This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 814761

D4.1

A set of flexible modules for sensor data collection, integration and real-time processing

Safe tolerance zone calculation and interventions
for driver-vehicle-environment interactions
under challenging conditions

iDREAMS

Project identification

Grant Agreement No	814761
Acronym	i-DREAMS
Project Title	Safety tolerance zone calculation and interventions for driver-vehicle-environment interactions under challenging conditions
Start Date	01/05/2019
End-Date	30/04/2022
Project URL	www.idreamsproject.eu

Document summary

Deliverable No	4.1
Deliverable Title	A set of flexible modules for sensor data collection, integration and real-time processing
Work Package	4
Contractual due date	31/01/2021
Actual submission date	29/01/2021
Nature	Other
Dissemination level	Public
Lead Beneficiary	CardioID
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Revision history (including peer review & quality control)

Version	Issue date	% Complete[1]	Changes	Contributor(s)
v1.0	16/12/2020	0	Initial deliverable structure	André Lourenço
V1.1	30/12/2020	80%	First draft	See 'contributions from' above
V1.2	12/01/2021	100%	Full draft for review	As above
V1.3	28/01/2021	100%	Revised according to external and internal review	As above

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[1] *i-DREAMS quality assurance process:*
Due date – 3 months: ready for internal review
Due date – 2 months: start review
Due date – 1 month: end review
Due date – 5 days: ready for submission / coordinator submits

Table of contents

List of Figures

List of Tables

Glossary and abbreviations

Word / Abbreviation	Description
ADAS	Advanced Driver Assistant Systems
AEB	Automatic Emergency Braking
API	Application Programming Interface
AVL	Automatic Vehicle Locator
BARRA	Barraqueiro Transportes
BLE	Bluetooth Low Energy
CardioGW	CardioGateway
CAN	Controller Area Network
ECG	Electrocardiogram
FCW	Forward Collision Warning
FMS	Fleet Management System
FTDI	Future Technology Devices International
GATT	Generic Attribute
GDPR	General Data Protection Regulation
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HMI	Human Machine Interface
HRV	Heart Rate Variability
i-DREAMS	smart Driver and Road Environment Assessment and Monitoring System
IBI	Interbeat Interval
ID	Identification
IHC	Intelligent High-Beam Control

IMU	Inertial Measurement Unit
IoT	Internet of Things
KSS	Karolinska Sleepiness Scale
LC	Lane Centering
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LDW	Lane Departure Warning
LKA	Lane Keep Assist
LOD	Lead-on Detection
ME	Mobileye
PCB	Printed Circuit Board
PPG	Photoplethysmography
PWM	Pulse Width Modulation
REP	Response
REQ	Request
SSH	Secure Shell
STZ	Safety Tolerance Zone
SWA	Steering Wheel Angle
TJA	Traffic Jam Assist
TSR	Traffic Sign Recognition
UK	United Kingdom
USB	Universal Serial Bus
UVC	USB Video Class
VRU	Vulnerable Road User
Wi-Fi	Wireless Fidelity

Executive Summary

The i-DREAMS project aims at setting up a framework for the definition, development, testing and validation of a context-aware safety envelope for driving, called the ‘Safety Tolerance Zone’ (STZ). To accomplish this task, vehicles will have to be equipped with a suite of integrated technologies, applicable to modes of transport with different operational contexts, namely cars, heavy vehicles (buses and trucks), and rail transport (trains and trams).

This deliverable describes the in-vehicle sensor technologies, that monitor the context, the operator, the vehicle and estimates the task complexity and coping capacity, and the system that will aggregate all the information and perform the real-time processing necessary to trigger the interventions to keep drivers in a safe driving zone.

The central element of this platform is CardioGateway, an edge computing device with multiple communication interfaces and computing power for real-time processing of the data. The sensors that were selected are associated with each of monitoring the perspectives: a) driver state, b) driving task complexity, and c) driving performance.

