, with the SDA and SCL pins on the sensor connected to the respective A4 (SDA) and A5 (SCL) pins on the Arduino. The ADXL335 accelerometer, which measures tremor levels along the x, y, and z axes, is interfaced with the analog pins A0, A1, and A2 on the Arduino corresponding to each axis. The configuration features clear labeling and a color-coded, facilitating the clear identification of each pin's function and ensuring effective data transmission from the sensors to the Arduino for processing. This structured configuration facilitates continuous monitoring and reliable data transmission to the cloud for further analysis and alert generation.





5.1.2 Analysis of Designed Circuits

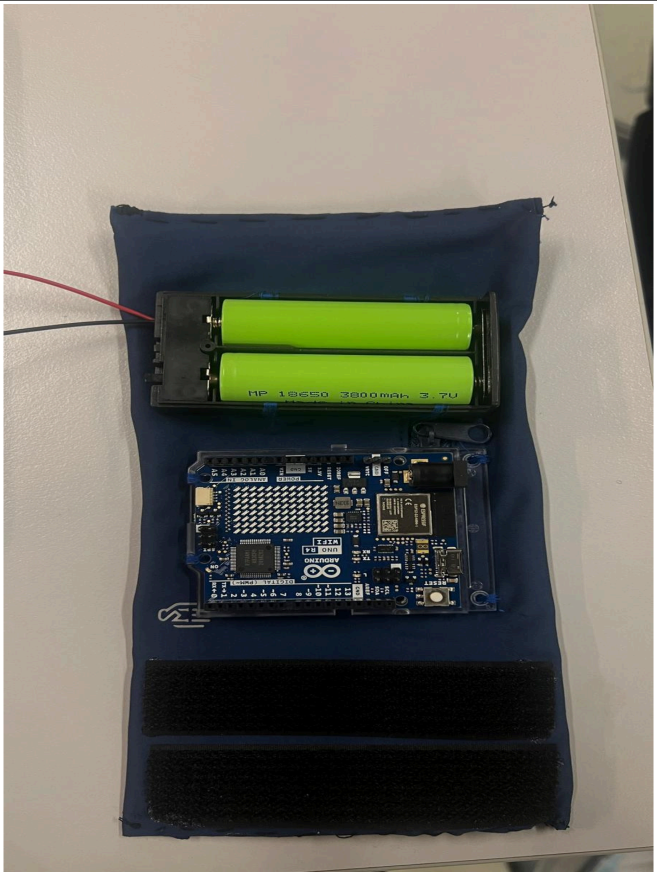
The analysis of the designed circuit centers on the interaction of components to facilitate precise fatigue monitoring. The circuit integrates the MAX30102 sensor for measuring SpO2 and heart rate alongside the ADXL335 accelerometer for detecting tremors along the x, y, and z axes. The sensors are linked to the Arduino Uno R4 WiFi microcontroller, which functions as the central processing unit. The MAX30102 communicates with the Arduino using the I2C protocol, facilitating efficient data transmission via the SDA and SCL pins, whereas the ADXL335 uses analog connections through the A0, A1, and A2 pins for each axis. The 7.4V battery provides power to the Arduino via the Vin pin, while ground connections provide stable current flow within the circuit. Uploading sensor data to the cloud facilitates real-time processing and machine learning analysis, enabling the system to precisely and rapidly detect fatigue signs. This configuration effectively integrates power efficiency and performance, making it suitable for constant monitoring in challenging construction settings.

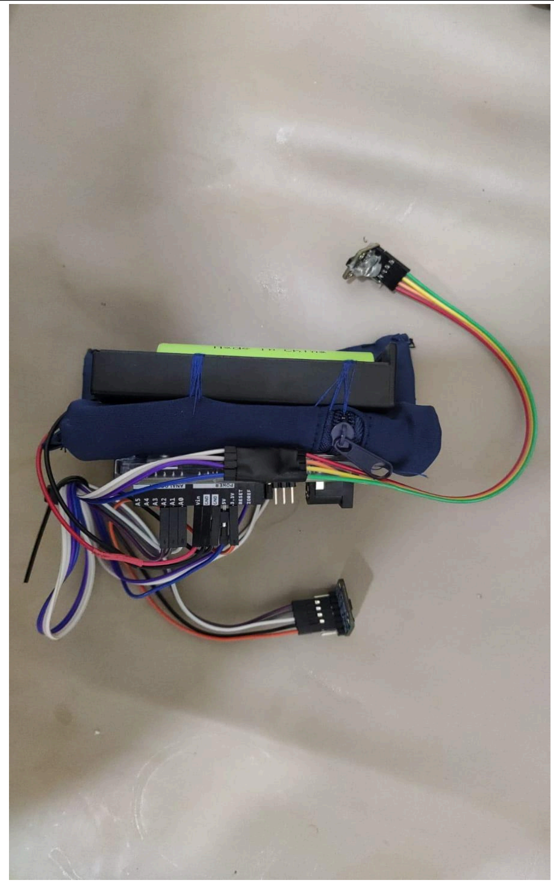
5.1.3 Visual Prototyping

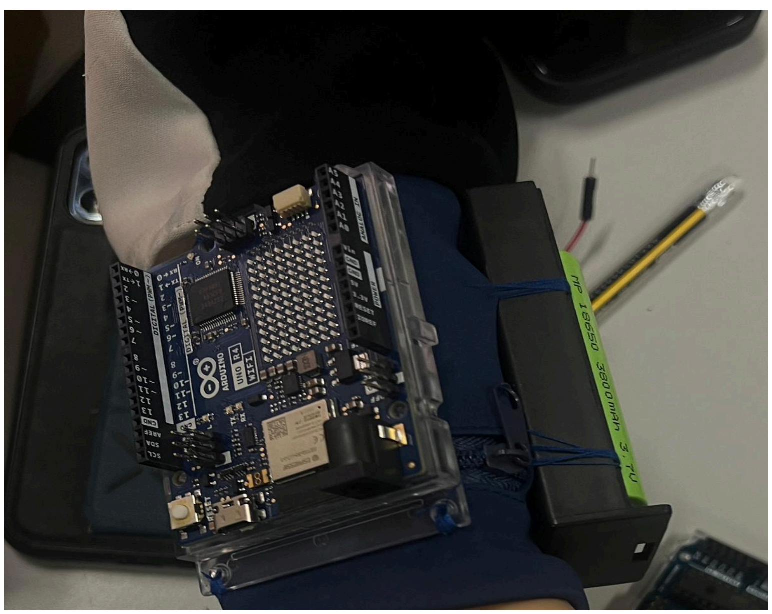
The prototype is represented in Figure X. The wristband has been meticulously designed to incorporate vital electrical components, achieving a harmonious balance between functionality and wearer comfort. The Arduino Uno R4 microcontroller, functioning as the device's central processing unit, is firmly affixed to the top of the wristband. Accompanying it is a battery pack with two cylindrical cells, guaranteeing the gadget sufficient power for real-time monitoring without the need for regular recharge. The elevated positioning of the bulkier components minimizes skin contact, hence improving comfort and facilitating a sleek appearance on the wrist's outside.

