Safe-Dash: Real Time Driver Drowsiness Detection and Monitoring System

Navdeep Singh, Shriyaansh Gupta, Vansh Goel, Taneshq Gupta, Rohan Aggarwal, Navedhya Goyal, Ojas More, Himanshi

School of Computing and Electrical Engineering, IIT Mandi

Abstract

SafeDash is a low-cost driver monitoring system designed to detect drowsiness and inattention in real time. The system uses a standard USB webcam and the MediaPipe face-and-eye tracking pipeline running on an NVIDIA Jetson Nano to continuously monitor the driver's facial landmarks. An attentiveness score is computed from eye closure, blink rate, and head orientation, and a three-stage alert mechanism—visual, audio, and haptic—is triggered when unsafe behavior is detected. All hardware components are integrated into a custom black acrylic enclosure for compact deployment. SafeDash demonstrates an accessible, replicable, and efficient approach to enhancing road safety through embedded microcomputer and affordable sensing technology.

1. Hardware in Context

Despite major improvements in road safety and vehicle design, human error remains the leading cause of road accidents. Among these, driver fatigue and drowsiness are particularly dangerous and often go unnoticed. As per police-department statistics in multiple regions, road-accident fatalities remain high and drowsy driving is a significant contributor to such events [1]. One of the biggest yet underestimated contributors to these accidents is drowsy driving. Drowsiness refers to sleepiness occurring in inappropriate situations. Even short episodes can have severe consequences. Fatigue reduces attention and alertness, leading to slower reaction times on the road. Physical signs include difficulty keeping the head upright, inability to maintain eye openness, and frequent yawning [6].

Traditional subjective scales such as the Stanford Sleepiness Scale (SSS) and

Karolinska Sleepiness Scale (KSS) are commonly used to assess drowsiness levels; however, they require conscious input from drivers and are not suitable for continuous monitoring [16]. Image-based measures, bio-signals, vehicle-behavior monitoring, and hybrid strategies have been proposed; SafeDash adopts an image-based, edge-compute approach because it is non-invasive, low-cost, and practical for in-vehicle deployment [2,3,6].

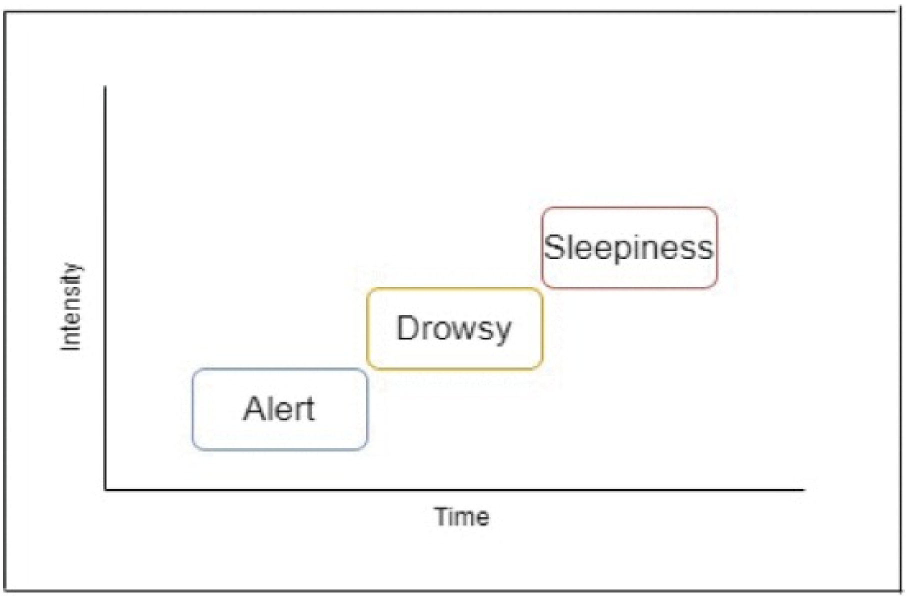


Figure 1: Attention of Driver divided into 3 States

Wierwille and Ellsworth proposed another drowsiness evaluation scale [14]. They define drowsiness stages on a five-level scale

Table 2.

Wierwille and Ellsworth drowsiness scale.

Levels	Verbal Description
1	Not drowsy
2	Slightly drowsy
3	Moderately drowsy
4	Significantly drowsy
5	Extremely drowsy

Figure 2: 5 Levels of Drowsiness

Researchers have proposed various measures to detect these drowsiness signs as early as possible, in order to avoid accidents. These measures can be divided into four main categories: firstly, image-based measures that are obtained using a camera to analyze the driver's movements and facial expressions; secondly, biological-based measures that relate to the driver's bio-signals and can be recorded by placing special sensors on the driver's body; thirdly, vehicle-based measures, which depend on monitoring the behavior and movement of the vehicle; finally, hybrid-based measures, using two or more measures.

These signs can be captured by using camera and further analysed by machine learning algorithm to detect the drowsiness condition and alert the driver. This measure is widely used to detect the driver drowsiness. Most of the studies mainly focus on eye blinking rate,Percentage of the eye closure (PERCLOS) , Eye State, Eye Blink Rate (EBR) , Yawing and facial action[16]. These measurements are reliable and help to detect the driver drowsiness.