For the driver monitoring, two physiological sensor alternatives were considered: a steering wheel cover that acquires the ECG (CardioWheel), or a wearable, that acquires the PPG (PulseOn). For vehicle monitoring, and to allow compatibility between modes, CardioGW acquires inertial information and GPS. For trucks and buses, it also reads the FMS CAN information. The contextual information is obtained using Mobileye and a dash camera (CardioDashcam).

The system includes a driver identification module to keep track of the identity of the drivers, which is especially relevant on vehicles with multiple drivers. It uses the intervention device as input, or in the case of professional vehicles, the FMS interface.

The data upload is performed via 4G or Wi-Fi internet connection, allowing the synchronization of a local database with the cloud’s API.

Several mechanisms and tools have been implemented to help verify the correct installation and functioning of the system, including a back-office platform and an Android application. The application is also used to document the installation procedure allowing to store evidence that the system was correctly installed and the vehicles were intact after the procedure.

1 Introduction

1.1 The *i*-DREAMS project

The overall objective of the *i*-DREAMS project is to setup a framework for the definition, development, testing and validation of a context-aware safety envelope for driving ('Safety Tolerance Zone'), within a smart Driver, Vehicle & Environment Assessment and Monitoring System (*i*-DREAMS). Taking into account driver background factors and real-time risk indicators associated with the driving performance as well as the driver state and driving task complexity indicators, a continuous real-time assessment will be made to monitor and determine if a driver is within acceptable boundaries of safe operation. Moreover, safety-oriented interventions will be developed to inform or warn the driver real-time in an effective way, as well as on an aggregated level after driving through an app- and web-based gamified coaching platform. Figure 1 summarizes the conceptual framework, which will be tested in a simulator study and three stages of on-road trials in Belgium, Germany, Greece, Portugal and United Kingdom, on a total of 600 participants representing car drivers, bus drivers, truck drivers and rail drivers.

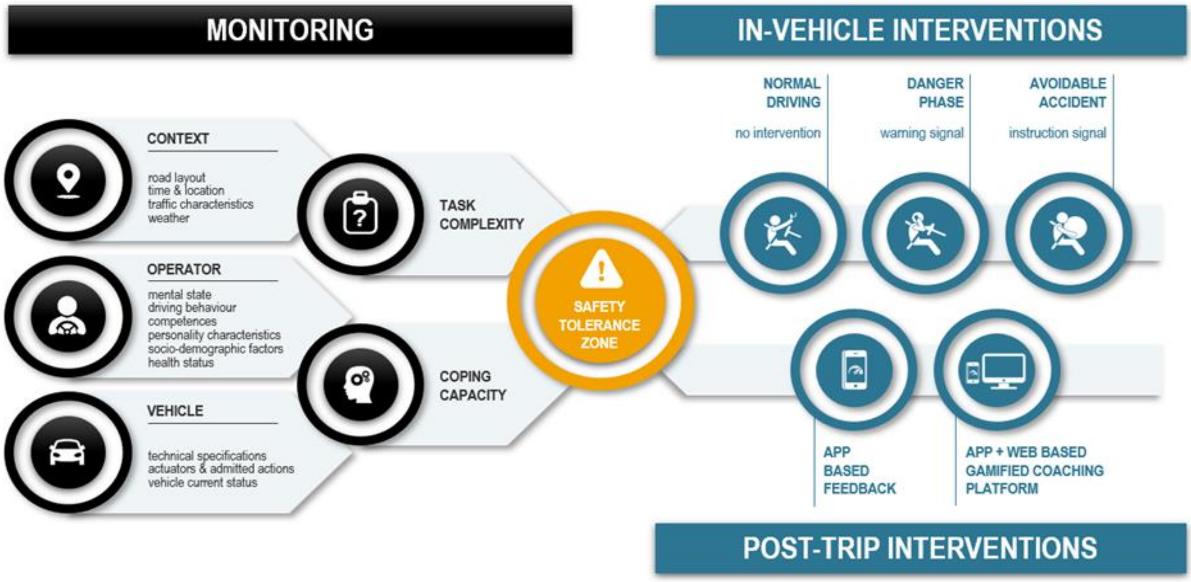

Figure 1: Conceptual framework of the i-DREAMS platform.