The MAX30102 and ADXL335 sensors are directly stitched into the fabric on the bottom of the wristband, with their surfaces exposed to ensure skin contact. The MAX30102 sensor is an optical device specifically designed to quantify heart rate and SpO_2, essential indicators for evaluating cardiovascular and respiratory health. Positioning it on the inside side of the wristband grants direct access to blood flow, hence enhancing the precision of its measurements. The ADXL335 accelerometer, located on the inner side, continuously observes wrist movement and identifies vibrations. This sensor is especially useful for collecting data on fatigue or involuntary muscular movement, as tremor frequency may signify physical depletion or neurological reactions.

Through the process of stitching these sensors onto the underside of the wristband, they are able to retain continuous touch with the skin, which guarantees the capture of an excellent level of data. The wearable is kept discrete, functional, and comfortable thanks to this smart arrangement, which also ensures that the necessary hardware is installed without any awkwardness. A non-invasive design is the goal of the design, which will allow users to wear the wristband for extended periods of time without experiencing any discomfort while simultaneously collecting real-time health data in an effective manner.


MP 18650 3800mAh 3.7V





5.1.4 Arduino Code for SpO2, Heart Rate, and Tremor Sensors

A specific Arduino code was built to read data from the sensors and transfer it to ThingSpeak for remote monitoring, as shown in Figures X and X. This code is designed to set up the sensors, verifying their proper connection via I2C communication, and to ensure each sensor is accurately configured for precise data collecting. The main objective of this configuration is to gather real-time data, including heart rate and SpO2 (oxygen saturation), with movement data reflecting tremors and to provide remote access to this information.

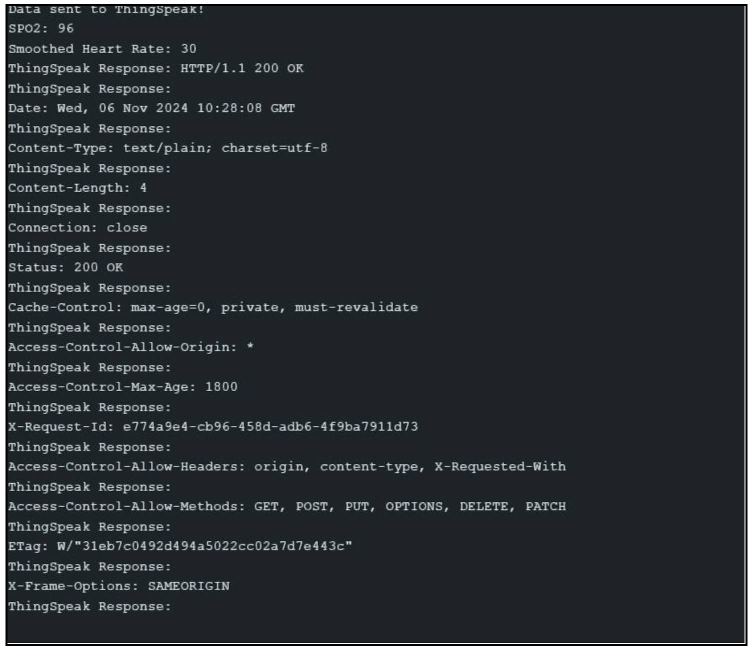
The Arduino code comprises numerous essential functions that oversee various operation components. A function is designated to establish the Wi-Fi connection by utilizing the specified SSID and password credentials to connect the device to a wireless network. This step is crucial for facilitating communication with ThingSpeak, the platform designated for data upload. Upon connection, the Arduino is capable of incessantly monitoring and transmitting data.

A separate function in the code facilitates data transmission to ThingSpeak via HTTP requests. This function formulates the request via the ThingSpeak API, incorporating the requisite Write API Key and channel details. The data is formatted and transmitted to designated fields inside the ThingSpeak channel, facilitating organized and systematic distant data storage.

Supplementary-specific capabilities are incorporated for the acquisition and documentation of data from each sensor. The MAX30105 sensor, utilized for heart rate and SpO2 measurements, is initialized and programmed to modify LED intensities for the best efficiency. It aggregates data in batches, which are analyzed to determine heart rate and SpO2 levels, assuring precision before transmission to ThingSpeak. The ADXL335 accelerometer, utilized for tremor monitoring, acquires raw data across three axes (x, y, and z). The data is analyzed to calculate the Root Mean Square (RMS) values, which offer a consistent assessment of tremor severity and frequency.

The primary loop in the code incessantly observes and gathers data from both sensors at predetermined intervals. Upon collecting and processing this data, it is transmitted to ThingSpeak, rendering it available for remote observation and study. The code is organized into separate functions for Wi-Fi connectivity, data transfer, and sensor data processing, resulting in an efficient and modular system that facilitates straightforward debugging and updates as required. This architecture guarantees dependable, real-time data acquisition and remote surveillance, rendering the wearable system an effective instrument for ongoing health and mobility monitoring. In the appendix section C, the remaining code will be displayed.

```
#include <WiFi.h>
#include <Wire.h>
#include "MAX30105.h"
#include "heartRate.h"
#include "spo2_algorithm.h"

// Wi-Fi credentials
const char* ssid = "Ibrahim Iphone";
const char* password = "12345678";

// ThingSpeak settings
unsigned long myChannelNumber = 2649311; // Your ThingSpeak Channel ID
String apiKey = "UQYE6K9L0JGBCVXY";     // Your Write API Key
const char* server = "api.thingspeak.com";
WiFiClient client;

// MAX30105 sensor object
MAX30105 particleSensor;

// Pin definitions for accelerometer
const int xInput = A0;
const int yInput = A1;
const int zInput = A2;

// Constants for tremor calculation
const int sampleSize = 10;
const int windowSize = 50;
int xWindow[windowSize];
int yWindow[windowSize];
int zWindow[windowSize];
int windowIndex = 0;

// Buffer for SpO2 and heart rate
uint32_t irBuffer[100];  // Infrared LED sensor data
uint32_t redBuffer[100]; // Red LED sensor data
int32_t spo2;            // SPO2 value
int8_t validSPO2;        // Valid SPO2 value
int32_t heartRate;       // Heart rate
int8_t validHeartRate;   // Valid heart rate

// Heart rate tracking variables
const byte RATE_SIZE = 4;
byte rates[RATE_SIZE];  // Array of heart rates
byte rateSpot = 0;
long lastBeat = 0;
float beatsPerMinute;
int beatAvg;
```



```
Data sent to ThingSpeak!
SPO2: 96
Smoothed Heart Rate: 30
ThingSpeak Response: HTTP/1.1 200 OK
ThingSpeak Response:
Date: Wed, 06 Nov 2024 10:28:08 GMT
ThingSpeak Response:
Content-Type: text/plain; charset=utf-8
ThingSpeak Response:
Content-Length: 4
ThingSpeak Response:
Connection: close
ThingSpeak Response:
Status: 200 OK
ThingSpeak Response:
Cache-Control: max-age=0, private, must-revalidate
ThingSpeak Response:
Access-Control-Allow-Origin: *
ThingSpeak Response:
Access-Control-Max-Age: 1800
ThingSpeak Response:
X-Request-Id: e774a9e4-cb96-458d-adb6-4f9ba7911d73
ThingSpeak Response:
Access-Control-Allow-Headers: origin, content-type, X-Requested-With
ThingSpeak Response:
Access-Control-Allow-Methods: GET, POST, PUT, OPTIONS, DELETE, PATCH
ThingSpeak Response:
ETag: W/"31eb7c0492d494a5022cc02a7d7e443c"
ThingSpeak Response:
X-Frame-Options: SAMEORIGIN
ThingSpeak Response:
```

5.1.5 Sensors Input and Data Collection

The Sensors Input / Data Collection section outlines the primary sensors employed in this wearable monitoring system, intended to monitor vital health metrics and identify movement anomalies. These sensors are essential for real-time monitoring of an individual's physiological condition, as they deliver continuous, comprehensive data on heart rate and SpO2, in addition to bodily movements, such as the tremor. The gathered data serves as the foundation for sophisticated analysis in subsequent phases of the system, facilitating the identification of possible indicators of exhaustion.