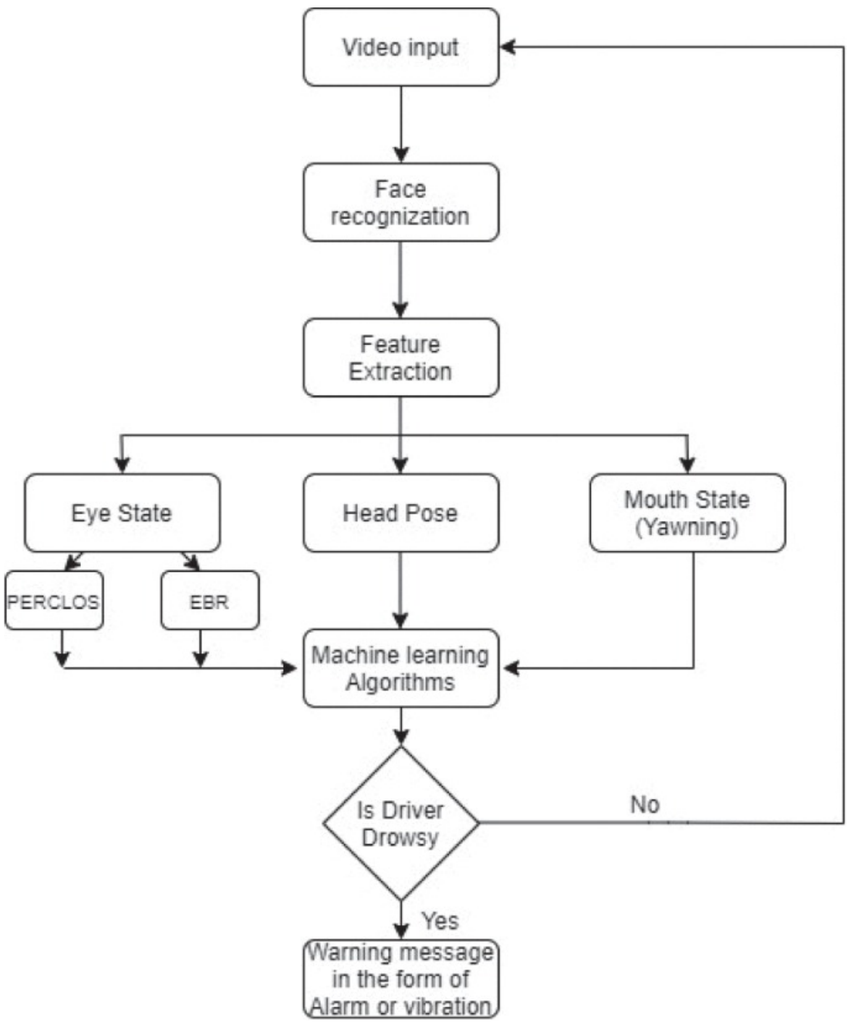


Figure 3: Driver drowsiness detection using Behavioral measures and machine learning techniques

2. Hardware Description

Nvidia Jetson devices can be used to build edge computing solutions that can perform tasks such as image processing, object detection, face recognition, speech recognition, natural language processing, and more[10].

There are increasing studies in the development of intelligent monitoring systems, such as the fatigue and alertness monitoring system. A specialized system is devised to monitor the physiological status of drivers, employing computer vision and neural networks. The developed system continuously checks the driver's activities through cabin-installed cameras and promptly issuing warning signals and alarms upon detecting any abnormal driving behaviors or actions. The cameras specifically monitor the driver's head and eye pose, as well as eye rotation. The acquired information and signals undergo analysis via an echo state network (ESN). This neural network runs on an NVIDIA Jetson Nano.[2]

This dual bidirectional motor driver, is based on the very popular L298 Dual H-Bridge Motor DriverIntegrated Circuit. The circuit will allow you to easily and independently control two motors of up to 2A each in both directions.It is ideal for robotic applications and well suited for connection to a microcontroller requiring just a couple of control lines per motor.

2.1 Core Processing Unit

The NVIDIA Jetson Nano (4 GB) acts as the central processing platform, executing computer-vision tasks locally without dependence on cloud connectivity. It runs MediaPipe Face Mesh and the associated eye-tracking pipelines to detect eye aspect ratios, blink frequency, and head orientation in real time. Use of Jetson-class edge GPUs enables parallelized convolutional inference and achieves the targeted 30+ FPS while running robust models on-device [2, 9, 10]. For higher-performance deployments the Jetson Xavier series is supported for more demanding models [17].

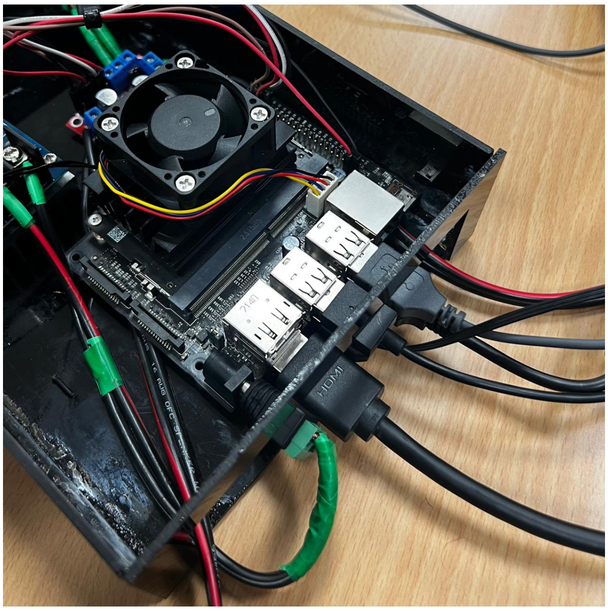


Figure 4: Jetson Nano

2.2 Sensing Subsystem

SafeDash employs a standard USB webcam as its primary sensor. The webcam captures a continuous video stream focused on the driver's face. MediaPipe extracts 468 facial landmarks per frame, enabling accurate detection of eye closure, blinking, and head pose. These features are used to compute an attentiveness score that drives the alert system [3,4]. Where needed for nighttime operation, IR-capable cameras or active IR illumination can be integrated to improve landmark detection under low-light conditions [8].

Figure 5: USB Webcam

2.3 Actuation and Multi-Layer Alert System

SafeDash features a three-stage alert hierarchy designed to re-engage the driver progressively as inattention persists:

- **Stage 1 (Visual):** An on-screen warning displayed on the integrated LCD.

(a) Non-Attentive (b) Attentive

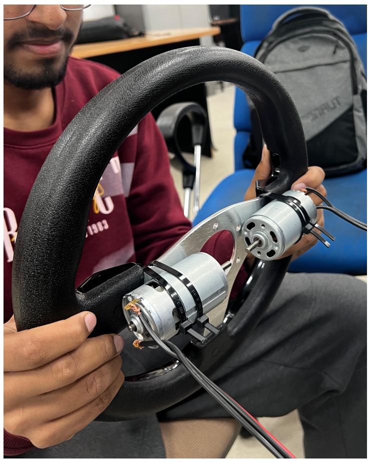
Figure 6: Visual Warning on LCD Screen

- **Stage 2 (Audio):** A voice alert such as "Wake up" issued via an external speaker connected to a USB sound card.

