ECEN 403

Electrical Design Laboratory - Summer 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."

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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:

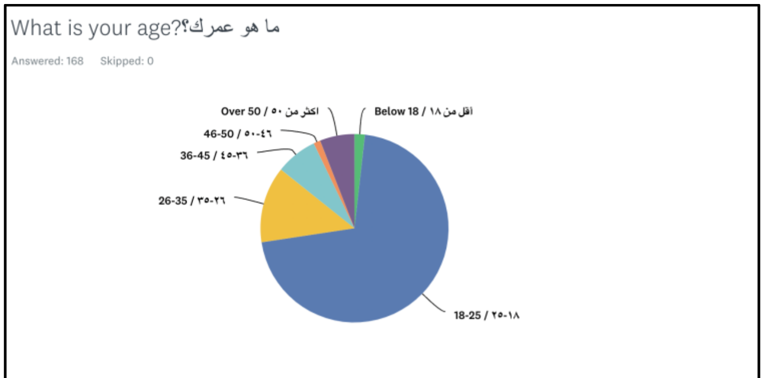
One University Interviews: Conducted with professors specializing in occupational health and safety, these interviews provided academic perspectives and insights into current research trends and technological advancements.

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 / ٢٥-١٨	70.83%	119
26-35 / ٣٥-٢٦	13.10%	22
36-45 / ٤٥-٣٦	7.14%	12
46-50 / ٥٠-٤٦	1.19%	2
Over 50 / اكثر من ٥٠	5.95%	10
TOTAL		168

Figure 1: Pie chart of participant age distribution.

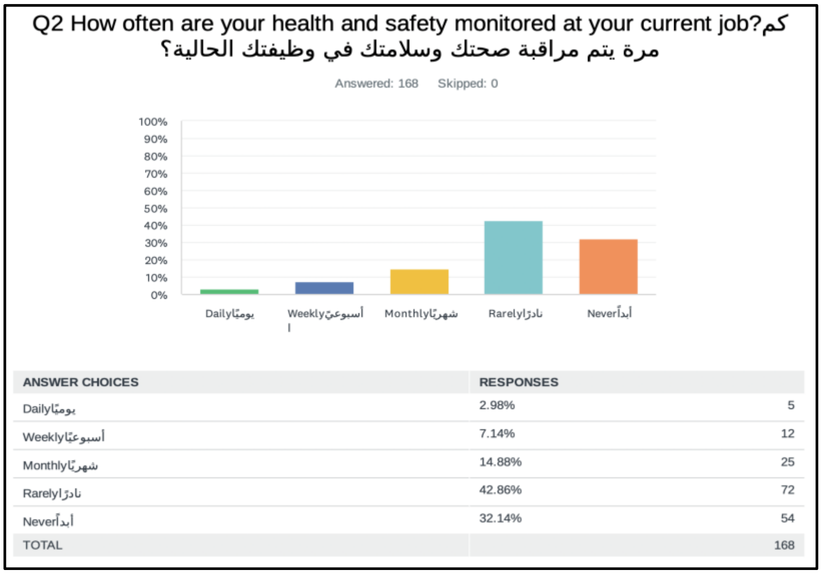
The survey's age group distribution indicates that young adults are overwhelmingly represented, with the 18–25 age group accounting for the greatest percentage of respondents (70.83%). This implies that a younger population was drawn to the poll, which may have been due to the survey's popularity among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