The initial sensor referenced is the MAX30102; this sensor uses optical methods to assess two vital health parameters: blood oxygen saturation and heart rate. Blood oxygen saturation levels indicate the efficiency of oxygen transport in the bloodstream, which is essential for detecting any respiratory problems. The heart rate data offers information into cardiovascular function, which may fluctuate with exercise level, stress, or exhaustion. Collectively, these metrics provide an extensive overview of the user's health condition and assist in detecting any abrupt alterations that may signify physical stress or exhaustion.

The second sensor in this configuration is the ADXL335 triple-axis accelerometer, a 5V-compatible device that quantifies motion along three axes (x, y, and z). This accelerometer identifies subtle movements, enabling it to perceive tremors or minor, repetitive motions in the user's body. By examining the patterns and frequency of these movements, the system can detect anomalies that may indicate Fatigue or muscular tension. For example, erratic or inconsistent movement patterns may signify the physical onset of fatigue, as the body finds it challenging to regulate movements when fatigued.

5.1.6 Machine Learning Integration for Fatigue Detection

The code depicted in Figure X is intended to enable the analysis and identification of fatigue using health data acquired from sensors, transmitted to ThingSpeak, and processed via machine learning algorithms. The main aim of this code is to facilitate real-time monitoring and fatigue detection utilizing essential parameter indicators, including blood oxygen saturation, heart rate, and tremor. The code initiates a connection with ThingSpeak and acquires a history dataset including 1500 readings, thus establishing a solid data foundation for analysis.

The preliminary phase in data processing involves clearing the dataset by eliminating rows with missing values, hence augmenting the analysis's dependability. The purified data is further divided into three different variables: SpO2, heart rate, and tremor. A critical data quality assessment is conducted to guarantee the inclusion of only legitimate readings, such as excluding SpO2 values below 89%, as exceedingly low values are deemed unreliable and may skew the results. The code subsequently calculates the average values for each indicator to establish a foundational comprehension of the historical data and evaluate its overall attributes.

To identify potential fatigue, the code employs predefined thresholds: a SpO2 level below 95%, a heart rate over 100 beats per minute , and tremor frequency between 10 and 20 Hz. The code employs K-Fold Cross-Validation, an effective technique for model assessment, to divide the historical data into training and testing sets across several folds. This technique evaluates the performance and generalizability of the Random Forest models employed for fatigue classification, with accuracies computed and averaged across all folds to determine the models' efficiency.

The machine learning segment of the code uses ensemble learning techniques, particularly Random Forests, to develop predictive models for each statistic. Random Forests are adept at this task due to their capacity to manage non-linear interactions and deliver high accuracy in classification challenges. The models are trained on normalized historical data, with binary labels denoting whether each reading resides within fatigue-inducing ranges. The code subsequently acquires real-time data from ThingSpeak, normalizes it with the same methodology as the historical data, and employs the trained models to identify indicators of fatigue. The fatigue analysis evaluates whether live SpO2 values are below the 95% threshold, heart rate readings surpass 100 bpm, and tremor frequency remains within the permitted range. The findings of this analysis are presented, indicating whether the existing data imply fatigue and providing alerts if required.

Name

Fatigue SPO2 / HR / TREMOR

MATLAB Code

```
% Define your ThingSpeak channel ID and read API key
channelID = 2649311;  % Your channel ID
readAPIKey = 'XD9591D3JH3PIZ15';  % Your Read API Key
fields = [1, 2, 3];  % Fields: SpO2 (Field 1), HeartRate (Field 2), and Tremor (Field 3)

% Retrieve the last 1500 historical readings available from ThingSpeak
[data, timestamps] = thingSpeakRead(channelID, 'Fields', fields, 'NumPoints', 1500, 'ReadKey', rea

% Check if historical data is empty
if isempty(data)
    disp('No historical data available from ThingSpeak.');
else
    % Remove rows with missing values before extracting data into separate variables
    data = rmmissing(data);  % Clean the entire dataset first

    % Now extract the data into separate variables
    SpO2_historical = data(:, 1);
    HeartRate_historical = data(:, 2);
    Tremor_historical = data(:, 3);

    % Check for valid historical data (exclude SpO2 < 89%)
    valid_idx_historical = SpO2_historical >= 89;
    SpO2_historical = SpO2_historical(valid_idx_historical);
    HeartRate_historical = HeartRate_historical(valid_idx_historical);
    Tremor_historical = Tremor_historical(valid_idx_historical);

    % Check for data contents and size
    disp(['Size of valid SpO2 (historical): ', num2str(size(SpO2_historical))]);
    disp(['Size of HeartRate (historical): ', num2str(size(HeartRate_historical))]);
    disp(['Size of Tremor (historical): ', num2str(size(Tremor_historical))]);

    % Calculate average for historical data and check for NaN
    SpO2_avg_historical = mean(SpO2_historical, 'omitnan');
    HeartRate_avg_historical = mean(HeartRate_historical, 'omitnan');
    Tremor_avg_historical = mean(Tremor_historical, 'omitnan');

    % Display the averages for historical data
    disp(['Average of SpO2 (historical): ', num2str(SpO2_avg_historical)]);
    disp(['Average of HeartRate (historical): ', num2str(HeartRate_avg_historical)]);
    disp(['Average of Tremor (historical): ', num2str(Tremor_avg_historical)]);

    % Define fatigue detection thresholds
    SpO2_threshold = 95;  % Fatigue if SpO2 < 95%
    HeartRate_threshold = 100;  % Fatigue if HeartRate > 100 bpm
    Tremor_min_threshold = 10;  % Minimum threshold for Tremor
    Tremor_max_threshold = 20;  % Maximum threshold for Tremor
```

5.1.7 Alert System (App and Cloud Integration)

The app's user interface was developed using Thunkable and integrated with Xcode migrator tools, leveraging Apple ID and Team ID configurations in Thunkable to ensure compatibility with iOS. The interface was designed to provide an intuitive and user-friendly experience, allowing users to access various functionalities seamlessly. The main features include a login screen, real-time health monitoring, calorie calculation, and data visualization.

Upon logging in, users are directed to a dashboard to monitor heart rate, SpO_2, and tremor data in real-time. The dashboard displays these metrics through easy-to-read gauges, providing a quick overview of vital signs that are essential for fatigue monitoring. Additionally, a calorie calculator tool allows users to estimate calories burned based on their heart rate, weight, age, and duration of activity. This feature helps users understand the relationship between their physical activity levels and energy expenditure.