Figure 7: Speakers for Audio Alert

- **Stage 3 (Haptic):** Haptic feedback via steering-mounted actuators driven by a dedicated motor driver.

(a) Responsive Haptic Feedback



(b) Steering-mounted Vibration Motors

Haptic drivers (e.g., DRV-series or integrated motor-driver ICs) provide programmable waveforms and stronger perceptual alerts than a simple buzzer, and are recommended in automotive HMI research [6,7,21].

2.4 Power and Connectivity

The hardware operates on dual voltage levels: 12 V for actuation components and 5 V for logic circuits and Jetson Nano operation. Power distribution is managed through automotive-grade buck converters and DC–DC regulators that protect sensitive electronics from automotive transients (load-dump, cold-crank) [18,19]. Robust power conditioning is essential for vehicle deployments to prevent data loss and unexpected resets [9,18]. Connectivity is facilitated by an automotive-capable Wi-Fi module (or LTE option) for telemetry and OTA updates; a 32 GB micro-SD card provides local storage.

Figure 9: Power Supply

2.5 Enclosure

All components are housed inside a custom black acrylic enclosure designed in SolidWorks. The enclosure provides antenna mounts, a ventilation cutout for the Jetson fan, front-panel power access, and an open rear for cable routing and serviceability. The enclosure design balances thermal management, EMI considerations, and serviceability.

(a) Acrylic Case Enclosure

(b) Internal Circuit

3. Driver Attention Algorithm and Jetson Runtime System

This section describes the vision-based behavioural model, features extracted from facial landmarks, the unified attention score, and the Jetson runtime pipeline that executes these computations in real time.

3.1 Facial Landmark Detection Framework

Each captured frame is processed using the MediaPipe Face Mesh model to extract 468 facial landmarks (primary detector). A Haarcascade frontal-face classifier serves as a fallback detector under challenging lighting or occlusion. A rolling buffer (typically 5–10 frames) is used for smoothing [3,28]. The hybrid MediaPipe+Haarcascade approach improves robustness without heavy computational overhead on the Jetson platform [3,28].

3.2 Eye Aspect Ratio (EAR)

The Eye Aspect Ratio (EAR) is computed using six eye landmarks:

$$EAR = \frac{||p_2 - p_6|| + ||p_3 - p_5||}{2||p_1 - p_4||}.$$

A closed-eye event is flagged when $EAR < \theta_{eye}$ where the prototype threshold is $\theta_{eye} = 0.26$ [4,16]. Continuous eye closure duration:

$$t_{\text{closed}} = t_{\text{now}} - t_{\text{start}}.$$

Drowsiness is declared if $t_{\text{closed}} > T_{drowsy}$, with $T_{drowsy} = 3.5$ s [4,16].

3.3 Mouth Aspect Ratio (MAR)

Yawning is detected using the Mouth Aspect Ratio:

$$MAR = \frac{||p_{top} - p_{bottom}||}{||p_{left} - p_{right}||}.$$

A yawn is flagged when $MAR > \theta_{mouth}$, with $\theta_{mouth} = 0.40$ [15].

3.4 Blink Rate Modeling

Blinks are counted using EAR zero-crossings in a sliding window of $W = 5$ s:

$$BR = \frac{N_{blinks}(t - W, t)}{W}.$$

A normal blink rate range is $1 \le BR \le 3$ (blinks per second averaged over the window) [4,6].

3.5 Head Pose Estimation

Yaw, pitch, and roll angles are derived from 3D facial keypoints:

$$yaw = \arctan\left(\frac{z_r - z_l}{x_r - x_l}\right), \qquad roll = \arctan\left(\frac{y_r - y_l}{x_r - x_l}\right),$$

$$pitch = 100 \cdot \left(z_{nose} - \frac{z_l + z_r}{2}\right).$$

Neck orientation classification:

$$Neck = \begin{cases} 3 & \text{if } |yaw| < 10^\circ \text{ and } |roll| < 10^\circ, \\ 2 & \text{if } 10^\circ < |yaw| < 60^\circ, \\ 1 & \text{if } |yaw| \ge 60^\circ. \end{cases}$$

Head-pose monitoring on embedded devices has been shown to detect nodding and gaze-aversion patterns indicative of micro-sleeps and distraction [11,20].

3.6 Unified Attention Score

Four features are defined:

$$feat_E = \begin{cases} 1 & \text{if eyes open,} \\ 0 & \text{if eyes closed,} \end{cases} \qquad feat_M = \begin{cases} 1 & \text{if mouth closed,} \\ 0 & \text{if yawning/ mouth open,} \end{cases}$$

$$feat_N \in \{0, 1, 2\}, \qquad feat_B = \begin{cases} 1 & \text{if blink rate normal,} \\ 0 & \text{otherwise.} \end{cases}$$

Weighted raw score:

$$Score = 4\, feat_E + 2\, feat_M + 3\, feat_N + 3\, feat_B.$$

The maximum raw score is $Score_{max} = 15$. The normalized rating in the 1–5 range is:

$$Rating = \left\lfloor \frac{Score}{Score_{max}} \times 4 \right\rfloor + 1.$$

3.7 Face-Not-Detected Logic

If the face is not detected for $t_{\text{missing}} > T_{\text{missing}}$ with $T_{\text{missing}} = 4$ s, the system triggers a haptic + audio alert indicating ”Face Not Detected”. Face-loss handling is critical to avoid false-negatives in practical deployments [6].

