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Smart Helmet: An AI-Powered Safety Monitoring System for Drivers

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Executive Summary

Road traffic crashes kill 1.19 million people each year. Motorcyclists face the highest risk. In the UAE, motorcycle crashes continue to cause deaths and injuries despite safety programs. Most helmets provide passive protection only. Fatigue, distraction, and unsafe maneuvers drive a large share of incidents.

This project delivers an AI Smart Helmet attachment that prevents crashes, not only protects them. The system monitors rider state and motion in real time, then issues timely alerts and logs events for review.

The Smart Helmet integrates an inward IR camera, EEG, and an IMU. On-device AI tracks eyelids and facial landmarks to compute PERCLOS, blink rate, EAR, gaze, and head pose. Thresholds near 8 to 12 percent PERCLOS trigger drowsiness alerts. IMU spikes highlight harsh maneuvers or impact. A circular video buffer stores 10 to 20 seconds around events. A cloud dashboard shows alerts, clips, driver scores, and trends. Data handling follows UAE PDPL with consent, minimization, and retention control.

Overview

Target market and their needs:

Today there are many solutions in the market that provide drivers safety including many products. LIVALL smart helmets are designed for cyclists that offer fall detection, and SOS alerts. They also have LED lights for visibility; however, it lacks protection at high speeds and has battery issues. Lytx provides active video solutions with accurate fatigue detection. They provide cloud dashboards, but their solution is costly and raises privacy concerns while not being suitable for motorcyclists. SmartCap uses EEG brainwave sensors to detect fatigue, they give real-time alerts and Analysis for risky sectors like mining, but its high cost, bulky, and have many ethical concerns. Each focusing on different aspects of road safety.

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1 Introduction

Worldwide, road traffic collisions pose a global public health issue, whereover 1.19 million people die because of it and other millions suffer with long-term injury (WHO, 2023). Of all road users, the most vulnerable drivers are motorcyclists as they have limited protection and are highly exposed to risks. Motorcycle-related crashes in the UAE contribute substantially to traffic deaths and injuries, despite the national safety programs (Tesorero, 2025)

Current technologies, such as wearable devices, smart helmets, and monitoring systems powered by AI, are designed to boost the driver's safety such as detecting fatigue, enabling quick emergency support and increase visibility, unfortunately most of current helmets gives only a passive protection. Crucially, these helmets fail to find the main causes such as drivers' exhaustion or distraction.

1.1 Problem Statement and Purpose

There is a clear demand to have a proactive safety solution that actively prevents riders and protects riders from getting into an accident. The AI powered Smart Helmet, integrated with advanced sensors, is the proposed mechanism that can fill this gap and monitor the driver's behavior, by detecting warning signs of a risk and having real time alerts to reduce injuries and fatalities.

The primary goal of this project is to construct an AI powered helmet that can monitor drivers' behavior continuously, in case of having any signs of unsafe driving or fatigues, by providing real time alerts that help prevent accidents. The systems purpose is to establish a proactive, data driven mechanism by combining machine learning models with embedded sensors and computer vision technology

1.2 Project and Design Objectives

The aim of the Smart Helmet project is to engineer and build a system that can identify a driver's distraction, fatigue, and unsafe way of driving in real time.

Key objectives include:

- **Multi sensor integration:** (EEG, camera modules, eye blink and IMU) to accurately capture driver movement and state.
- **Real time detection:** Building AI models such CNN/RNN to detect distraction and fatigue with low latency (<200ms).
- **Cloud based Monitoring platform:** It's a dashboard that is used for alerts visualization, record driver events and calculate performance scores of a driver.

- **Privacy Assurance:** Ensure compliance for minimal retention and data privacy that follows UAE PDPL.
- **Operational efficiency:** Optimize power efficiency of the prototype to enable it to work continuously for at least 8 hours.

1.3 Intended Outcomes and Deliverables

The principal results of this project will be the functionality of the Smart Helmet prototype and a verified Proof of concept (POC). The integration of the system is made up an embedded software, sensor-based design and a cloud-based platform that facilitate immediate driver monitoring and collision prevention.

The principal outcomes:

- To develop a Smart helmet prototype that is functional and is able to recognize fatigue, distraction and crash events.
- To create an Embedded Software able to acquire data and process from camera models, EEG and IMU.
- Deploy a fully developed cloud based platform for data storage, perfomance monitoring of drivers and real time visualization of driver status.
- To complete testing results and documentation, validating system's accuracy, reliability and its compliance with data privacy standards of the UAE.

1.4 Motivations

The core motivation of this project is the increasing number of road collisions and deaths that are linked to unsafe behavior done by drivers such as distraction and fatigue. Based on the global and local statistics, such cases keep causing significant deaths, injuries and economic losses throughout the year.

The counter this problem, the Smart Helmet sets a goal to address this issue by integrating AI algorithms and advanced sensors to identify the earliest warning alert of inattention or fatigue. This approach focuses on prevention rather than reaction, as the systems focus is not only on the driver but all other road users. A motivation that strongly aligns with UAE's commitment on leveraging AI technologies, to improve public wellbeing and road safety, in line with UAE vision 2031.

1.5 Summary of Report Structure

This report is organized into several chapters:

- **Chapter 1 – Introduction:** Explains the project's aims, problem statement, intended goals/outcomes, and motivations.
- **Chapter 2 – Background and Literature Review:** Provides an overview of local and global accident statistics, showcases current smart safety solutions, and used technologies in fatigue detection.