The app also includes a data analysis section where users can view graphical representations of their SpO_2, heart rate, and tremor data over time. These graphs provide valuable insights into physiological trends and are particularly useful for identifying fatigue patterns. For ease of use, a "Download all Data" button allows users to save their data for further analysis or sharing with health professionals. Overall, the app UI is structured to support real-time monitoring, user engagement, and data accessibility, making it a comprehensive tool for tracking and managing fatigue.

5.1.8 Mechanical Structures

The mechanical design of the device prioritizes effective sensor placement to ensure accurate data collection. Proper sensor positioning is essential to capture reliable measurements for SpO_2, heart rate, and tremor, which are crucial for monitoring fatigue in real-time. Each sensor is strategically placed to optimize contact with the skin, reducing the likelihood of data interference or signal loss. This careful placement enhances the device's ability to consistently track physiological parameters accurately, even in demanding environments like construction sites.

Another key aspect of the design is its adjustable fit, which allows the device to comfortably accommodate users of different wrist sizes. An adjustable band ensures that the sensors maintain close contact with the skin, improving data accuracy and user comfort. This feature is particularly important for prolonged use, as it minimizes discomfort and enables the device to be worn securely throughout a work shift. The combination of optimal sensor placement and an adjustable fit creates a user-friendly and efficient device suited to the needs of construction workers.

5.2 Functional Prototyping:

5.2.1 Hardware and Software

During the functional prototyping phase, multiple troubleshooting steps were taken to ensure smooth hardware and software integration. One of the initial challenges was data retrieval, where the application failed to retrieve data from ThingSpeak due to an incorrect API key configuration. This issue was resolved by double-checking the ThingSpeak channel settings and updating the API keys for accurate data retrieval.

Another issue involved handling missing data, where certain sensor readings were absent, leading to errors in analysis. To address this, we implemented a data cleaning process using MATLAB's missing () function, effectively removing any missing values before analysis.

To enhance the accuracy of machine learning predictions, especially during K-Fold Cross-Validation, adjustments were made to the model parameters, and different thresholds were tested. Additionally, data normalization was applied to handle varying ranges in heart rate data, resulting in improved classification accuracy.
In terms of UI and display, the WebView component's display was misaligned, with gauges appearing too small on mobile devices. This was corrected using HTML and CSS adjustments to ensure the data was centered and the gauges were adequately sized for mobile viewing.
Lastly, real-time updates presented a challenge, as the app occasionally lagged while fetching data from ThingSpeak. To balance real-time performance with system efficiency, data-fetching intervals were optimized, and the request frequency was minimized to ensure smooth operation.

5.2.2 Testing of Sensors

The testing phase for sensors focused on validating the reliability, accuracy, and seamless integration of SpO_2, heart rate, and tremor measurements, which are essential for real-time fatigue monitoring. To achieve this, several testing goals were established.
First, we assessed the accuracy of data retrieval by verifying the app's ability to reliably pull the latest sensor data from ThingSpeak, ensuring consistent and accurate readings for key metrics such as SpO_2, heart rate, and tremor. This involved testing the retrieval of multiple data points to confirm that the data was both up-to-date and correctly displayed within the app.
Additionally, we evaluated the machine learning predictions generated by our fatigue detection model, using predefined thresholds for each metric to assess the model's effectiveness in identifying fatigue states. By running the model with both historical and live sensor data, we were able to fine-tune its predictive accuracy, ensuring that it could accurately detect fatigue indicators based on real-time data input.
The app's performance was another key focus, as we measured its responsiveness when fetching real-time data and updating the user interface, particularly the gauge displays and charts. This step was crucial for ensuring that the app could maintain smooth operation without lag, providing users with reliable, immediate feedback.
To ensure a seamless user experience, we tested the app on multiple devices, including both Android and iOS platforms, verifying that it maintained consistent performance and a user-friendly layout across all devices. Finally, cross-platform compatibility and error-handling tests were conducted to confirm that the app could appropriately handle missing data and display clear error messages when necessary. These tests confirmed that the sensor data integration was robust, laying a solid foundation for reliable real-time fatigue monitoring.

5.2.3 Troubleshooting

The Hemaya wristband is a sophisticated multi-sensor device designed to monitor vital parameters such as heart rate, oxygen saturation, and tremors. While it provides invaluable data for fatigue analysis in construction workers, like any technological product, it may encounter issues during usage. This section outlines detailed troubleshooting steps, categorized by potential problem areas, to ensure the device operates effectively.

1. Sensor Malfunction

The sensors are the core components of the Hemaya wristband, responsible for collecting physiological data. Issues here can compromise the wristband's functionality.

Potential Problems:

- Failure to detect or record heart rate, oxygen saturation, or tremors.
- Inconsistent or no readings displayed on the app.

Solutions:

1. **Calibration:**
    - o Regularly calibrate the sensors to maintain accuracy.
    - o Follow the calibration procedure in the user manual or app.
2. **Proper Placement:**
    - o Ensure the wristband is snugly fitted on the wrist. Loose contact can cause signal loss or weak readings.
    - o Avoid placing the wristband over excessively hairy or moist areas.
3. **Cleaning:**
    - o Clean the sensor surface with a lint-free cloth to remove dirt or sweat that may obstruct readings.
    - o Avoid using harsh chemicals that could damage the sensor materials.
4. **Replacement:**
    - o If the sensor consistently fails, it may need replacement. Contact support for a replacement unit or repair.

2. Connectivity Issues

Hemaya uses Bluetooth for real-time data transmission between the wristband and the accompanying app. Connectivity issues can hinder data monitoring and analysis.

Potential Problems:

- Intermittent or complete loss of Bluetooth connection.
- Difficulty pairing the wristband with the app.

Solutions:

1. **Device Compatibility:**
    - o Ensure the smartphone meets the app's minimum system requirements (e.g., Bluetooth version, operating system).
    - o Use a compatible operating system (iOS or Android) as specified in the manual.
2. **Reset Pairing:**
    - o Unpair the device and remove it from the smartphone’s Bluetooth list. Re-pair by following the app's instructions.
    - o Restart both the wristband and the smartphone to refresh the connection.
3. **Signal Range:**

   - o Keep the wristband within the Bluetooth range (usually 10 meters).
   - o Avoid barriers like walls or other electronic devices that may interfere with the signal.
4. **Firmware Updates:**
   - o Update the wristband firmware and mobile app to fix potential bugs causing disconnection.

3. Battery Drain

Powering multiple sensors and Bluetooth transmission can strain the wristband's battery, leading to shorter uptime.

Potential Problems:

- Rapid depletion of battery power.
- Wristband fails to power on due to insufficient charge.

Solutions:

1. **Power Management:**
   - o Enable power-saving modes that reduce sensor activity during idle periods.
   - o Lower the frequency of data transmission to conserve energy.
2. **Charging Protocols:**
   - o Use the original charger and cable provided with the device to ensure compatibility and efficient charging.
   - o Avoid overcharging, as it can degrade the battery over time. Disconnect when the battery reaches 100%.
3. **Usage Habits:**
   - o Turn off the wristband when not in use.
   - o Avoid leaving the wristband in extreme temperatures, as this can affect battery life.
4. **Battery Replacement:**
   - o If the battery performance does not improve, contact support for replacement. Use only authorized parts to maintain device integrity.

4. Data Inaccuracy

Accurate data collection is vital for effective fatigue analysis. Inconsistent or erroneous readings undermine the wristband's reliability.