3.8 Jetson Runtime System

The Jetson pipeline consists of:

1. **Frame capture:** Low-latency V4L2 capture.
2. **Vision processing:** MediaPipe Face Mesh (primary) with Haarcascade fallback.
3. **Feature extraction:** EAR, MAR, blink windows, head pose per frame.
4. **Rating computation:** Rolling-buffer smoothing to prevent unstable jumps.
5. **Alert engine:** Multi-modal alerts based on Rating, EAR, MAR, BR, yaw, pitch, faceDetected.
6. **Cloud telemetry:** Non-blocking background thread sends JSON packets every 5 s to the Flask backend.

Edge inference on Jetson-class modules for driver monitoring is an established approach in recent ADAS literature because it balances latency and privacy [2,10].

4. Dashboard

The dashboard offers a clear, instant overview of the driver-monitoring data captured and processed by our Jetson-based sensing unit. Each sensing device has its own unique Jetson ID, which we use to easily pull up recent and historical driver-attention metrics. Even though the system doesn’t yet include a user login or device registration process, the core design focuses on the device itself, ensuring you get real-time visualization of safety-critical information without delay.

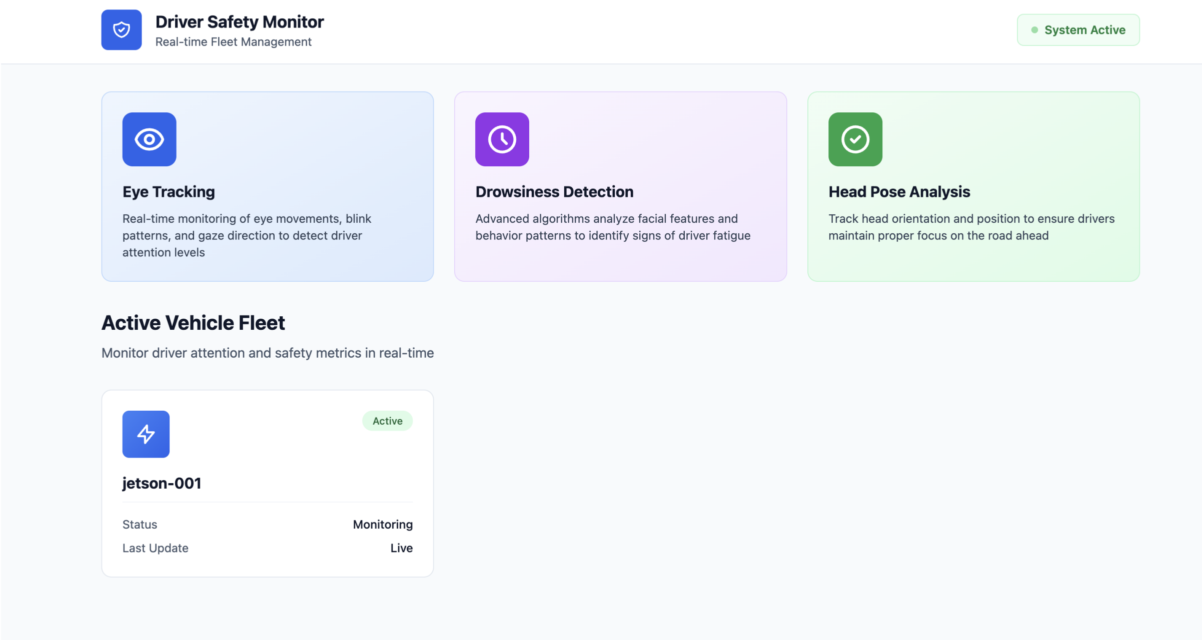


Figure 11: User-Friendly Dashboard

4.1 Receiving and Storing Data from the Jetson Devices

Each Jetson sends structured data packets in JSON format to our Flask backend at the `/stream` endpoint. These packets include key parameters like the driver's attention score, blink frequency, drowsiness indicators, head-pose estimates, and timestamps. The backend processes these packets and performs two essential tasks.

First, the system stores the data using Redis, a high-speed, in-memory key-value store that is perfectly suited for real-time web applications [22]. Each entry is indexed by its epoch time and automatically expires after 24 hours to keep the storage efficient. We use sorted sets to keep entries in chronological order, which allows for the fast time-range queries needed to render charts on the dashboard.

Second, the system provides an automatic alert. When the attention score drops below a critical threshold, the backend checks certain cooldown conditions and, if necessary, sends an HTML-formatted warning via SMTP email at regulated interval of 15 seconds. This ensures supervisors are immediately warned about dangerous situations, such as micro-sleep episodes or strong driver distraction.[13,16]

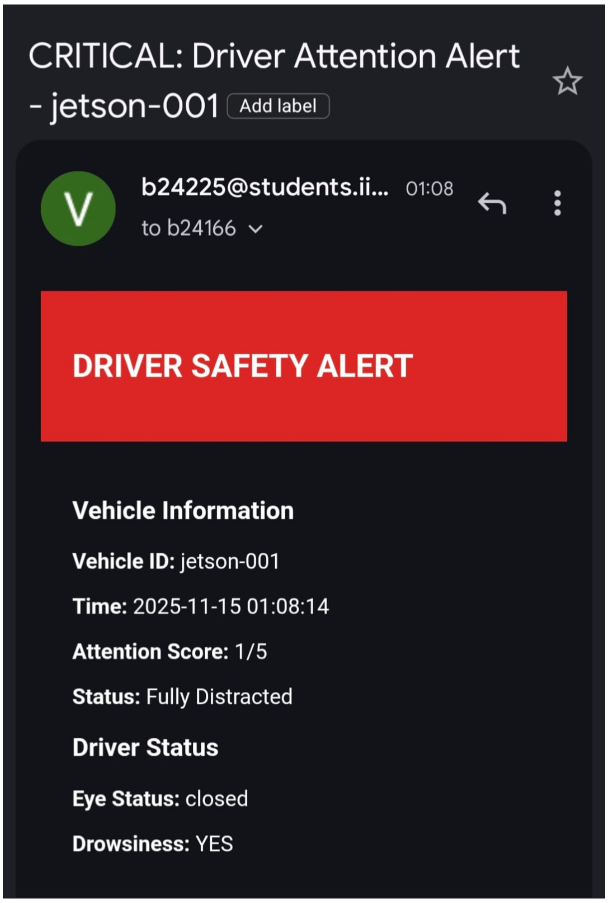


Figure 12: CRITICAL: Driver Attention Alert

4.2 Data Retrieval to Dashboard Visualization

The endpoint /api/data/<jetson_id> allows for high-performance retrieval of time-series data from Redis. The dashboard regularly requests data from this endpoint, ensuring all visual elements are perfectly synced with the latest driver activity. Dynamic statistical summaries, like the 10-second mean and mode, are calculated on the client side to support short-term behavioral an ics approaches [24].