- **Chapter 3 – Preliminary Design:** Describes system functional and non-functional requirements, design, and architecture models, in addition to software and hardware components, communication interfaces, and development platforms for cloud integration such as **FreeRTOS** and **REST Python API.**
- **Chapter 4 – Ethical, Economic, and Environmental Analysis:** Covers estimated costs, code of ethics framework in the UAE, consider environmental effects, and how the project is relevant to UAE and the region.
- **Chapter 5 – Project Plan:** Outlines project management, such as team organization, schedule, project plan and Work Breakdown Structure (WBS). It includes timeliness, Gantt chart and system Design.
- **Chapter 6 – Implementation and Testing:** Introduce specific details of the hardware–software integration, used validation strategy, and results obtained.
- **Chapter 7 – Conclusion:** Highlights the outcomes, limitations, and future improvements of the Smart Helmet.

2 Background and Literature Review

2.1 Relevant literature search

2.1.1 Global accident statistics

- In 2023 in the United States up to 6,335 motorcyclists died in crashes. The highest number ever recorded making every 100 motor vehicle crashes result in deaths 15 even though motorcycles are only 3% of registered vehicles (iihs, 2025).
- All over the world motorcyclists have accidents of fatality rate 20 times higher than the average car driver, for the traveled distance.
 (Afilalo & Vigderman, 2025).
- The World Health Organization (WHO) reports that two wheelers powered vehicle account for about 43% of road traffic deaths in Southeast Asia (Taylor, 2022).

- More than 80% of motorcycle accidents result in injury or deaths (Clagget & Sykes Trial Lawyers, 2023).

2.1.2 UAE accident statistics

- Motorcycles Caused 783 traffic accidents, leading to 42 deaths and 1,020 injuries in the UAE (Saeed, 2024).
- In 2022, 605 motorcycle accidents result in 45 fatalities and 819 injuries, showing how high the persistent risks for riders (Emirates 24/7, 2023).
- Police reported 74 motorcycle accidents, 6 deaths, and 14 severe injuries in an 11-month period (Abu Dhabi Police, 2012).
- Research shows that motorcycle crashes make 6% of road traffic deaths in the UAE overall and 2% in Abu Dhabi specifically (El-Sadig, Norman, Lloyd, & Romilly, 2002).

2.1.3 Global and regional injury data

Global Injury and Death Statistics

- Road traffic crashes result in 1.19 million deaths every year worldwide, making it a public health crisis (World Health Organization, 2023).
- Due to traffic accidents between 20 to 50 million people have non-fatal injuries annually and many resulting in disability and poor life (World Health Organization, 2023).
- More than 50% of global traffic deaths involve vulnerable road users, including pedestrians, cyclists, and motorcyclists (World Health Organization, 2023).
- The global mortality rate from road traffic injuries was reported at 15 deaths per 100,000 population in 2021, highlighting a persistent global burden (Chang, Huang, Schwebel, & Alan HS Chan, 2020).
- Low income and middle-income countries have a lower number of vehicles compared to high-income nations; however, they experience 92% of all road traffic deaths. (WHO, 2023).
- Road injuries are the leading cause of death among individuals aged 5 to 29 years (WHO, 2023).

- Males account for about 75% of road traffic deaths showing gender differences in risk-taking behavior (United Nations, 2021).

UAE Local Injury and Death Statistics

- Motorcycles Caused 384 deaths and 6032 injuries in traffic accidents making 9% increase in fatalities in 2024 compared to last year (Saeed, 2024).
- 67 lives of motorcyclists were taken representing 17% of all road deaths in the UAE for 2024 (Saeed, 2024).
- The estimated motorcyclist traffic rate of 5.5 deaths per 100,000 population, with young people between 18 to 30 years including half of the fatalities in the UAE (AlHarthi, AlHosani, & Alhosani, 2023).
- The total number of deaths due to traffic accidents reported by the UAE is 3650, which is around 10 deaths per day showing the high level of danger despite efforts to advertise public safety (Hashim, 2020).
- In Abu Dhabi, 74 reported accidents involved motorcyclists, which resulted in 6 deaths and 14 serious injuries, demonstrating the level of risk motorcyclists have compared to other users of the road (Abu Dhabi Police, 2012).

2.2 Existing solutions and technological background

The market for smart safety solutions in transportation has evolved into several categories, ranging from consumer-focused smart helmets to advanced fleet monitoring systems and wearable fatigue-detection devices. Each of these solutions helps to improve road safety from a different perspective.

2.2.1 Review of existing smart safety solutions

LIVALL

Focus its targets on bicycle users, light and simple two wheeled vehicles. They are integrating safety and communication technologies into protective headgear. A core feature category is Active Safety and Emergency Response, which includes the patented fall detection and SOS alerts to automatically notify emergency contacts with GPS location. The second category is Rider Visibility and Signaling, adding smart lighting systems ranging from integrated LED taillights and brake warning lights. These features collectively aim to increase rider visibility and safety.

Figure 1 - Livall

LYTX is a Vehicle Mounted technology solution specializing in Video Analysis and driver behavior monitoring. The system uses Artificial Intelligence and Machine Vision to identify signs of driver-tired behaviors, like frequently closing his eyes or swerving on the lane. After using AI detection, they still rely on human review to ensure high accuracy. Lytx offers cloud dashboards with smart analytics that support safety programs, only supported for large stable Vehicles.