Potential Problems:

- Abnormal spikes or drops in heart rate or oxygen saturation levels.
- Tremor measurements that deviate significantly from expected values.

Solutions:

1. **Environmental Factors:**
   - o Avoid using the wristband in areas with extreme temperatures or excessive vibrations, which can affect sensor readings.
   - o Allow the wristband to acclimate to ambient temperature before use.
2. **Recalibration:**

- o Perform regular recalibration of sensors using the app or guided instructions in the user manual.

3. **Validation:**
   - o Compare sensor readings with a verified medical device to ensure accuracy.
   - o If significant discrepancies exist, report the issue to the manufacturer.
4. **Firmware and Software Updates:**
   - o Keep the wristband firmware and app updated, as updates often include fixes for data processing errors.

5. Environmental Interference

External factors can impact the wristband's performance, especially on construction sites where dust, vibrations, and electromagnetic interference are common.

Potential Problems:

- Irregular or disrupted sensor readings.
- Physical damage to the wristband.

Solutions:

1. **Protective Measures:**
   - o Use protective covers to shield the wristband from dust and debris.
   - o Regularly clean the device to prevent build-up of dirt or grime.
2. **Temperature Management:**
   - o Avoid exposing the wristband to direct sunlight or high humidity.
   - o Operate the wristband within the recommended temperature range specified in the manual.
3. **Motion Artifacts:**
   - o Enable motion compensation algorithms in the app to reduce errors caused by excessive movement.
   - o Secure the wristband tightly to minimize shifting during physical activity.

6. App Malfunction

The app serves as the interface for viewing and analyzing data. Issues with the app can disrupt the user experience.

Potential Problems:

- App crashes during operation.
- Real-time data not displayed correctly or at all.

Solutions:

1. **Updates:**
   - o Ensure the app is updated to the latest version to benefit from performance improvements and bug fixes.
2. **Storage Management:**
   - o Clear the app's cache and unnecessary data to improve responsiveness.
   - o Ensure sufficient storage space is available on the smartphone.
3. **Reinstallation:**

4. Uninstall and reinstall the app if the issues persist. Log back in using your account credentials.

5.2.4 Experimental Results

Created at	Entry id	Spo2	HR	Tremor
2024-11-05T05:26:10+03:00	9029	99	73	4.13
2024-11-05T05:26:17+03:00	9030	99	79	4.17
2024-11-05T05:26:24+03:00	9031	100	78	4.14
2024-11-05T05:26:31+03:00	9032	100	75	4.11
2024-11-05T05:26:37+03:00	9033	100	79	4.08
2024-11-05T05:26:44+03:00	9034	99	84	4.08
2024-11-05T05:26:51+03:00	9035	99	87	4.14
2024-11-05T05:26:57+03:00	9036	99	82	4.13
2024-11-05T05:27:04+03:00	9037	98	82	4.10
2024-11-05T05:27:11+03:00	9038	99	81	4.16
2024-11-05T05:27:18+03:00	9039	96	82	4.05
2024-11-05T05:27:24+03:00	9040	99	79	4.00
2024-11-05T05:27:31+03:00	9041	100	88	4.03
2024-11-05T05:27:38+03:00	9042	100	87	4.16
2024-11-05T05:27:45+03:00	9043	89	91	4.02
2024-11-05T05:27:51+03:00	9044	99	92	4.13
2024-11-05T05:27:58+03:00	9045	100	91	4.14
2024-11-05T05:28:05+03:00	9046	99	89	4.20
2024-11-05T05:28:12+03:00	9047	0	89	4.00
2024-11-05T05:28:18+03:00	9048	89	84	4.05
2024-11-05T05:28:25+03:00	9049	98	81	4.08
2024-11-05T05:28:32+03:00	9050	63	82	4.05
2024-11-05T05:28:39+03:00	9051	99	87	4.00
2024-11-05T05:28:45+03:00	9052	98	89	4.03

Figure 24:The readings at the first run

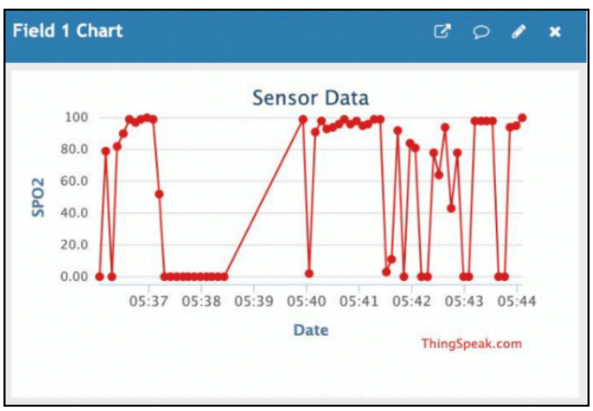


Figure 25:The graph of Spo2 output

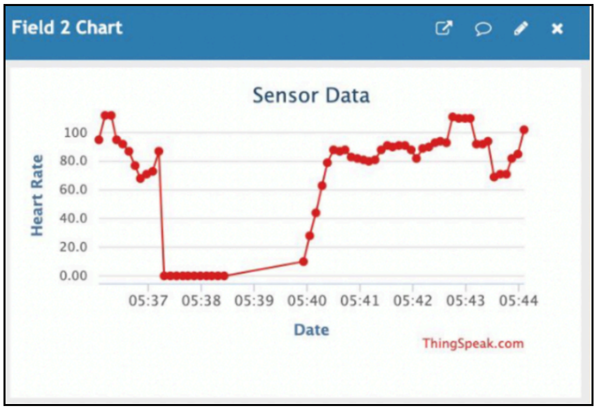


Figure 26:The graph of Heart Rate output

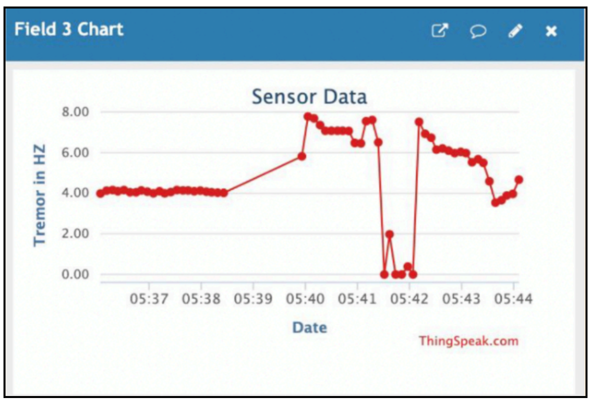


Figure 27:The graph of Tremor output

MATLAB Analysis Output

Size of valid SpO2 (historical): 100 1

Size of HeartRate (historical): 100 1

Size of Tremor (historical): 100 1

Average of SpO2 (historical): 34.4000

Average of HeartRate (historical): 45.2200

Average of Tremor (historical): 4.5052

Mean Accuracy for SpO2 (historical): 1

Mean Accuracy for HeartRate (historical): 1

Mean Accuracy for Tremor (historical): 0.99333

Live SpO2: 100 | Fatigue: 0

Live HeartRate: 102 | Fatigue: 1

Live Tremor: 4.67 | Fatigue: 0

Figure 28:The ML MATLAB analysis output

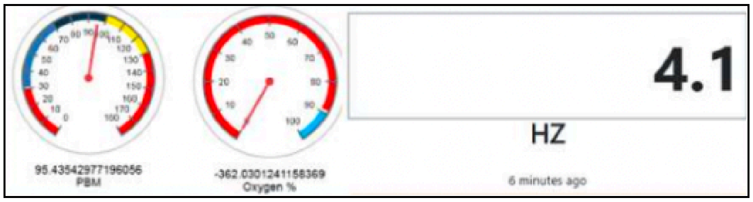


Figure 29:The output of the application platform

Chapter 6 : Discussion , Future Recommendations & Conclusion

Discussion

The Hemaya non-invasive, multi-sensor wristband represents significant progress in fatigue prevention technology. By integrating multiple sensors that monitor oxygen saturation, heart rate variability, and tremor, Hemaya provides a comprehensive tool for assessing and managing fatigue. Its real-time data collection facilitates immediate feedback, enhancing users' awareness of their physical state and enabling timely fatigue management strategies. The non-invasive nature of the wristband ensures minimal disruption to users' daily activities. Furthermore, integrating a mobile application for personalized insights and recommendations boosts user engagement and promotes healthier habits.