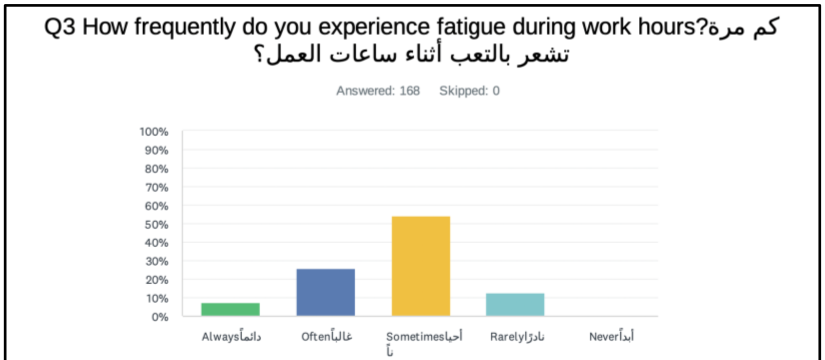
ANSWER CHOICES	RESPONSES	
Dailyيوميًا	2.98%	5
Weeklyأسبوعيًا	7.14%	12
Monthlyشهريًا	14.88%	25
Rarelyنادرًا	42.86%	72
Neverأبدًا	32.14%	54
TOTAL		168

Figure 2: Bar chart 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
Rarelyنادراً	12.50%	21
Neverأبداً	0.60%	1
TOTAL		168

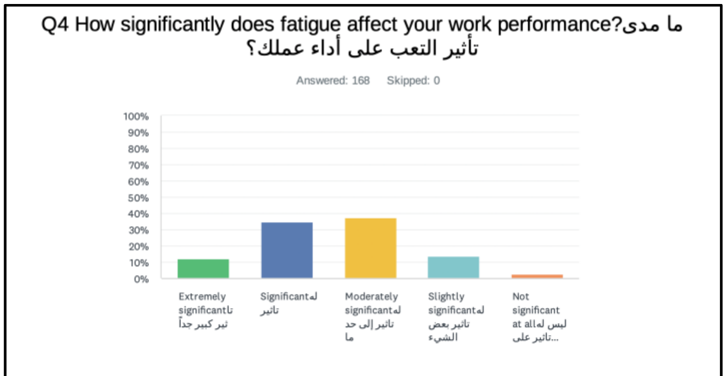
Figure 3: Bar chart of experiencing fatigue during working hours

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?



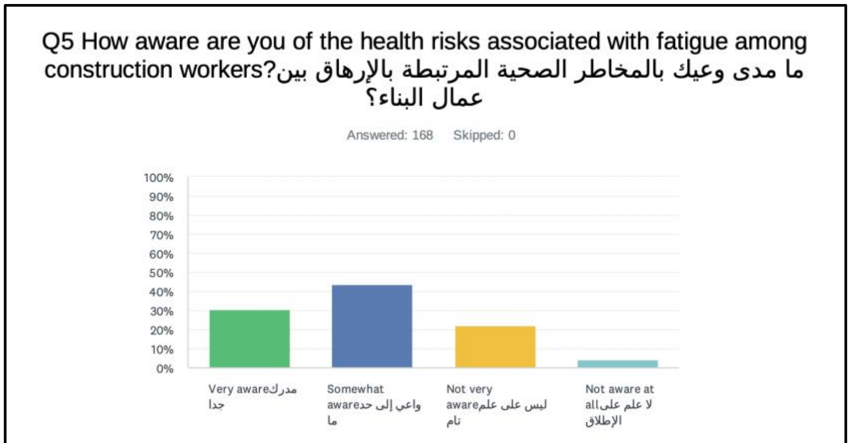
ANSWER CHOICES	RESPONSES	
Extremely significantتاثير كبير جداً	11.90%	20
Significantله تاثير	34.52%	58
Moderately significantله تاثير إلى حد ما	37.50%	63
Slightly significantله تاثير بعض الشيء	13.69%	23
Not significant at allليس له تاثير على الإطلاق	2.38%	4
TOTAL		168

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.