The key output of the project will be an integrated set of monitoring and communication tools for intervention and support, including in-vehicle assistance and feedback, and notification tools, as well as a gamified platform for self-determined goal setting, working with incentive schemes, training and community building tools. Furthermore, a user-license Human Factors database with anonymized data from the simulator and field experiments will be developed[2].

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[2] Further general project information can be found on the website: https://idreamsproject.eu

1.2 Deliverable overview and report structure

i-DREAMS is divided into five broad technical work areas: State of the Art (monitoring and interventions), Methodological Development, Technology Development, Trials, and Analysis. WP4 was responsible for all the technology development that supports the trials, in particular all the hardware, embedded and API software infrastructure that aggregates all data in the cloud – collectively entitled it as ***i*-DREAMS platform**.

The main aim of this deliverable is to document all the modules related with sensor data collection, integration and real-time processing of all the data acquired. Data from the different system components (driver capability, vehicle capability and task demand) is collected, merged and processed to obtain a real-time assessment of the 'critical safety risk', including when and how interventions, such as in-vehicle notifications and driver training & coaching, are initiated to keep the driver within the acceptable boundaries of the Safety Tolerance envelope. The data collected from the different sensors, technologies and questionnaires will be stored in the backend database for data mining purposes.

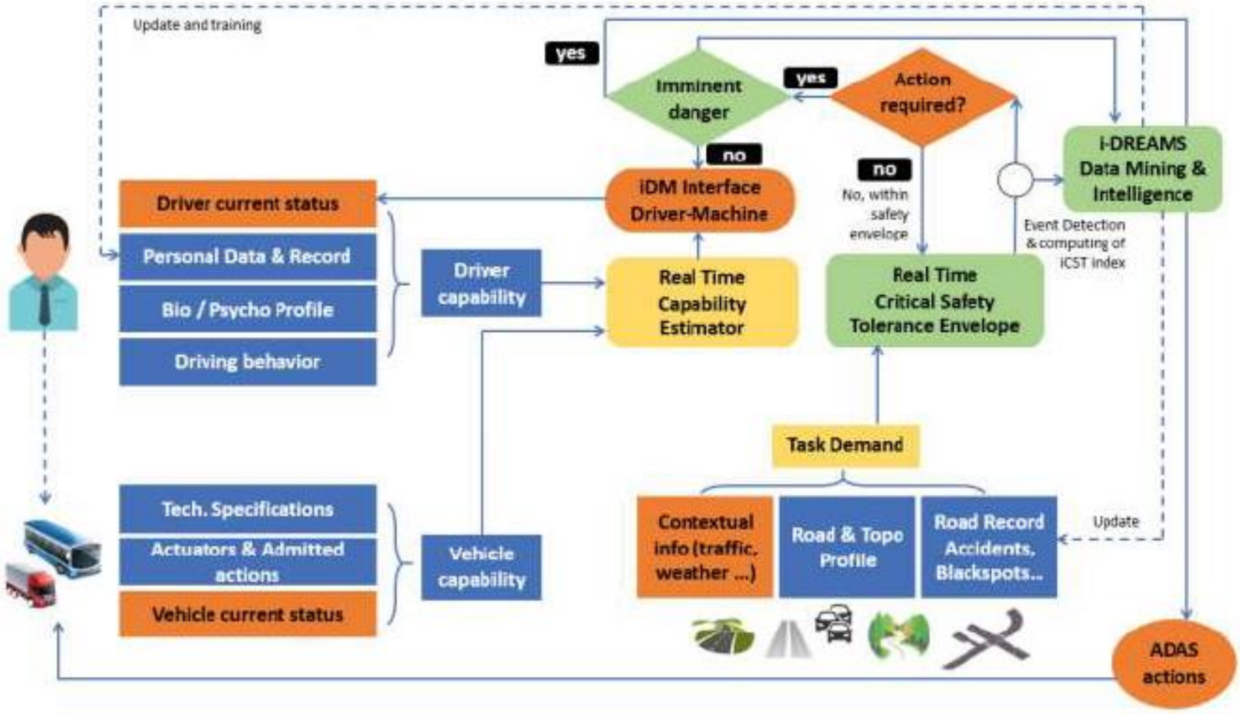

Figure 2: Methodological framework behind the i-DREAMS platform with overview of process from raw data input streams via real-time critical Safety Tolerance Zone envelope to intervention outputs.