4.3 Alert Status and Real-Time Monitoring Panel

The dashboard features a prominently displayed Critical Attention Alert module, which activates instantly when unsafe conditions are detected—a key best practice for real-time safety HMIs [25]. Each device's dashboard displays:

- Current attention score (color-coded for risk severity)
- 10-second average

- 10-second mode
- Eye state
- Blink rate
- Drowsy indicator
- Head-pose: yaw, pitch, roll
- Face-detection status
- Last update timestamp

Data refreshes every five seconds to guarantee fast response and complete situational awareness.

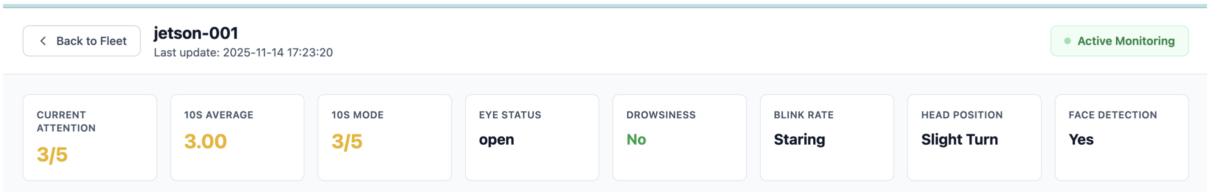


Figure 13: Real Time Parameter Monitoring

4.4 Graphical Visualization

The dashboard utilizes Chart.js, a lightweight JavaScript charting library commonly chosen for web-based scientific visualizations [23]. Multiple synchronized graphs support both detailed and broad behavioral analysis:

- Attention Score Time-Series: Continuous monitoring of cognitive alertness trends.
- Blink Frequency Timeline: Useful for spotting drowsiness, as irregularities in blinking are strongly linked with fatigue [6].
- Head Orientation (Yaw, Pitch, Roll): Helps easily recognize distraction events like looking away from the road.
- Aggregated Bar Charts: Sums attention scores across user-defined time periods (1–60 minutes), enabling the longer-term analysis used in human factors research [26].

Color coding immediately highlights the risk severity to operators, making interpretation quicker and easier.

Figure 14: Live Critical Analysis

4.5 Device Discovery and Interaction

A dedicated API endpoint (`/api/devices`) finds all active Jetson devices by scanning the Redis timelines. On the dashboard's homepage, each active device is represented by an interactive card showing its ID, operational status, and update time. Selecting a device opens its detailed monitoring interface, which makes managing multiple devices very smooth, as recommended by distributed IoT monitoring frameworks [27].

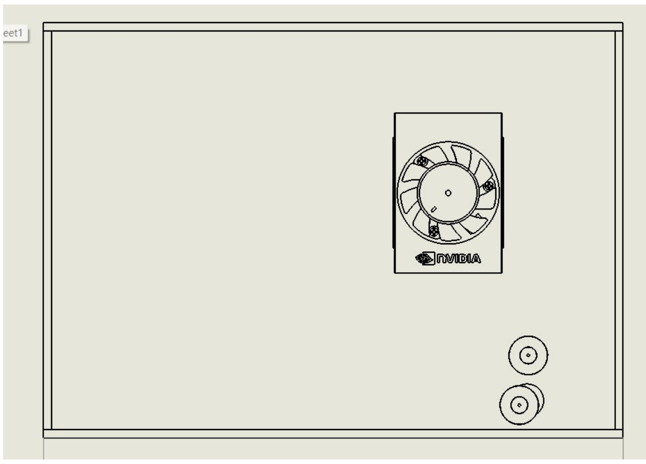
5. CAD Design and Assembly

5.1 CAD Design Overview

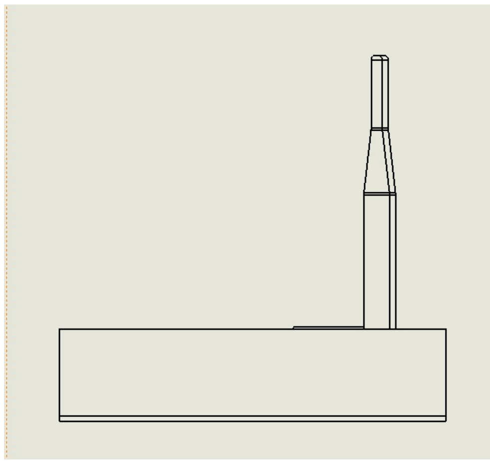
The SafeDash enclosure was designed in SolidWorks using 3 mm black acrylic sheets to create a compact, durable, and visually clean housing. The modular laser-cut panels are assembled with screws and adhesive, allowing easy maintenance and upgrades.

5.2 Mechanical Features

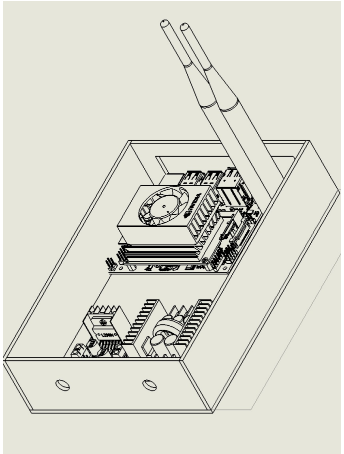
Top panel: dual antenna mounts for the Wi-Fi module and a ventilation cutout for the Jetson Nano fan to maintain airflow during prolonged inference workloads.
Front panel: 12 V and 5 V power-input cutouts for easy access.
Rear panel: intentionally open to provide access to the webcam, haptic motor wiring, speaker connection, and debugging ports.
Internal layout: Jetson Nano mounted centrally, motor driver near the rear for motor wiring, buck converters near power inputs, and cable routing channels along edges to reduce clutter.