However, several challenges must be addressed for optimal functionality. Hemaya relies heavily on sensor precision and data interpretation algorithms for reliability. Individual physiological variations and environmental conditions can impact data accuracy. Moreover, consistent and long-term user engagement is vital for collecting meaningful data, which requires strategies to encourage users to wear the device regularly.

6.1 Discussion of Project Successes and Challenges

Innovative Technology Integration: One major success of the Hemaya project was the seamless integration of advanced sensors into a compact, non-invasive wristband. By incorporating oxygen saturation, heart rate variability, and tremor, the device provides real-time physiological data, offering valuable insights into users' health and fatigue levels.

User-Centric Design: The project prioritized user comfort and practicality, resulting in a lightweight, adjustable wristband that was well-received during testing. Participants highlighted

the comfort of wearing the device for extended periods, underscoring the effectiveness of the user-focused design.
Positive User Feedback: User testing produced encouraging results, with participants praising the device's functionality and the accompanying mobile app. Personalized recommendations and practical insights were particularly appreciated, showcasing Hemaya's potential to empower users in their health and wellness journey.
Challenges:

- Sensor Accuracy and Calibration: Maintaining the accuracy and consistency of sensor readings proved challenging due to individual physiological differences and varying environmental conditions. Regular calibration and future advancements in sensor technology will be essential for improvement.
- User Engagement: Sustaining long-term user commitment was another challenge. While initial feedback was positive, maintaining daily usage requires strategies such as gamification and incentives.
- Data Privacy Concerns: Addressing privacy concerns regarding the collection and management of sensitive health data was vital. Establishing trust through transparency and robust data security measures remains a priority.

6.2 Verification

Verification is essential for ensuring that Hemaya meets its design and operational goals. The process includes comprehensive sensor calibration, which is conducted under controlled conditions to ensure accuracy in oxygen saturation, heart rate, and tremor. Data accuracy is verified by comparing sensor outputs with gold-standard medical equipment.
Key performance indicators (KPIs) for evaluation include:

- Sensor accuracy and precision
- User feedback and satisfaction ratings
- Battery performance over time
- Frequency and severity of any adverse events during trials

The results of these verification activities will guide any necessary refinements and inform decisions for product rollout and future updates.

6.3 Future Recommendations

Enhancing Sensor Technology: Future research should focus on improving sensor accuracy and reliability, particularly in varied conditions. Collaborations with sensor manufacturers and biomedical engineers could yield significant advancements.
Algorithm Refinement: Leveraging machine learning algorithms to better analyze user data and enhance fatigue prediction models will be crucial. This can lead to more tailored and accurate recommendations.
User Education and Training: Educating users on the importance of managing fatigue and the correct use of the wristband can boost engagement. Training materials should emphasize the benefits of consistent device usage and data interpretation.

6.4 Improvements and Optimizations

Advanced Calibration Techniques: Implementing adaptive calibration methods that adjust to individual user baselines can enhance sensor accuracy. Sensor Fusion Algorithms: Developing algorithms that combine data from multiple sensors for a comprehensive analysis can improve fatigue detection. Energy Efficiency: Utilizing low-power sensors and innovative battery technology can extend battery life. Adaptive Power Management: Intelligent power-saving modes can optimize energy consumption based on user activity. Gamification Features: Adding gamification elements to the mobile app, such as challenges and rewards, can encourage consistent use. Personalized Notifications: Tailored alerts and reminders based on user behavior can increase engagement.

6.5 Conclusion

The development of the Hemaya multi-sensor wearable wristband marks a significant step forward in health technology, particularly in the prevention and management of fatigue. By combining cutting-edge sensors with an intuitive, user-centric design, Hemaya empowers users with real-time insights into their health, promoting timely interventions and supporting a proactive approach to fatigue management. User feedback during testing highlighted its potential to improve health awareness and facilitate healthier lifestyle decisions. This aligns with current trends in health technology that prioritize data-driven wellness and personalized solutions.
To maintain its competitive edge and relevance in the market, Hemaya must continuously address challenges such as sensor accuracy, user engagement, and data privacy. Iterative improvements based on user feedback, technological advances, and interdisciplinary collaboration will enhance its functionality and user experience. By focusing on these areas,

Hemaya can become a leader in wearable health solutions, offering a reliable tool that improves safety and productivity, especially in high-risk environments like construction sites.

The journey of Hemaya demonstrates a commitment to innovative problem-solving and user-focused development. With ongoing research and development, the potential of this device extends beyond fatigue management to other areas of health monitoring and prevention. By empowering users to take control of their well-being and fostering greater awareness of fatigue, Hemaya can contribute to building a healthier, more resilient society.

In summary, Hemaya showcases the transformative power of wearable technology in health monitoring. It has the potential to significantly improve quality of life by providing accessible, non-invasive monitoring that supports users in achieving better health outcomes. With strategic advancements in sensor accuracy, user engagement strategies, and data protection, Hemaya is well-positioned to make a meaningful impact in health technology.

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7. Appendix

Appendix I: Public Survey

Q1: What is your age?

ما هو عمرك؟

- Below 18

  أقل من١٨
- 18-25

  ١٨-٢٥
- 26-35

  ٢٦-٣٥
- 36-45

  ٣٦-٤٥
- 46-50

  ٤٦-٥٠
- Over 50

  اكثر من٥٠

Q2: How often are your health and safety monitored at your current job?

كم مرة يتم مراقبة صحتك وسلامتك في وظيفتك الحالية؟

- Daily

  يوميًا
- Weekly

  أسبوعيًا
- Monthly

  شهريًا
- Rarely

  نادرًا
- Never

  أبداً

Q3: How frequently do you experience fatigue during work hours?

كم مرة تشعر بالتعب أثناء ساعات العمل؟

- Always

  دائماً
- Often

  غالباً
- Sometimes

  أحياناً
- Rarely

  نادرًا
- Never

  أبداً

Q4: How significantly does fatigue affect your work performance?

ما مدى تأثير التعب على أداء عملك؟

- Extremely significant

  تاثير كبير جداً
- Significant

  له تاثير
- Moderately significant

  له تأثير إلى حد ما
- Slightly significant

  له تأثير بعض الشيء
- Not significant at all

  ليس له تأثير على الإطلاق

Q5: How aware are you of the health risks associated with fatigue among construction workers?