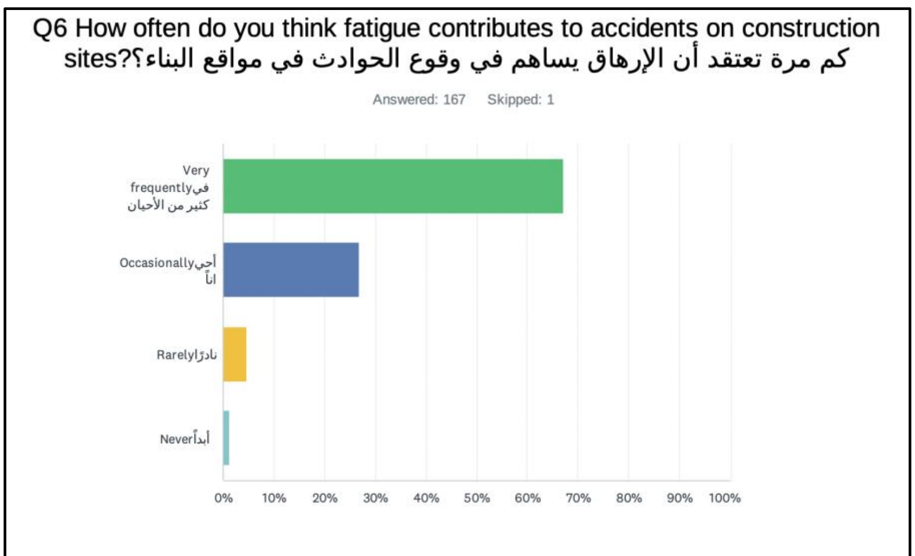
Survey responses also indicated that there is a strong belief that wristbands with multiple sensors can significantly improve safety and productivity among construction workers. Most people emphasized that monitoring vital signs such as heart rate, oxygen saturation, and vibration provides early warning 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.

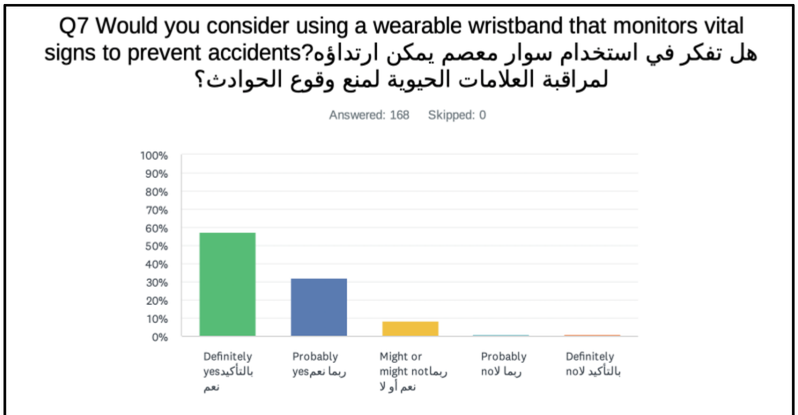


ANSWER CHOICES	RESPONSES	
Very frequentlyفي كثير من الأحيان	67.07%	112
Occasionallyأحياناً	26.95%	45
Rarelyنادراً	4.79%	8
Neverأبداً	1.20%	2
TOTAL		167

Figure 6: Bar chart 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?