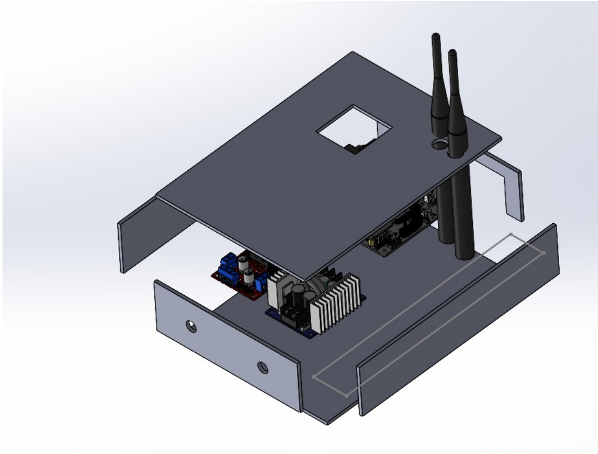
(a) Top View



(b) Side View



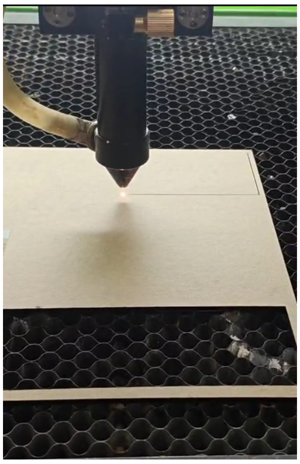
(a) Isometric View



(b) Final 3D CAD Design[29]

5.3 Assembly Workflow

The acrylic enclosure panels were laser-cut directly from the exported CAD drawings to ensure precise dimensions and clean edges. Poly-Flix industrial adhesive was used to bond the acrylic sheets together, producing a rigid and seamless structure. The assembly process maintains proper thermal spacing for the Jetson Nano's active cooling system and allows easy routing of internal wiring while keeping the enclosure compact and serviceable.



(a) Laser Cutting

(b) Cutting of Acrylic Sheets

6. Specifications

Table 1 summarizes the SafeDash prototype specifications.

Table 1: Specifications Table

Specification	SafeDash System
Hardware Name	SafeDash Driver Monitoring System
Subject Area	Road Safety, Driver Drowsiness Detection
Hardware Type	Embedded AI Vision System
Power Required	12 V (Actuators), 5 V (Jetson Nano & Logic)
Processor	NVIDIA Jetson Nano (4 GB)
Primary Sensor	USB Webcam (RGB), 30–45 FPS
Detection Pipeline	MediaPipe Face Mesh + Haarcascade (fallback)
Alert Modes	Visual (LCD), Audio (Voice), Haptic (Vibration motors)
Connectivity	Wi-Fi (Intel AC8265)
On-Device Storage	32 GB micro-SD
Backend Support	Flask + Redis Dashboard
Telemetry Interval	Every 5 s
Attention Rating Range	1–5 (normalized)
Enclosure Material	3 mm Black Acrylic (laser-cut)
Assembly Type	Modular screw + adhesive construction
Operating Temperature	0 °C – 50 °C
Maintenance Period	1 year (recommended)
Number of Alert Motors	2 (steering-mounted)
Internet Connectivity	Yes (Wi-Fi)
Bluetooth Connectivity	Yes
Mounting Type	Dashboard/vehicle cabin mount
Use Case	Drowsiness and distraction monitoring

7. Bill of Materials

This Bill of Materials lists all procured components, mechanical parts, wiring, power modules, and tools used during SafeDash development. Prices are indicated in Indian Rupees (INR).

Table 2: Bill of Materials (Full)

No.	Component	Qty	Price (INR)
1	Power adapter	1	700
2	Cooling fan	1	418
3	16 AWG wire	1	369
4	External USB sound card	1	861
5	3-inch LCD	1	2919
6	Motors (DC / vibration)	2	253
7	Steering wheel assembly	1	2304
8	Motor driver (L298N)	1	184
9	Cable zip ties	1	271
10	Fedus 20x DC connector	1	304
11	HDMI cable	1	139
12	Evelta speaker	1	406
13	15A 400W buck converter	1	1376
14	Wi-Fi module	1	1618
15	Female-to-male splitter cable	1	105
16	Black acrylic sheets	1	755
17	Dupont jumper wires	1	259
18	Poly-Flix adhesive	1	389

8. Validation and Testing

This section presents the validation and testing of the proposed real-time driver drowsiness monitoring system implemented on the NVIDIA Jetson Nano platform. The system was evaluated using continuous video input under controlled indoor conditions. Multiple behavioral and physiological indicators—attention score, head orientation, and blinking patterns—were analyzed to verify robustness and responsiveness.