Figure 2 - Lytx

SmartCap is a wearable solution for showing fatigue signs using new technology, primarily focusing on risky industries like mining and long-distance driving. Its main feature is the use of EEG brainwave sensors to measure and alert the driver's state in real time. This technology has been both tested in Lab and Field environments enabling it to detect fatigue before visible signs like eyelid closure or head posture appear, thus providing a much earlier and more accurate warning than other systems

Figure 3 - SmartCap

2.2.2 Comparative features table

Feature Category	LIVALL (Cycling Helmets)	Lytx (Fleet Telematics)	SmartCap
Target Users	Cyclists, scooter riders	Trucking, logistics fleets	Mining operators, long-haul drivers
Core Focus	Rider visibility, emergency SOS	Fatigue & distraction detection	Brainwave-based fatigue monitoring
Accident Detection	Fall detection + SOS alerts	AI + human-verified fatigue alerts	microsleeps via EEG
Rider/Driver Monitoring	None	Eye-tracking, head movement	EEG-based alertness measurement
Connectivity	Bluetooth for calls, navigation	Cloud dashboards & fleet analytics	Operator alerts + supervisor dashboard
Visual Aid / Awareness	LED lights, brake warnings	Lane monitoring, video alerts	Fatigue scoring & trend analytics
Strengths	Affordable, easy adoption	High accuracy, scalable for fleets	Early detection of fatigue before physical signs
Weaknesses	Limited to low-speed Cyclists	Not wearable, costly, privacy issues	High cost, limited mostly to industrial sectors

Table 1 - Comparative features table

3 Preliminary Design

3.1 System proposal and added value

3.1.1 Proposals:

1. **Sensors Fusion:** By using eye blink sensors and embedded EEG devices to detect fatigue, modules for road status and facial recognition analysis using cameras, and using gyroscopes, and accelerometers as IMU for head motion monitoring. By combining these features, they will provide complete environmental safety conditions and driver awareness assessment.

2. **Detection Models Powered by AI**: We will use CNNs and RNNs which stand for Convolutional and Recurrent Neural Networks, and we will train and test them to be able to detect distraction and fatigue based on good value datasets, this will enable real-time detection of dangerous driving behaviors (Benmohamed & Zarzour, 2024).

3. **Urgent Response to an Accident**: By combining IoT connectivity with the impact caused by the detection of fatigue or distraction. This will allow the system to send an automatic notification to emergency service providers and company headquarters in case of an accident, so this will make the response more time efficient (E, D, M, & S, 2025).

4. **Monitoring Dashboard is Centralized**: We will develop a platform that relies on the cloud where any workplace can enter and get real time alerts, driver safety scores, and incident logs. These gamification traits will encourage the driver to follow a safety behavior through collecting gifts or receiving a fine (hafidy, Rachad, Idri, & Zellou, 2021).

5. **Combination and scalability:** Extending the system to transport safety programs offered by the government and the providers of insurance will enable incentive mechanisms and policy-level adoption to practice safe driving.

3.1.2 Values Added by our Device:

1. **Improving Safety:** The accidents that are caused by fatigue are a big concern in accounting for global road fatalities high percentage and commercial driving (World Health Organization, 2023). By having our device this will be a solution to face this challenge by identifying distraction and drowsiness before collisions happen.

2. **Being Financial Efficient:** Deducing the expenses of accidents, downtime of the vehicle, and the impact of the damage. Our system generates savings for long-term purposes for transportation companies and logistics facilities. Moreover, communicating with insurance systems can be beneficial by giving a reward for safe driving behavior with low premiums, which will result incentivizing compliance.

3. **Responsibility in Social Terms:** By protecting pedestrians, drivers, and passengers, our system follows national and worldwide rules and strategies for road safety. According to UAE, these initiatives align with the 2031 Vison strategy, which is an essential concern of our government to use AI in public to enhance wellbeing and safety (UAE Government, 2024).

4. **Data Utilization and Creativity:** Smart helmet is a more innovative version of a traditional helmet. Our device is a genius active product that solves issues by preventing and protecting from having collisions. Our system creates data that allows workplaces and guideline makers to upgrade training, accountability, and safety regulations.

3.2 Requirement specifications

In this sector of our report we will discuss the key requirement development, supporting, system, functional, and non-functional requirements of our prototype, which is the smart helmet. We will outline what the requirement will produce in terms of reliability, successful implementation by using necessary system dependencies, and expected performance.

3.2.1 Functional requirements

FR 1. Identification of Fatigue: Calculate blink rate, EAR, and PERCLOS periodically, if the thresholds are over some value that is literature-based (approx. 8-12 % PERCLOS) trigger fatigue alert.

FR 2. Identification of Distraction: Use a scientific prediction for gaze and head pose deviation, if angular values pass certain thresholds trigger a configurable distraction alert.

FR 3. Identification of Danger Motion: Identify IMU spikes (> 1 g peaks or ≥ 0.3–0.5 g sustained) for crash proxies or harsh maneuvers.

FR 4. Record the Event: Provide a video buffer that is circular and store ± 10–20 s clips around the recorded event.

FR 5. Transmission of the Event: Transmit the event using protocols of telemetry like HTTPS / MQTT with uploaded encrypted video that is optional.

FR 6. Visualize Status on Dashboard: Show event videos, trend graphs, alerts, and drivers.

3.2.2 Non-Functional requirements

NFR 1. Delay (Latency): Having an alert for less than 200 ms end to end detection

NFR 2. Power (Power Consumption): consumes an Average power of ≤ 3.5 W and 8-hour operation on 10,000 mAh battery.

NFR 3. Privacy: Follow PDPL compliance (minimization, retention control, and consent).

NFR 4. Reliability: system is uptime >99% and the mean time between false alerts (>2 hr).

NFR 5. Scalability: Be able to handle more than 1000 connected devices on backend.

NFR 6. Maintainability: OTA for possible updates and using a modular code structure.