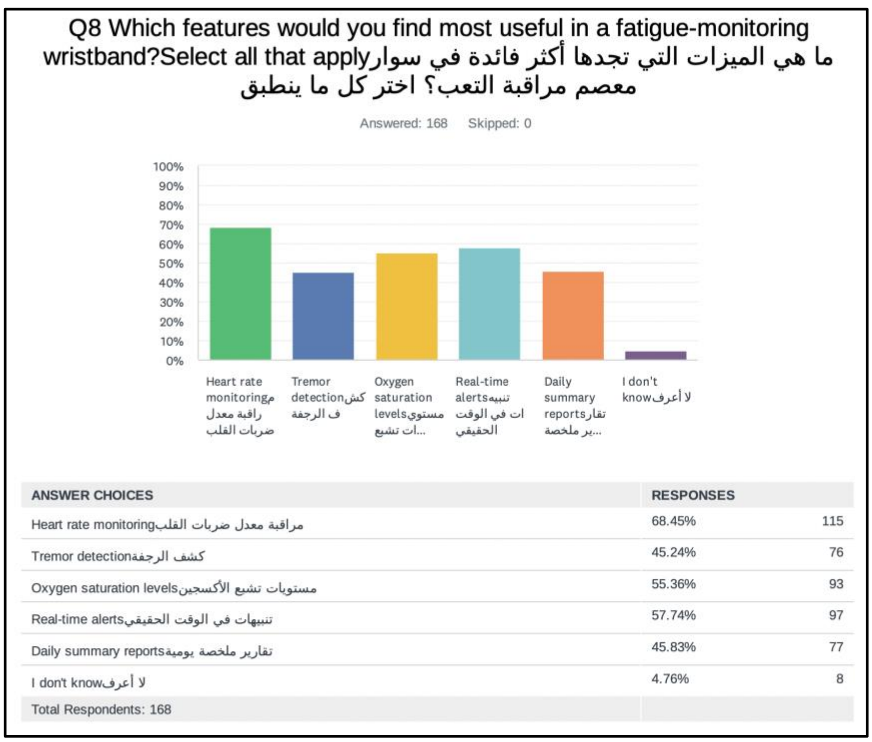


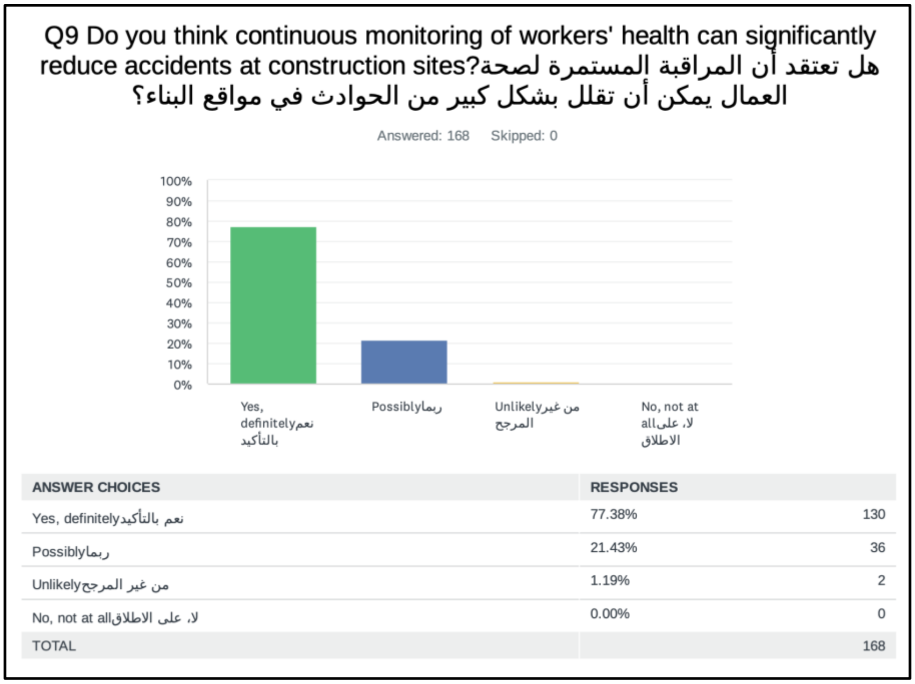
Figure 8: Bar chart of most useful features in a fatigue-monitored wristband

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?