ما مدى وعيك بالمخاطر الصحية المرتبطة بالإرهاق بين عمال البناء؟

- Very aware

  مدرك جدا

- Somewhat aware
  واعي إلى حد ما
- Not very aware
  ليس على علم تام
- Not aware at all
  لا علم على الإطلاق

Q6: How often do you think fatigue contributes to accidents on construction sites?
كم مرة تعتقد أن الإرهاق يساهم في وقوع الحوادث في مواقع البناء؟

- Very frequently
  في كثير من الأحيان
- Occasionally
  أحياناً
- Rarely
  نادرًا
- Never
  أبداً

Q7: Would you consider using a wearable wristband that monitors vital signs to prevent accidents?
هل تفكر في استخدام سوار معصم يمكن ارتداؤه لمراقبة العلامات الحيوية لمنع وقوع الحوادث؟

- Definitely yes
  بالتأكيد نعم
- Probably yes
  ربما نعم
- Might or might not
  ربما نعم أو لا
- Probably no
  ربما لا
- Definitely no

بالتأكيد لا

Q8: Which features would you find most useful in a fatigue-monitoring wristband? Select all that apply

ما هي المميزات التي تجدها أكثر فائدة في سوار معصم مراقبة التعب؟ اختر كل ما ينطبق

- Heart rate monitoring
  مراقبة معدل ضربات القلب
- Tremor detection
  كشف الرجفة
- Oxygen saturation levels
  مستويات تشبع الأكسجين
- Real-time alerts
  تنبيهات في الوقت الحقيقي
- Daily summary reports
  تقارير ملخصة يومية
- I don't know
  لا أعرف

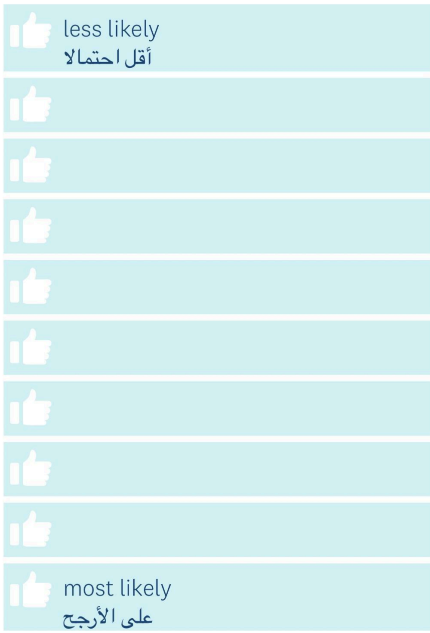
Q9: Do you think continuous monitoring of workers' health can significantly reduce accidents at construction sites?

هل تعتقد أن المراقبة المستمرة لصحة العمال يمكن أن تقلل بشكل كبير من الحوادث في مواقع البناء؟

- Yes, definitely
  نعم بالتأكيد
- Possibly
  ربما
- Unlikely
  من غير المرجح
- No, not at all
  لا، على الإطلاق

Q10: How likely are you to recommend our fatigue-monitoring wristband to other construction companies or workers?

ما مدى احتمالية أن تقترح سوار المعصم الخاص بمراقبة التعب لشركات البناء أو العمال الآخرين؟



Appendix II: Interview Questions

General Questions

1. Can you tell us a bit about your background and experience in the field of occupational health and safety, particularly related to construction workers?
2. How significant is the issue of fatigue among construction workers, and what are the common consequences if it is not properly managed?

Technical Questions

3. In your opinion, how effective are current methods and technologies for monitoring fatigue in construction workers?
4. What do you think about the use of wearable technology for health monitoring in high-risk environments like construction sites?
5. In your opinion, how important is it to monitor physiological indicators such as oxygen saturation, heart rate, and tremor in detecting fatigue?

Project-Specific Questions

6. How do you see the potential impact of a multi-sensor wearable wristband designed to detect fatigue on construction workers' safety and productivity?
7. What challenges do you foresee in implementing and adopting this kind of wearable technology in the construction industry?
8. Are there any specific features or functionalities that you believe are essential for the success of a wearable fatigue detection device for construction workers?

Future Directions

9. How do you envision the future of wearable technology in occupational health and safety, particularly for fatigue detection?

10. What further research or developments do you think are necessary to enhance the effectiveness of wearable fatigue detection systems?

Concluding Questions

11. What advice would you give for developing wearable technology for fatigue detection?

12. Are there any additional thoughts or insights you'd like to share about the importance of fatigue detection in construction workers and the role of technology in addressing this issue?

Appendix III: Tested sensor GY-MAX30102 Codes and Results

Appendix III.A: Blood oxygen level (SpO2)

Trial2_spo2.ino

```
#include <Wire.h>
#include "MAX30105.h"
#include "spo2_algorithm.h"

MAX30105 particleSensor;

#define MAX_BRIGHTNESS 255

#if defined(__AVR_ATmega328P__) || defined(__AVR_ATmega168__)
//Arduino Uno doesn't have enough SRAM to store 100 samples of IR led data and red led data in 32-bit format
//To solve this problem, 16-bit MSB of the sampled data will be truncated. Samples become 16-bit data.
uint16_t irBuffer[100]; //infrared LED sensor data
uint16_t redBuffer[100];  //red LED sensor data
#else
uint32_t irBuffer[100]; //infrared LED sensor data
uint32_t redBuffer[100];  //red LED sensor data
#endif

int32_t bufferLength; //data length
int32_t spo2; //SPO2 value
int8_t validSPO2; //indicator to show if the SPO2 calculation is valid
int32_t heartRate; //heart rate value
int8_t validHeartRate; //indicator to show if the heart rate calculation is valid

byte pulseLED = 11; //Must be on PWM pin
byte readLED = 13; //Blinks with each data read

void setup()
{
  Serial.begin(115200); // initialize serial communication at 115200 bits per second:

  pinMode(pulseLED, OUTPUT);
  pinMode(readLED, OUTPUT);

  // Initialize sensor
  if (!particleSensor.begin(Wire, I2C_SPEED_FAST)) //Use default I2C port, 400kHz speed
  {
    Serial.println(F("MAX30105 was not found. Please check wiring/power."));
    while (1);
  }

  Serial.println(F("Attach sensor to finger with rubber band. Press any key to start conversion"));
  while (Serial.available() == 0) ; //wait until user presses a key
  Serial.read();

  byte ledBrightness = 60; //Options: 0=Off to 255=50mA
```

```
  byte sampleAverage = 4; //Options: 1, 2, 4, 8, 16, 32
  byte ledMode = 2; //Options: 1 = Red only, 2 = Red + IR, 3 = Red + IR + Green
  byte sampleRate = 100; //Options: 50, 100, 200, 400, 800, 1000, 1600, 3200
  int pulseWidth = 411; //Options: 69, 118, 215, 411
  int adcRange = 4096; //Options: 2048, 4096, 8192, 16384

  particleSensor.setup(ledBrightness, sampleAverage, ledMode, sampleRate, pulseWidth, adcRange); //Configure sensor with
}

void loop()
{
  bufferLength = 100; //buffer length of 100 stores 4 seconds of samples running at 25sps

  //read the first 100 samples, and determine the signal range
  for (byte i = 0 ; i < bufferLength ; i++)
  {
    while (particleSensor.available() == false) //do we have new data?
      particleSensor.check(); //Check the sensor for new data

    redBuffer[i] = particleSensor.getRed();
    irBuffer[i] = particleSensor.getIR();
    particleSensor.nextSample(); //We're finished with this sample so move to next sample

    Serial.print(F("red="));
    Serial.print(redBuffer[i], DEC);
    Serial.print(F(", ir="));
    Serial.println(irBuffer[i], DEC);
  }

  //calculate heart rate and SpO2 after first 100 samples (first 4 seconds of samples)
  maxim_heart_rate_and_oxygen_saturation(irBuffer, bufferLength, redBuffer, &spo2, &validSPO2, &heartRate, &validHeartRa

  //Continuously taking samples from MAX30102.  Heart rate and SpO2 are calculated every 1 second
  while (1)
  {
    //dumping the first 25 sets of samples in the memory and shift the last 75 sets of samples to the top
    for (byte i = 25; i < 100; i++)
    {
      redBuffer[i - 25] = redBuffer[i];
      irBuffer[i - 25] = irBuffer[i];
    }

    //take 25 sets of samples before calculating the heart rate.
    for (byte i = 75; i < 100; i++)
    {
        while (particleSensor.available() == false) //do we have new data?
          particleSensor.check(); //Check the sensor for new data

        digitalWrite(readLED, !digitalRead(readLED)); //Blink onboard LED with every data read

        redBuffer[i] = particleSensor.getRed();
        irBuffer[i] = particleSensor.getIR();
        particleSensor.nextSample(); //We're finished with this sample so move to next sample

        //send samples and calculation result to terminal program through UART
        Serial.print(F("red="));
        Serial.print(redBuffer[i], DEC);
        Serial.print(F(", ir="));
        Serial.print(irBuffer[i], DEC);

        Serial.print(F(", HR="));
        Serial.print(heartRate, DEC);

        Serial.print(F(", HRvalid="));
        Serial.print(validHeartRate, DEC);

        Serial.print(F(", SPO2="));
        Serial.print(spo2, DEC);

        Serial.print(F(", SPO2Valid="));
        Serial.println(validSPO2, DEC);
      }

      //After gathering 25 new samples recalculate HR and SP02
      maxim_heart_rate_and_oxygen_saturation(irBuffer, bufferLength, redBuffer, &spo2, &validSPO2, &heartRate, &validHeartRate);
    }
  }
```