3.2.3 Hardware implementation scope

1. **Detect**:
    a. Using head pose and coarse gaze deviation (To estimate 3D orientation for landmarks) to find **distraction**.
    b. Using **Inertial Measurement Unit** (IMU) spikes for crash proxies, harsh turns and braking to find **dynamics that are not safe**.
    c. Using **blink rate, Eye Aspect Ratio (EAR), and PERCLOS** from facial landmarks to find **fatigue.**
2. **Device Decision Making:** Hysteresis to reduce false alerts & Low-latency thresholds.
3. **Alert:** Send events compacted to a dashboard in cloud, upload & record video clips only around events (short). Privacy-by-design and bandwidth control, like **G-sensor** dashcams that auto-lock footage on impact (Gupta, 2024).

3.2.4 Development requirements

*Hardware Design Requirements***:**

- A structure of the helmet that can be customized to support many connected sensors (IR camera, IMU, power module, and EEG module) without affecting safety or comfort.
- **Processing unit for embedded systems** (Raspberry Pi Zero 2 W or equivalent) to handle communication, sensor data processing, and AI inference.
- **Integration of an electronic board** to use stable connections between processing components, sensors, and battery.
- Using a **supporting system for power management** to have efficient energy use and sustainable power use for at least 8 hours.

*Software Design Requirements***:**

- To identify distraction and fatigue, we need to have an **embedded AI pipeline** using PERCLOS, IMU data fusion, and facial landmark tracking.
- Using a **firmware development environment** for event handling logic and sensor interfacing.
- Enabling event storage, dashboard visualization using RESTful APIs, and data transmission by using **cloud platform development.**
- Event transport using TLS through MQTT to send events to a broker
- Transfer video files through to the cloud using HTTPS.
- ACME automated certificate issuance and renewals for TLS compliance

- To validate the performance under many different lighting and driving conditions, use **calibration tools and testing scripts.**

By combining and mixing the use of software and hardware requirements, this will provide better real-time performance, scalability for future deployment, and modularity of the system.

3.2.5 Supporting systems requirements

This project needs many supporting systems to have data management, user accessibility, and robust performance:

- **RTOS stands for a Real Time Operating System** which will be used in the project. It uses **FreeRTOS** to ensure reliable scheduling of AI inference, communication tasks, and sensor data acquisition, and multitasking operation management.
- **RESTful Python API** (developed by FastAPI / Flask) is a **web integration and cloud interface** that helps secure data messaging between cloud dashboard and the helmet.
- To have an **infrastructure considered as a backend** use a cloud platform that has an event logging time series database (example: **TimescaleDB), and video clips data analytics object storage (S3-compatible).**
- Creating a **user interface layer** by having a dashboard using web-based techniques gives visualization of driver performance, metrics, and alerts trends in real time.
- Protocols like HTTPS & MQTT provide **safe and secure networking**, and they are used for data encryption during transmission, ensuring alignment with privacy regulations (UAE PDPL).

By using these systems that support the backbone of our project's data analytics backend, connecting embedded hardware, user facing integrated platform to the cloud dashboard, and **end to end environment**.

3.3 System architecture (high level)

Embedded Device: Raspberry Pi Zero 2 W for a first implementation using a quad-core ARM. The typical power consumption ranges from ~0.4–0.8 W light load to ~2–3 W under a heavier CPU, with tuning, idle can drop below ~0.4 W. A Pi 4 or USB **NPU** accelerator (example: Coral) is a contingency if headroom is needed (AUFRANC, 2021).

Sensing:

- **IR LEDs & Inward IR Camera (NoIR)**: landmark tracking in low light and robust eyelid (Kim, Park, Kim, & Paik, 2023).
- **IMU (example: Bosch BMI160)**: low-power, and 6-axis gyro/accel with interrupt-driven motion detection (Bosch, 2020).

Edge AI Pipeline (on the device):

- Face detection → **facial landmarks** (68/98-point) → **PERCLOS**, **blink rate**, and **EAR** in rolling windows; **gaze** (coarse); **head pose** via PnP from landmarks.
- **Event buffer**: continuous circular video buffer; persist ±10–20 s clip and emit an **event, when** thresholds trip (IMU g-event, PERCLOS, and distraction).

Backend & Connectivity:

- HTTPS or MQTT uplink (opportunistic 4G/ Wi-Fi).
- Ingest → object storage for clips & time-series DB → web dashboard (event feed, trend scoring, driver list, clip replay).

3.4 Mechanical & Regulatory Constraints

- Following **helmet standards such as ECE 22.06** which introduces rotational tests, checks for accessories, and stricter impact. **Adjusting liner or shell compromises the certification.** So, the product will be **clip-on module**, and it is mounted in non-impact-critical zones, with a path to OEM integration later (Moto Central, 2025).

3.5 Data Model & Privacy-by-Design

- For the **telemetry of events-first** it includes: {driverID, tripID, metric, score, timestamp, optional video, severity} and a video around the event only.

- The data model follows and **aligns with PDPL which stands for UAE Personal Data Protection Law** principles. These principles exploit purpose limitation, retention control, data minimization, data subject rights (correction, objection, access, restriction), and explicit consent. When required, provide an events-only mode video (UAE Government, 2025).

4 Preliminary investigation of economical, ethic, and contemporary issues

4.1 Preliminary cost estimation and justification

Bill of Materials (Prototype-level, indicative)

Component	Model/Ref	Purpose	Cost
Raspberry Pi Zero 2 W	Broadcom BCM2710A1	Embedded Device	150 AED
Camera Module	Raspberry Pi NoIR V2	IR-sensitive imaging	90 AED
IR LED Array	850–940 nm & MOSFET driver	Night visibility	35 AED
IMU	Bosch BMI160 6-axis	Motion sensing	40 AED
Battery Pack	≥ 10 000 mAh @ 5 V	Power supply	70 AED
3D-Printed Mount	Custom (ABS & PLA)	Clip-on helmet mount	25 AED
MicroSD Card	≥ 32 GB	video buffer & OS	30 AED
Optional NPU	Google Coral USB TPU	Edge acceleration	350 AED

Table 2 - Bill of Materials

Having an estimated approximation of a one prototype cost (around 800 to 900 AED) is great. Covering the most critical devices like IR camera, IMU sensor, power bank, 3D printed mount, LED array, and the microcontroller itself (Raspberry Pi Zero 2 W). These costs are justified by the advanced system abilities to detect distraction and fatigue and use safety traits at small part of a commercial systems used to monitor fleet (1 unit > 5000 AED (Often)). The modular design enhances scalability for future product commercialization and corporate fleets at a low cost.