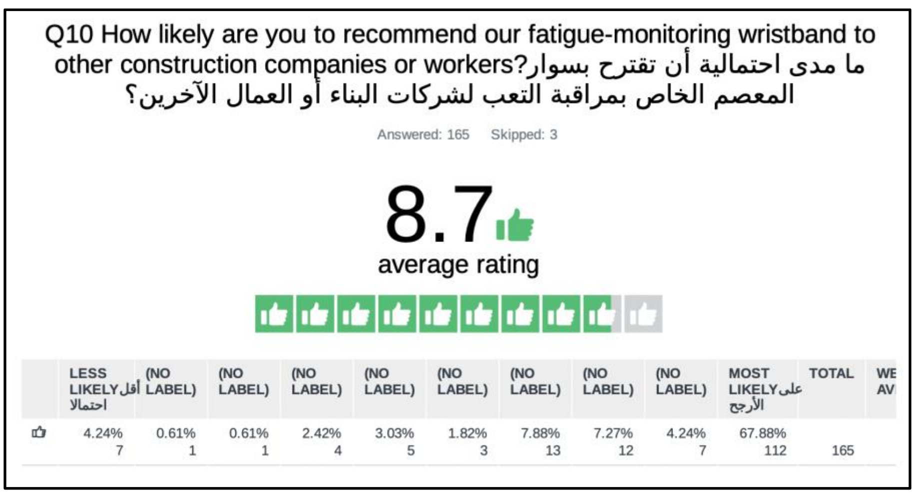
The survey results indicate a strong consensus among respondents on the effectiveness of continuous health monitoring in reducing accidents at construction sites. Out of 168 respondents, a significant majority of 77.38% firmly believe that such monitoring can indeed significantly decrease the occurrence 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 LIKELYأقل احتمالا	(NO LABEL)	(NO LABEL)	(NO LABEL)	(NO LABEL)	(NO LABEL)	(NO LABEL)	(NO LABEL)	(NO LABEL)	MOST LIKELYعلى 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: Picture of Oura Ring Generation 3 [9]

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 Weight	Approximately 0.301 kg	0.25 Pounds / 0.11 kg	4 - 6 grams (depending on ring size)	39.0 grams	46.49 grams
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.

2.2 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 user's 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.

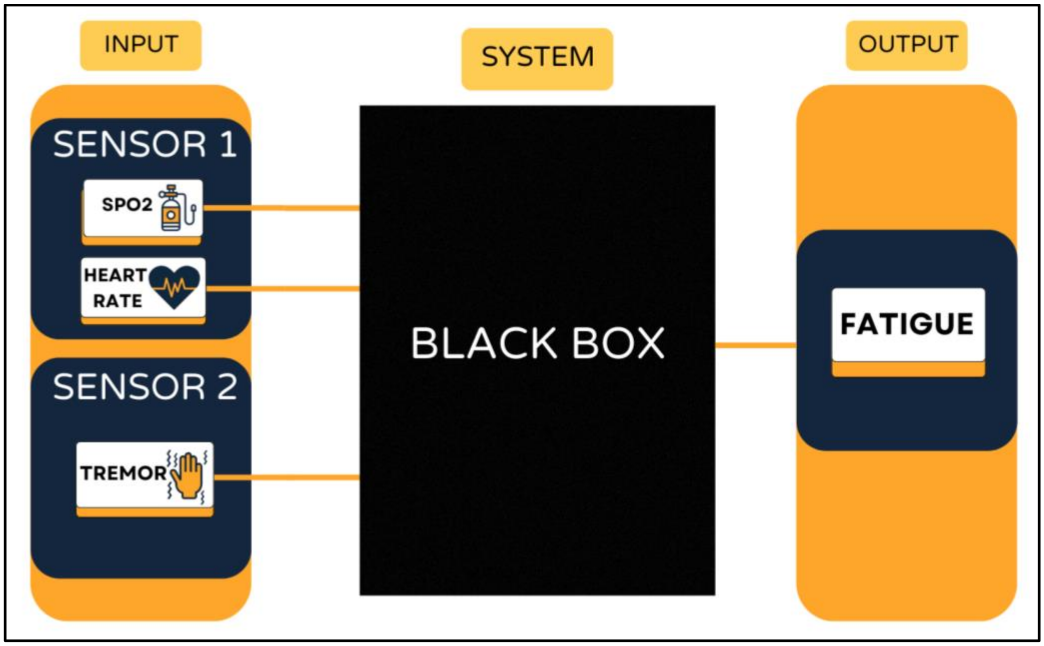


Figure 15 : Upper-Level Functional Modeling Diagram

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.