Figure 19: Code implemented for sensor GY-MAX30102 ((Blood oxygen level (SpO2)) [52]

```
red=62105, ir=54598, HR=66, HRvalid=1, SPO2=98, SPO2Valid=1
red=62128, ir=54577, HR=64, HRvalid=1, SPO2=98, SPO2Valid=1
red=62155, ir=54554, HR=66, HRvalid=1, SPO2=98, SPO2Valid=1
red=62164, ir=54519, HR=61, HRvalid=1, SPO2=98, SPO2Valid=1
red=62178, ir=54484, HR=63, HRvalid=1, SPO2=98, SPO2Valid=1
red=62207, ir=54448, HR=66, HRvalid=1, SPO2=98, SPO2Valid=1
red=62196, ir=54421, HR=66, HRvalid=1, SPO2=98, SPO2Valid=1
red=62217, ir=54424, HR=66, HRvalid=1, SPO2=98, SPO2Valid=1
red=62286, ir=54410, HR=66, HRvalid=1, SPO2=98, SPO2Valid=1
red=62324, ir=54374, HR=64, HRvalid=1, SPO2=98, SPO2Valid=1
red=62333, ir=54369, HR=63, HRvalid=1, SPO2=98, SPO2Valid=1
red=62411, ir=54328, HR=61, HRvalid=1, SPO2=98, SPO2Valid=1
red=62403, ir=54331, HR=66, HRvalid=1, SPO2=98, SPO2Valid=1
```

Figure 20: Result of code [52]

Appendix III.B: Heart rate (HR)

Trial1_heartrate.ino

```
#include <Wire.h>
#include "MAX30105.h"
#include "heartRate.h"

MAX30105 particleSensor;

const byte RATE_SIZE = 4; //Increase this for more averaging. 4 is good.
byte rates[RATE_SIZE]; //Array of heart rates
byte rateSpot = 0;
long lastBeat = 0; //Time at which the last beat occurred

float beatsPerMinute;
int beatAvg;

void setup() {
  Serial.begin(115200);
  Serial.println("Initializing...");

  // Initialize sensor
  if (!particleSensor.begin(Wire, I2C_SPEED_FAST)) {
    Serial.println("MAX30102 was not found. Please check wiring/power. ");
    while (1);
  }
  Serial.println("Place your index finger on the sensor with steady pressure.");

  particleSensor.setup(); //Configure sensor with default settings
  particleSensor.setPulseAmplitudeRed(0x0A); //Turn Red LED to low to indicate sensor is running
  particleSensor.setPulseAmplitudeGreen(0); //Turn off Green LED
```

```
void loop() {
  long irValue = particleSensor.getIR();

  if (checkForBeat(irValue) == true) {
    //We sensed a beat!
    long delta = millis() - lastBeat;
    lastBeat = millis();

    beatsPerMinute = 60 / (delta / 1000.0);

    if (beatsPerMinute < 255 && beatsPerMinute > 20) {
      rates[rateSpot++] = (byte)beatsPerMinute; //Store this reading in the array
      rateSpot %= RATE_SIZE; //Wrap variable

      //Take average of readings
      beatAvg = 0;
      for (byte x = 0 ; x < RATE_SIZE ; x++)
        beatAvg += rates[x];
      beatAvg /= RATE_SIZE;
    }
  }

  Serial.print("IR=");
  Serial.print(irValue);
  Serial.print(", BPM=");
  Serial.print(beatsPerMinute);
  Serial.print(", Avg BPM=");
  Serial.print(beatAvg);

  if (irValue < 50000)
    Serial.print(" No finger?");

  Serial.println();
```

Figure 21: Code implemented for sensor GY-MAX30102 (Heart Rate (HR)) [53]

```
10:43:26.174 -> IR=81940, BPM=74.91, Avg BPM=78
10:43:26.221 -> IR=81922, BPM=74.91, Avg BPM=78
10:43:26.221 -> IR=81926, BPM=74.91, Avg BPM=78
10:43:26.271 -> IR=81922, BPM=74.91, Avg BPM=78
10:43:26.271 -> IR=81955, BPM=74.91, Avg BPM=78
10:43:26.315 -> IR=81977, BPM=74.91, Avg BPM=78
10:43:26.315 -> IR=81987, BPM=74.91, Avg BPM=78
10:43:26.315 -> IR=81981, BPM=74.91, Avg BPM=78
10:43:26.363 -> IR=81987, BPM=74.91, Avg BPM=78
10:43:26.363 -> IR=81992, BPM=74.91, Avg BPM=78
10:43:26.409 -> IR=82002, BPM=74.91, Avg BPM=78
10:43:26.409 -> IR=82021, BPM=74.91, Avg BPM=78
10:43:26.456 -> IR=82039, BPM=74.91, Avg BPM=78
10:43:26.456 -> IR=82068, BPM=74.91, Avg BPM=78
```

Figure 22: Result of code [53]