4.2 Relevant codes of ethics and moral frameworks

The ethical principles that are addressed by our project and computer professionals and engineers are NSPE and IEEE. These codes represent respect for privacy, safety, and responsibility. The data collection phase we are using in our project aligns with UAE PDPL (Personal Data Protection Law). By following this law, we will have minimized data, retention control, and user consent. Producing data that is sensitive (ex. biometric or video), the data is well secured by using encryption and allocated around major events. Maintaining user autonomy and transparency and contributing to moral frameworks that give importance to human dignity and public welfare are crucial team goals.

4.3 Relevant environmental considerations

The impact that is being caused by the environment is reduced by using recyclable materials and resource efficient hardware. The Raspberry Pi consumes not more than an average of 3.5 W; this will minimize the power use during long term operations. To support sustainable practices for our prototype, we will use a biodegradable PLA to provide a 3D clip-on mount. Our project prevents accidents, and it is beneficial to minimize associated waste and vehicle damage, and this represents a further environmental responsibility.

4.4 Relevance to UAE and region (social, cultural, and political)

Our project aligns and supports the UAE Vision 2031 strategy which is to use smart tech and AI in enhancing public wellbeing and safety. In our region, there are major road accidents and challenges that can be caused due to commercial driver fatigue, so our project system solves this issue. Enabling organizational accountability and promoting safe behavior in driving. Our project follows UAE's national AI agenda and contributes to regional guidelines that rely on human welfare, innovation, and sustainability.

4.5 Other issues and constraints (Risks & Mitigations)

- **Helmet Integrity (Certification risk):** it avoids liner or shell modification, uses clip-on module and plans OEM path (Moto Central, 2025).
- **Low occlusion and light** (ex. head turn & sunglasses): Uses multi-frame smoothing, fuse **head pose** with PERCLOS before alerting, and IR illumination (Kim, Park, Kim, & Paik, 2023).
- **Annoyance & False Positives:** Using per driver calibration, some thresholds with hysteresis, and multi-signal fusion (IMU, PERCLOS, and pose) (Kim, Park, Kim, & Paik, 2023).
- **Heat & power:** Using quantize models, IMU high power triggered paths, duty cycle IR, and off helmet relocated battery if it is required (AUFRANC, 2021).
- **Compliance & Privacy:** Using retention controls, consent UX, events first logging, and Data Subject Access Request (DSAR) workflows per PDPL (UAE Government, 2025).

5 Project Plan

5.1 Work Breakdown Structure (WBS)

5.1.1 Project Breakdown (Domain/Scope Summary table)

Domain	Scope Summary
Hardware (HW)	Embedded platform (Raspberry Pi Zero 2 W or Pi 4), IR camera module, IMU, LED array, power system, and 3D-printed clip-on mount.
Software (SW)	Edge AI pipeline (face detection, EAR/PERCLOS, head pose, IMU fusion), MQTT/HTTPS eventing, backend server (TimescaleDB, S3 storage), and web dashboard.
Documentation (DOC)	Design documents, API specs, hardware schematics, test protocols, and PDPL compliance docs.
Quality (QA)	Verification of fatigue/distraction detection, latency < 200 ms, ROC/precision validation, false-alert rate < 5/hr.
Security (SEC)	PDPL-compliant data minimization, encryption at rest (AES-256) and in transit (TLS 1.3), secure MQTT broker, driver consent management.
Governance (PRIVACY)	Events-only mode, retention limits, DSAR (data subject access request) handling, PDPL alignment.

Table 3 - Project Breakdown

5.2 Schedule

Problem Definition & Evidence of Need

Driving in commercial and industrial situations carries an elevated risk of fatigue and unsafe behaviors (being distracted, aggressive maneuvers, etc.). A widely used way to measure drowsiness is using “PERCLOS” Percentage of eyelid closure. It is defined as the proportion of eyelids covering pupils over a certain window of time; Higher PERCLOS correlates with reduced alertness and crash risks. Mostly in fielded systems, thresholds are defined to 8-9% for initial alerts, and full warnings at 12% PERCLOS which is used according to transport studies. (Office of Motor Carrier Research and Standards, 1998).

Modern Driver Monitoring Systems “DMS” use computer vision solutions that estimate facial landmarks, blinks, and head positioning, often combined with infrared “IR” illumination for night visibility. They are deployed at scale and proven to operate well in real time with a modest number of computers. Recent benchmarks confirm their suitability for blink/PERCLOS estimation under varied conditions reliably. (Kim, Park, Kim, & Paik, 2023).

5.2.1 Milestone-Based Implementation Plan

M1 — Requirements & Design Freeze

- Finalize monitored metrics (PERCLOS, EAR/blink rate, head pose, IMU g-events).
- Approve clip-on mechanical concept, battery strategy, and privacy requirements (consent, retention).

M2 — Hardware Bring-Up

- Assemble Pi + NoIR camera + IR LEDs + IMU; verify camera stream, IR illumination, IMU interrupts; measure idle and load power on bench (AUFRANC, 2021).