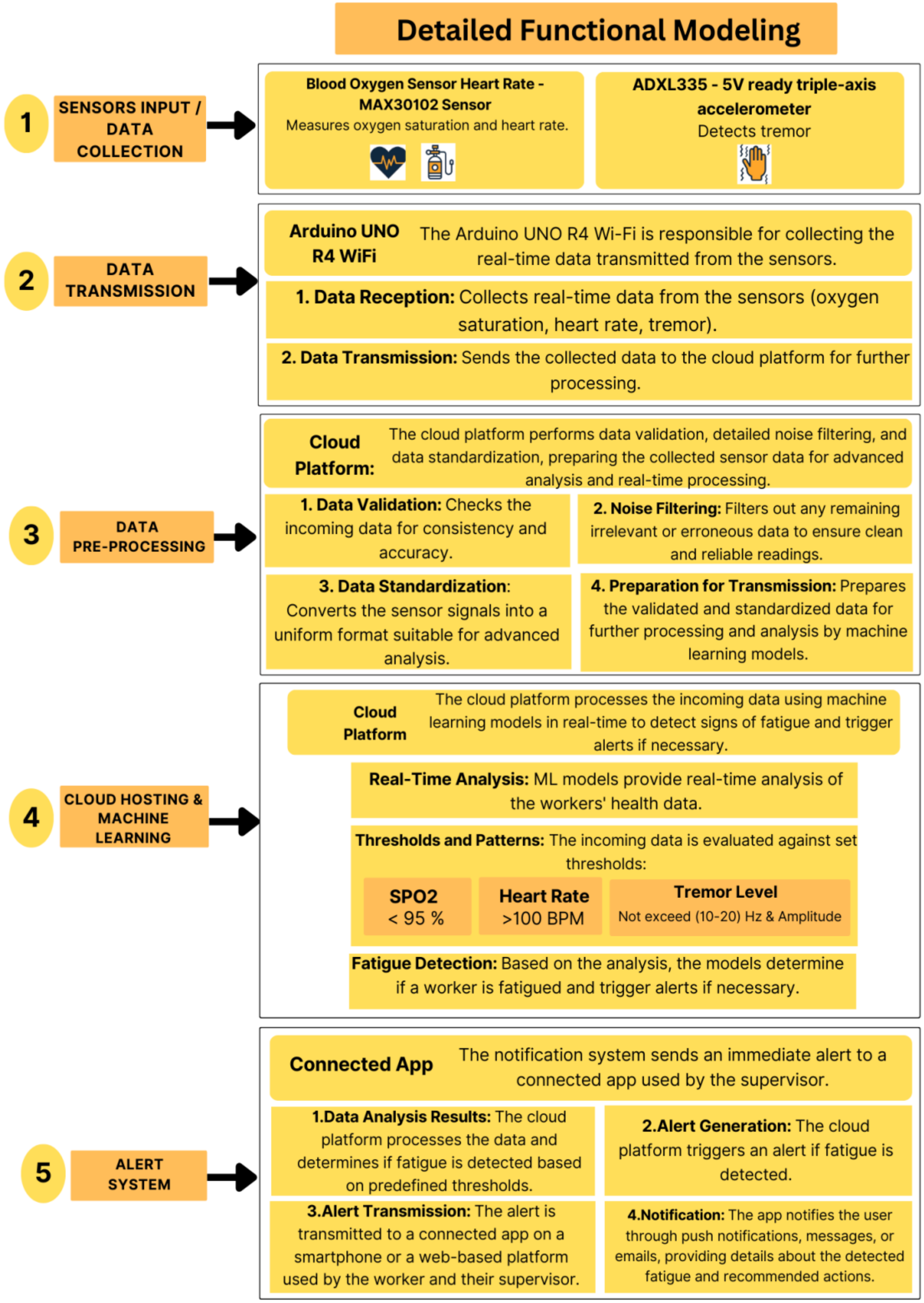


Figure 16: Functions Detailed Description

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 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: Timeline and Conclusion