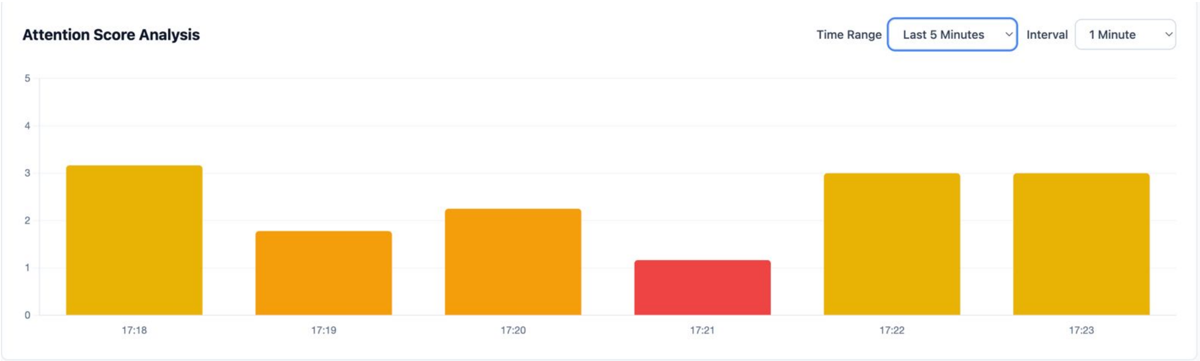


Figure 18: Past 5 Minutes Attention Score Analysis

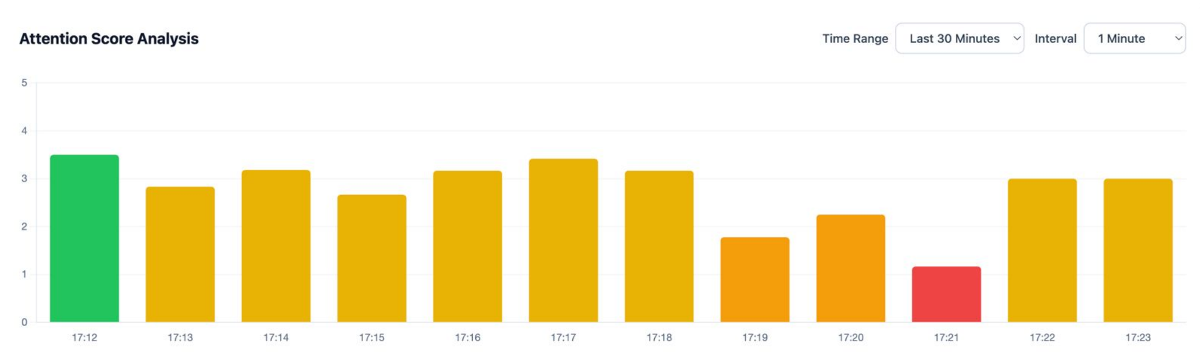


Figure 19: Past 30 Minutes Attention Score Analysis

Figure 20: Past 60 Minutes Attention Score Analysis

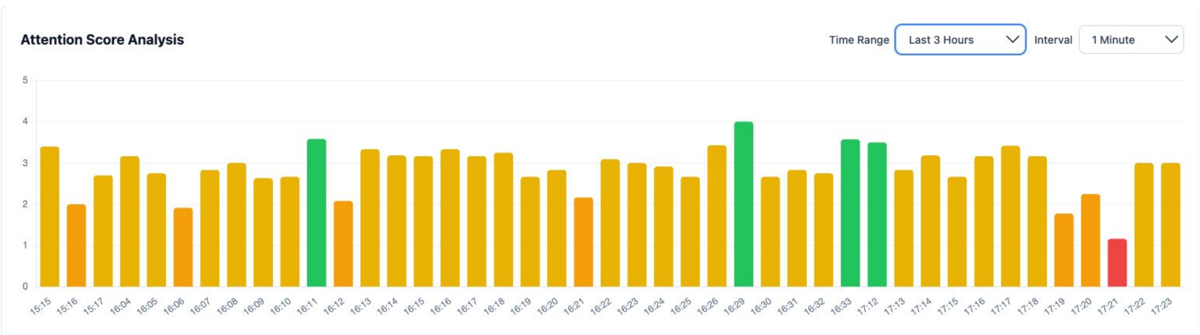


Figure 21: Past 180 Minutes Attention Score Analysis

The results are supported by visual analytics generated from live inference logs.

8.1 Attention Score Evaluation

The Attention Score Analysis graph (Fig. X) illustrates the temporal variation of the driver's attention levels computed at one-minute intervals over the last hour. The model assigns a score ranging from 0 to 5, derived from an ensemble of parameters including:

- Eye state probability
- Blink frequency
- Facial landmark stability
- Head pose deviation
- Yawning probability

Key observations:

- **Stable alertness detection:** Most intervals fall between 2.8 and 3.5, indicating consistent detection of normal attention levels.
- **Peak attention states:** Higher values (e.g., 3.57 at 16:33) indicate transient periods of increased alertness.
- **Correct low-attention identification:** Noticeable drops (e.g., at 17:21) verify that the algorithm successfully flags low-attention states.

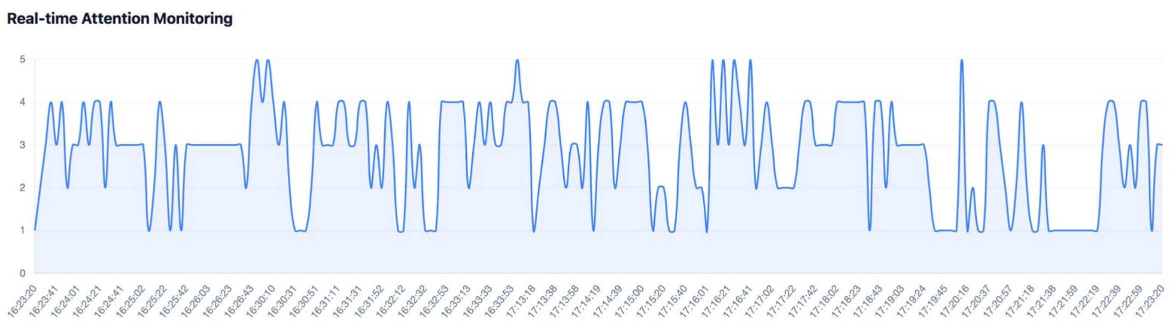


Figure 22: Real Time Attention Monitoring

8.2 Real-Time Head Orientation Analysis

The Head Orientation graph (Fig. Y) shows real-time yaw, pitch, and roll variations extracted using a 3D head-pose estimation model based on facial landmarks.

Key observations:

- **Yaw (Red Curve):** Oscillations between –60 and +80 indicate lateral head movements and off-road gaze events.
- **Pitch (Blue Curve):** Repeated negative pitch values (–40 to –80) correspond to downward tilts associated with drowsiness.
- **Roll (Yellow Curve):** Roll remains relatively stable near 0.