M3 — Perception v1 (On-Device AI)

- Implement face/landmark detection (MediaPipe/Dlib/FAN as appropriate) → EAR/blink/PERCLOS; head-pose estimation; tune windows for stable PERCLOS tracking (Rahman, Woodman, & Donzella, 2025).

M4 — Event Buffering & Telemetry

- Circular video buffer with event persistence (±10–20 s); MQTT/HTTPS event uplink; minimal dashboard (event table, clip playback). (Gupta, 2024)

M5 — Field Tuning & Fusion

- Day/night runs; fuse PERCLOS + head-pose + IMU; add hysteresis/debounce; target false-alert rate < 5/hr under normal driving.

M6 — Privacy & Governance Completion

- Implement consent flows, retention toggles, export of driver data on request, and events only mode aligned with PDPL rights (access, correction, restriction, objection). (UAE Government, 2025)

M7 — Power/Thermal Hardening

- Quantize models, duty-cycle IR, confirm average power within day use budget; validate comfort/thermal limits on-head. (AUFRANC, 2021)

M8 — Demo-Ready Integration

- End-to-end scenario: detected drowsiness/distraction → local alert → event uplink → dashboard clip + score update; compile test metrics and limitations.

5.2.2 Gantt Plan

Phase	Duration	Milestone	Key Outputs
Week 1-2	M1	**Requirements & Design Freeze**	Metrics finalized (PERCLOS, EAR, IMU triggers), privacy plan approved
Week 3-5	M2	**Hardware Bring-Up**	Bench test Pi + IR Cam + IMU, verify power budget
Week 6-9	M3	**Perception v1**	Face landmarks → EAR/PERCLOS + head pose working in real time
Week 10-12	M4	**Event Buffer & Telemetry**	Circular video buffer, MQTT/HTTPS uplink, simple dashboard
Week 13-16	M5	**Field Tuning & Fusion**	Night/day testing, multi-signal fusion, false-alert reduction
Week 17-18	M6	**Privacy & Governance**	PDPL-compliant consent flows, retention toggles
Week 19-21	M7	**Power/Thermal Hardening**	Quantized models, duty-cycle IR, verified 8-hour runtime
Week 22-24	M8	**Demo-Ready Integration**	End-to-end validated prototype, dashboard metrics, final report

Table 4 – Gantt Plan

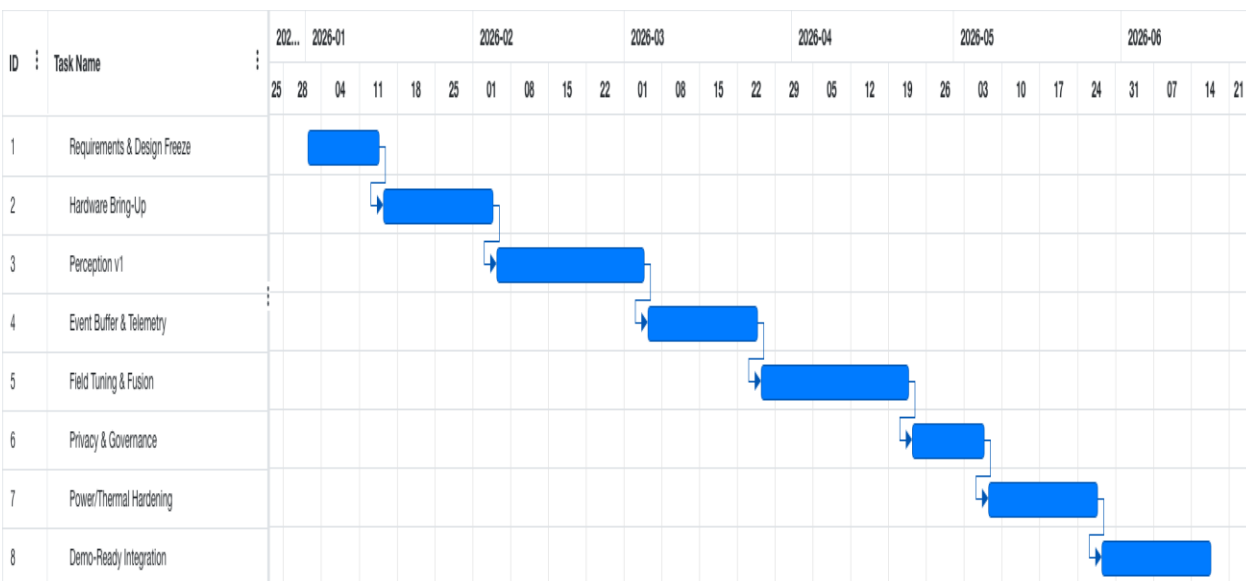

Figure 4 – Gantt Chart

5.3 Team organization (Resource & Task Allocation)

Member	Main Responsibilities	Deliverables
Student 1 – Hardware & Integration Engineer	• Select and integrate hardware components (Pi Zero 2 W, IR camera, IMU, battery). • Design and test IR illumination circuit and power delivery. • Perform thermal and power profiling. • Build and 3D-print the clip-on helmet mount. • Ensure mechanical design doesn't violate helmet safety zones.	– Working hardware prototype (Pi + camera + IMU). – Power/thermal validation report. – 3D-printed mount and wiring diagram.
Student 2 – Edge AI & Embedded Software Engineer	• Develop and deploy AI pipeline (face landmarks → EAR, PERCLOS, blink rate, head pose). • Optimize inference with TFLite/ONNX Runtime. • Implement event detection logic (fatigue, distraction, IMU). • Handle IR LED duty-cycling and system control scripts. • Quantize models for low power and latency.	– Functional fatigue/distraction detection code. – AI model validation with test videos. – Real-time demo on Pi.
Student 3 – Cloud & Dashboard Developer	• Build MQTT/HTTPS server and data ingestion API. • Set up TimescaleDB and S3-compatible video storage. • Develop simple web dashboard (event list, clips, metrics). • Implement cloud analytics (PERCLOS trend, fatigue scoring). • Ensure secure authentication and encrypted communication.	– Working dashboard with event replay. – Cloud storage and DB integration. – Encrypted MQTT/HTTPS uplink verified.
Student 4 – QA, Documentation & Compliance Engineer	• Define test cases (bench + road + fatigue simulation). • Perform validation (precision, false alerts, latency). • Document PDPL compliance (consent, data retention, access rights). • Maintain project logs, user manual, and safety compliance docs. • Coordinate Gantt tracking and final demo report.	– Full validation dataset and ROC analysis. – Compliance and privacy report. – Final technical documentation and project poster.