5.1 Progress Timeline

Task Completed	Senior Project Timeline Chart						
Task in Progress	Hemaya: Non-invasive multi-sensor wearable wristband for fatigue prevention						
Task Remaining	May		June			July	
Weeks	3	4	1	2	4	1	2
Tasks							
Project Proposal							
Team Agreement							
Project Website							
Customer Needs Study							
Project Video							
Benchmarking							
Functional Modelling							
Re-submission of Proposal/ Customer Needs							
Re-submission of Benchmarking/ Functional Modeling							
Project Progress							
Final Presentation							
Final Report							

Figure 17: Progress Timeline of ECEN 403

5.2 Future Timeline

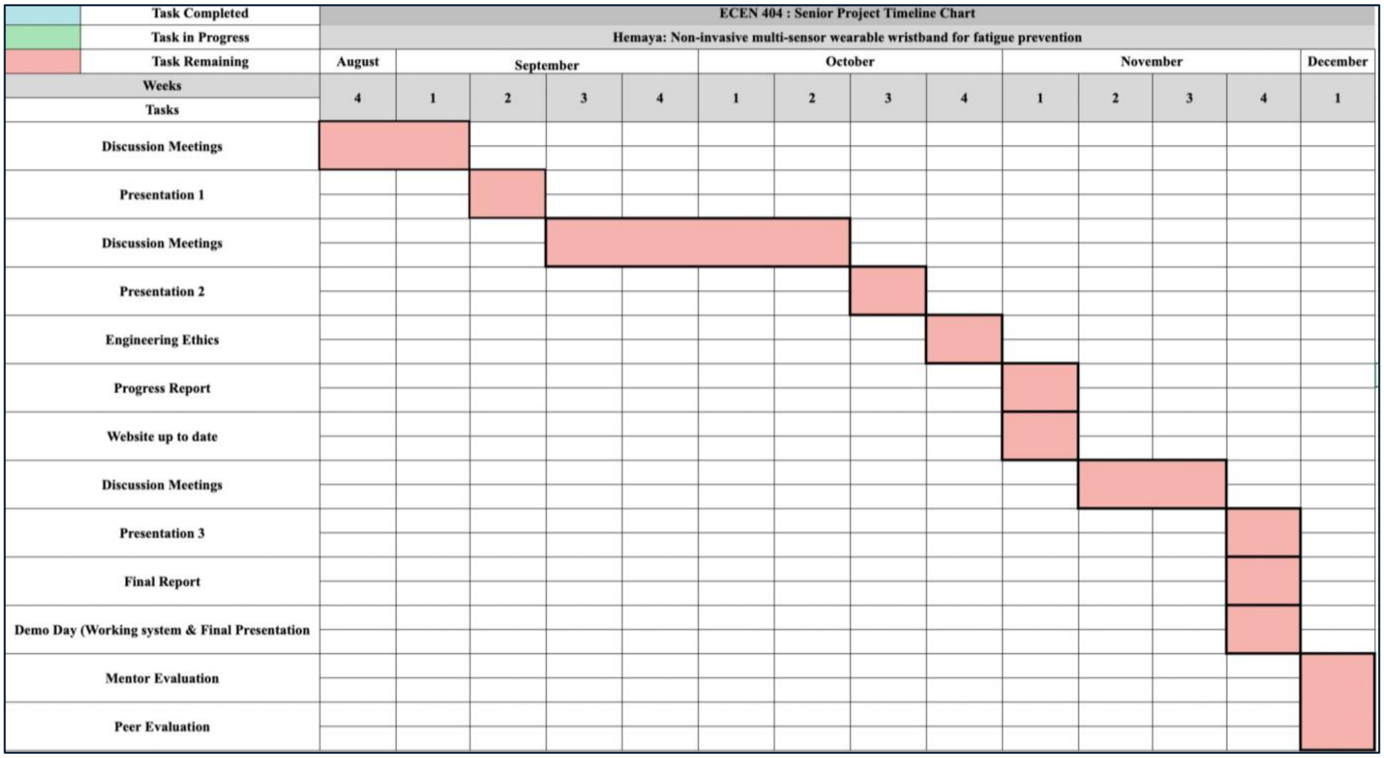


Figure 18: Future Timeline of ECEN 404

5.3 Conclusion

Our project aimed at enhancing safety and well-being among construction workers by developing a non-invasive multi-sensor wearable device, the Hemaya Wristband, designed to prevent fatigue. Our approach included several key activities.

Firstly, a comprehensive literature review was performed to understand the state of wearable technologies for health monitoring, particularly with respect to fatigue detection. This review highlighted the strengths and weaknesses of existing methodologies, which guided our design process. Next, we conducted a customer needs assessment by surveying and interviewing our target users. Surveys were administered to the general public and professionals in the field, while interviews provided expert perspectives. This approach was crucial in identifying and understanding the specific needs and preferences of our target users.

We also conducted benchmarking by evaluating existing solutions like the OURA Ring Generation 3, Apple Watch Series 9, Whoop 4.0, and Samsung's Galaxy Watch 5 Pro. This exercise allowed us to weigh the features, strengths, and limitations of these products against our own, ensuring the uniqueness and value of the Hemaya