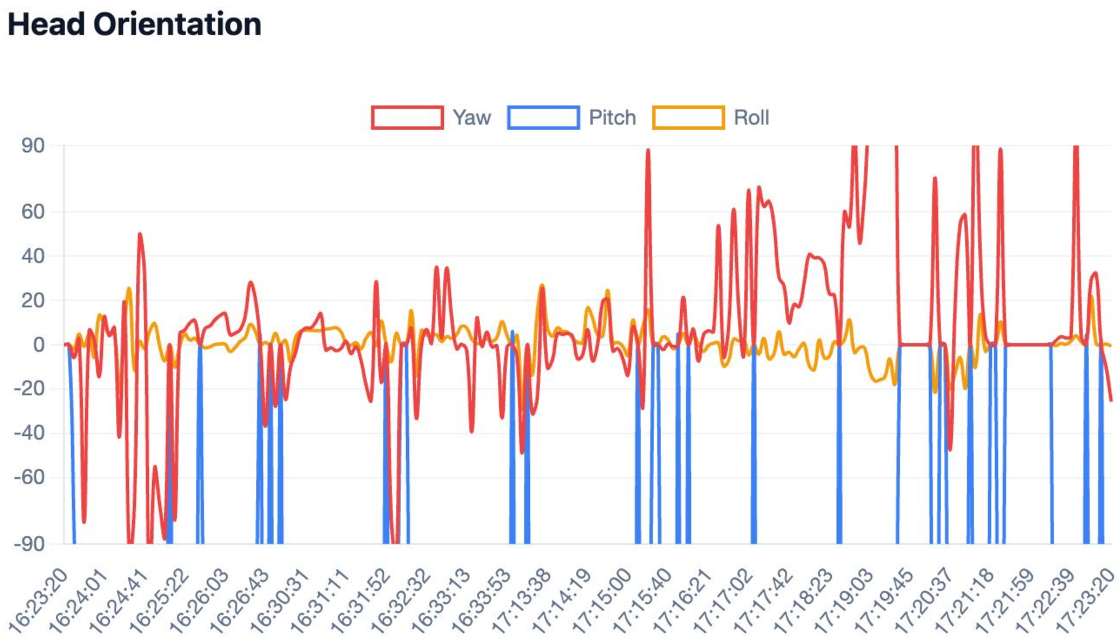


Figure 23: Live Line Plot of Head Orientation

8.3 Blink Pattern Verification

The Blink Analysis graph (Fig. Z) presents blink frequency and amplitude across the test duration.

Behavior observed:

- **Increased blink bursts:** High peaks correspond to extended or rapid blinking episodes associated with early drowsiness.
- **Drop in blink activity:** Periods of low blink intensity indicate stable attention, matching high attention scores.
- **Correlation with attention score:** Blink abnormalities align with dips in attention score, confirming internal consistency.

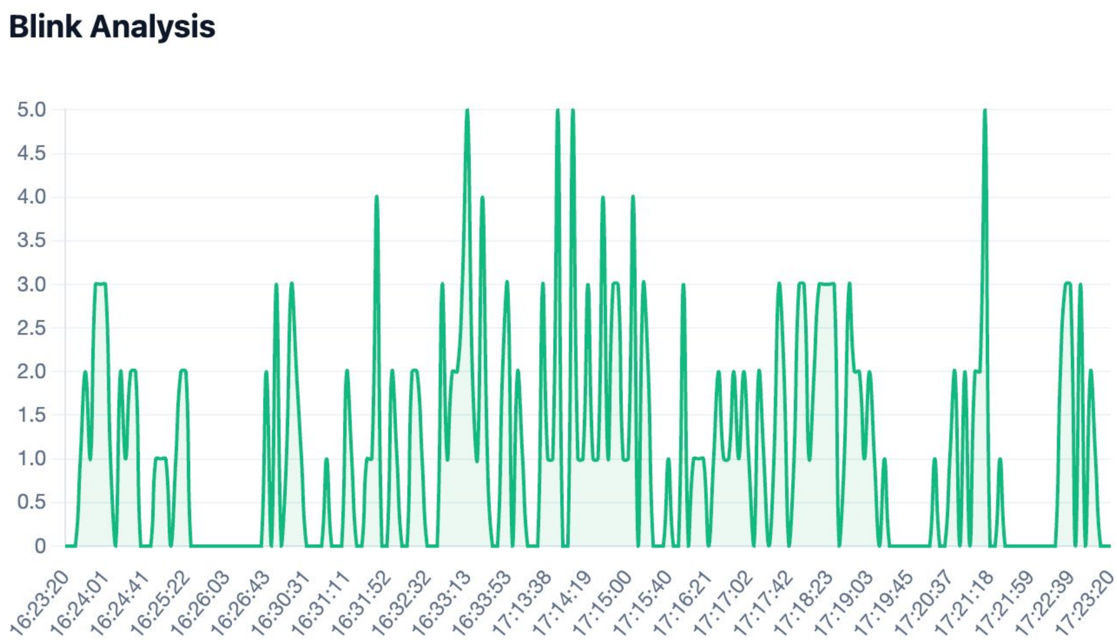


Figure 24: Real Time Eye Blink Rate Monitoring

9. Acknowledgement

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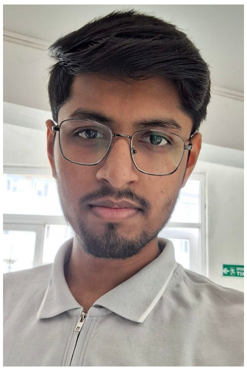
Authors

Navdeep Singh is a PhD scholar in Mechanical Engineering at IIT Mandi.

Rohan Aggarwal is a B.Tech 2nd year student in Data Science and Engineering at IIT Mandi.

Taneshq Gupta is a B.Tech 2nd year student in Computer Science and Engineering at IIT Mandi.



Vansh Goel is a B.Tech student in Data Science and Engineering at IIT Mandi.

Shriyaansh Gupta is a B.Tech student in Computer Science Engineering at IIT Mandi.

Navedhya Goyal is a B.Tech student in Mechanical Engineering at IIT Mandi.

Himanshi is a B.Tech student in Engineering Physics Department at IIT Mandi.

Ojas More is a B.Tech student in Electrical Engineering at IIT Mandi.