Table 5- Resource & Task Allocation

6 Implementation

6.1 System overview

The Driver Monitoring Module continuously monitors a driver's face and motion patterns using:

- **IR camera** for facial landmark tracking (eyes, eyelids, gaze).
- **IMU** for dynamic motion analysis (harsh braking, impacts).
- **Edge AI** pipeline that computes PERCLOS, EAR, and head pose in real time.
- **Cloud dashboard** that displays alerts, events, and video snippets.
- **Privacy layer** ensuring only event-based uploads occur.

Signal Flow:
Driver → IR Cam + IMU → Pi Zero 2 W (AI Inference) → Event Uplink → Cloud Dashboard.

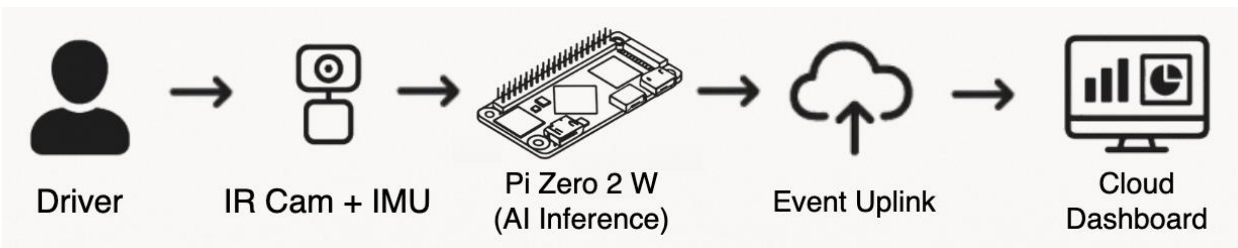

Figure 5 - Signal Flow

6.2 System Architecture

Edge Device Subsystem

- **Input Layer:** IR camera, IMU.
- **Processing Layer:** Pi Zero 2 W; ONNX inference; OpenCV for PERCLOS.
- **Event Manager:** Circular video buffer; threshold logic; MQTT client.
- **Output Layer:** Buzzer/LED (local alert), network uplink.

Cloud Subsystem

- **Ingestion:** MQTT broker or REST API gateway.
- **Storage:** TimescaleDB (time-series) + S3-compatible blob storage.
- **Analytics:** Driver scoring, daily fatigue summaries.
- **UI Layer:** Web dashboard.

6.3 Software stack

- On-device: Raspberry Pi OS Lite, libcamera, OpenCV, TFLite/ONNX Runtime.
- Perception: Face/landmarks → EAR/blinks → PERCLOS; head-pose (PnP); IMU ISR for g-events.
- Eventing: circular video buffer; event packer to MQTT/HTTPS.

- Backend/UI: MQTT broker or REST ingest; Postgres/Timescale + S3-compatible storage; web dashboard (events, playback, scoring).

6.4 Power & Thermal Feasibility (Day-Use Target)

2.0–3.5 W average (Pi Zero 2 W + camera + IR LEDs duty-cycled + IMU). For an 8-hour shift, approximately 16–28 Wh is needed (e.g., 10,000 mAh @ 5 V power bank, accounting for conversion losses). Event-driven IR and compute, plus model quantization, keep average draw down. (AUFRANC, 2021)

7 Testing Plan

7.1 Validation Strategy

- **Bench tests**: induce long blinks and head nods; verify EAR/PERCLOS tracks expected thresholds and latency (< 200 ms for alerting). Thresholds guided by literature showing alert points ~8–12% PERCLOS depending on integration window (Blanco, et al., 2009).
- **Road and simulator tests**: annotate distraction/fatigue episodes; compute ROC/precision for events.
- **Dynamic events**: simulate harsh braking/bumps; confirm IMU G-sensor-like triggers lock clips reliably (±10–20 s). (Gupta, 2024)

7.2 Methodological approach

- **Black-box testing (system level):** Validate end-to-end behavior against user-visible requirements (alerts, event clips, dashboard entries) without inspecting internals.
- **White-box testing (module level):** Unit and component tests for the on-device perception pipeline (EAR/PERCLOS, head-pose, IMU triggers), event buffering, and telemetry code paths.
- **Gray-box / HIL (hardware-in-the-loop):** Run the embedded stack on the Raspberry Pi with a real camera/IMU while injecting controlled inputs (scripted videos, IMU pulses) to verify timing, fusion logic, and thresholds.
- **Acceptance tests:** Gate the release against explicit, measurable criteria drawn from project requirements (e.g., **<200 ms** alert latency, **false-alert rate <5/hr**, **8-hour** day-use on a 10 000 mAh pack).