Wristband's advantages. Elaborate functional models were then developed to detail how the system would work, from the input from the sensors to data processing and alert generation. Diagrams and flowcharts were created to describe the interaction of different components of the wristband and the major activities involved in data processing.

In the system design phase, our group designed the system architecture for the Hemaya Wristband, integrating a sensor, microcontroller, and a cloud-based machine-learning algorithm. Technical standards and probable restrictions were considered to achieve a reliable and robust device design. Prototyping and testing were also key components of our project. Multiple prototypes of the Hemaya Wristband were designed and tested under real-world conditions. This process included iterative improvements based on feedback to enhance accuracy, usability, and reliability.

With these efforts in place, we have developed a system that ensures the effective monitoring and prevention of fatigue hazards among construction workers. The project contributes positively to promoting health and well-being at work, aligning with the greater good.

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7. Appendix

Appendix I: Public Survey

Q1: What is your age?

ما هو عمرك؟

- Below 18

  أقل من ١٨

- 18-25

  ١٨-٢٥

- 26-35

  ٢٦-٣٥

- 36-45

  ٣٦-٤٥

- 46-50

  ٤٦-٥٠

- Over 50

  اكثر من ٥٠

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

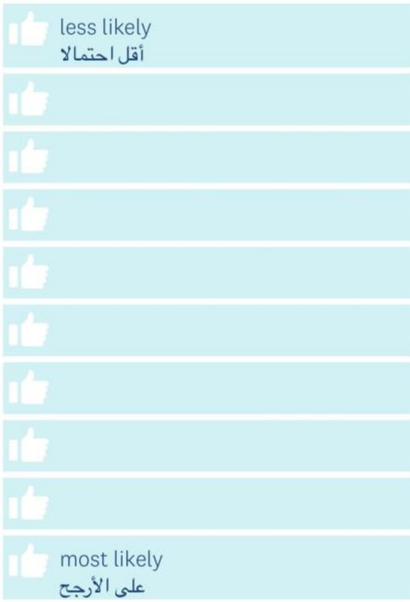
- Heart rate monitoring
  مراقبة معدل ضربات القلب
- Tremor detection
  كشف الرجفة
- Oxygen saturation levels
  مستويات تشبع الأكسجين
- Real-time alerts
  تنبيهات في الوقت الحقيقي
- Daily summary reports
  تقارير ملخصة يومية
- I don't know
  لا أعرف

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]