8 Conclusions

Our project has illustrated successfully the social impact and feasibility of combining embedded sensing tech, IoT, and AI to improve safety in driving using proactive prevention and monitoring instead of reactive protection. By using facial landmark tracking, IMU motion analysis, and EEG-based fatigue sensing our system have a high percentage of identifying early signs of unsafe movements, fatigue, and distraction. The system uses a dashboard that is cloud-connected. This dashboard enables companies to promote accountability in drivers, visualize alerts, and have safety patterns analysis.

Smart Helmet accomplishes the major objective: by configuring a proof of concept (POC) for embedded AI identification of fatigue and distraction, a cloud platform that is secure to analyze and display data, and a functional prototype that can be used to save people lives. The optimization of pipelined inference on the microcontroller (**Raspberry Pi Zero 2 W)** and the implementation of data processing in real time using FreeRTOS proved that to have a limited power consumption and efficient performance can be delivered by using edge computing. Furthermore, our system design follows UAE PDPL privacy principles to have a responsible handling of behavioral and biometric data.

From our perspective as computer engineering students, we think that our project visualized the effect of model quantization, event-driven communication, and multi-sensor fusion in getting a high accuracy as a result with a low latency (<200 ms). In Financial terms, the project is cheap and it is an alternative solution that you can afford instead of the existing commercial solutions. A prototype approximately costs form 400 to 500 AED making it reliable and scalable for industrial or fleet use. In terms of envinroment, it have components that can be recycled and these components provide low power making it perfect for sustainable engineering practices.

Our project aligns with the expected goals of UAE Vision 2031, which demonstrates the use of artificial intelligence to enhance public wellbeing and safety. Also, the project showcases ethical innovation importance, by exploring how solutions in an engineering perspective can save lives while preserving and respecting societal values and privacy.

Overall, our project is a proof of concept for AI-driven, intelligent safety wearables that can transform how accident prevention and driver monitoring are faced. There are some future enhancements that can be provided on wireless communication optimization, AI model refinement using larger datasets, and hardware miniaturization. By using more industrial collaboration and testing, our project will reach a higher level in commercially viable systems that help to have a sustainable, safer, smarter environment in the transportation field.

9 Statement of Contribution

Table - Statement of Contribution

Task	Student ID	Contribution Percentage
Executive Summary	**202230373**	40%
	202107716	20%
	700041219	20%
	202112121	20%
Introduction	**202230373**	20%
	202107716	40%
	700041219	20%
	202112121	20%
Background and Literature Review	**202230373**	20%
	202107716	20%
	700041219	40%
	202112121	20%
Preliminary Design	**202230373**	20%
	202107716	20%
	700041219	20%
	202112121	40%
Preliminary investigation of economical, ethic, and contemporary issues	**202230373**	20%
	202107716	40%
	700041219	20%
	202112121	20%
Project Plan	**202230373**	25%
	202107716	25%
	700041219	25%
	202112121	25%

Section	Student ID	Contribution Percentage
Implementation	**202230373**	40%
	202107716	20%
	700041219	20%
	202112121	20%
Testing Plan	**202230373**	40%
	202107716	20%
	700041219	20%
	202112121	20%
Conclusions	**202230373**	20%
	202107716	40%
	700041219	20%
	202112121	20%

Table – Student Signatures

Student Name	**Student ID**	**Signature**
Suhail Khaled Alblooshi	202230373	Suhail K. Alblooshi
Mohammed Abdulla Alshamsi	202107716	
Ahmed Omar Mustafa	700041219	
Abdulla Salem Alshamsi	202112121	

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Terminology & Definitions

Terminology	Definition
Artificial Intelligence (AI)	A technology that enables computers and machines to simulate human learning, comprehension, problem solving, decision making, creativity, and autonomy.
Machine vision	Technology and methods used to provide imaging-based automatic inspection and analysis
Inertial measurement unit (IMU)	A sensor that precisely measure a vehicle's short-term movement and orientation
Infrared (IR) Camera	A camera sensor that captures images using infrared light, which are not visible to the human eye
Neural Processing Unit (NPU)	A chip manufactured for special ML tasks and AI acceleration by performing parallel processing for faster and more resource efficient neural computation compared to graphical processing and central processing unit
PERCLOS (Percentage of Eye Closure)	The percentage of time in a minute that the eye is closed has popular way for assessing driver's alertness
EEG (Electroencephalography)	Brainwave sensors to measure and alert the person's active state

Biography

- **Mohammed Abdulla Alshamsi – 202107716**
  I am a fourth-year Computer Engineering student at UAEU and a scholar of Ministry of Interior, with a passion to integrate the hardware and software systems with Artificial Intelligence. He is a smart engineer who uses critical thinking and problem-solving skills to make a better solution. Mohammed aims to use his skills to serve his country in all sectors and especially in the IT sector.

- **Ahmed Omar Mustafa – 700041219**
  I am a fourth-year student at UAEU, and I study Computer Engineering. I am very skilled in the technical part and have a big interest in hardware components where I like to integrate them into a system. I aim to pursue a career integrating machine learning models into embedded systems, contributing to the development across the UAE.

- **Abdulla Salem Alshamsi – 202112121**
  I am a fourth-year student in Computer Engineering major in UAEU, a scholar in the Ministry of Interior and in Sheikh Mohammed program in NYUAD. I am a hard-working engineer who likes to acquire new skills. I am interested integrating AI on embedded systems.

- **Suhail Khaled Alblooshi –202230373**
  I am a fourth-year computer engineering student at UAEU. I am a professional technician and interested in circuits, embedded systems, cloud computing, and development. I like to make projects in this sector to contribute to the UAE society and the worldwide open-source community. Also, I completed internships at both Microsoft and AWS and has a vast portfolio of projects related to cloud infrastructure, virtualization, container orchestration, and electronic and embedded hardware systems that I work on in his own personal time at home.

Appendix