As shown in Figure 2, the i-DREAMS architecture is conceived in such a way that it enables the flexible integration of different technologies (sensors, questionnaires) for data collection, guaranteed by using API's that enable flexible inputs for the different subcomponents; it enables the implementation of different instances of the i-DREAMS platform for different transport modes (indeed the i-DREAMS architecture supports this flexibility such that the system does not need to be redesigned from scratch for each mode of transport); it enables the relatively independent implementation of subcomponents (vehicle capability, driver capability and task demand) such that redesigning one of the subcomponents (e.g. to add extra complexity, to add new inputs, to adapt to low latency and response times) will not affect the other subcomponents. The definition of a standardized set of outputs for each subcomponent will ensure that other model subcomponents, who are dependent on reading these outputs as an input, will not be interfered.

This deliverable contains six sections, including the introduction. Section 2 will describe the general system architecture, and detail the set of sensor technologies selected for each transport mode, including the simulators' setup. Section 3 will focus on the various data collection instruments, with description of its base hardware for collection of raw data and the outputs that are obtained. Section 4 will go through the embedded software running on CardioGateway, which will support sensor data collection, STZ computation, driver user interface control, data upload and diagnostics and maintenance, being a critical component of i-DREAMS system. Section 5 will provide insights on the back-office support software infrastructure, developed to assist each field trial country coordinator managing the systems installed. Finally, Section 6 will present the main conclusions of this deliverable and final considerations for the project.

1.3 Impact and implications of the COVID-19 pandemic.

At the time of writing this deliverable, there has been a global COVID-19 pandemic.

From a technological point of view, it has brought stock shortages and long lead times from suppliers, with implications on the development, finalization and production of i-DREAMS hardware infrastructure, demanding a greater effort in procurement activities for alternative components and solutions. Testing activities were also affected, delaying the final validation of the technologies, and, to guarantee training and installation activities in the field trial countries, partners were forced to search for local installers and trainers, and prefer online training whenever possible as an alternative, once the initial plan was jeopardized due to recurrent lockdown periods with unknown extension in each of the countries.

Although COVID-19 pandemic has clearly shaped a new reality in terms of transportation of goods and people, and carried numerous challenges to overcome its impact, all the efforts are being made to have the integrated suite of technologies for i-DREAMS project ready in February 2021 to fulfil the initial timeline.

2 General Architecture

This section aims to describe the general architecture of *i*-DREAMS platform, in terms of hardware and software infrastructure. The hardware platform includes both monitoring and intervention dimensions, coordinated by a central element – CardioGateway (CardioGW) – an edge computing device that aggregates all information from the monitoring sensors, computes the STZ and triggers the interventions in the intervention device.

The monitoring dimension takes into consideration, several perspectives. Figure 3 illustrates the data collection sensors associated with each of the perspective: a) driver state; b) driving task complexity, c) driving performance.

Figure 3: Hardware monitoring infrastructure components.

A safety-oriented intervention system was developed to effectively inform or warn the driver in real-time, using an intervention device, which will provide visual and sound alerts, and information on the state of the STZ, described with further detail in Deliverable 4.4.

In terms of software infrastructure, *i*-DREAMS platform is composed of CardioGW embedded software (*i*-DREAMS on-vehicle software), and cloud APIs for data aggregation/processing (*i*-DREAMS data processor), post-processing (*i*-DREAMS post-intervention framework), and front-end (*i*-DREAMS web platform). Figure 4 illustrates the interconnections between each of the modules.

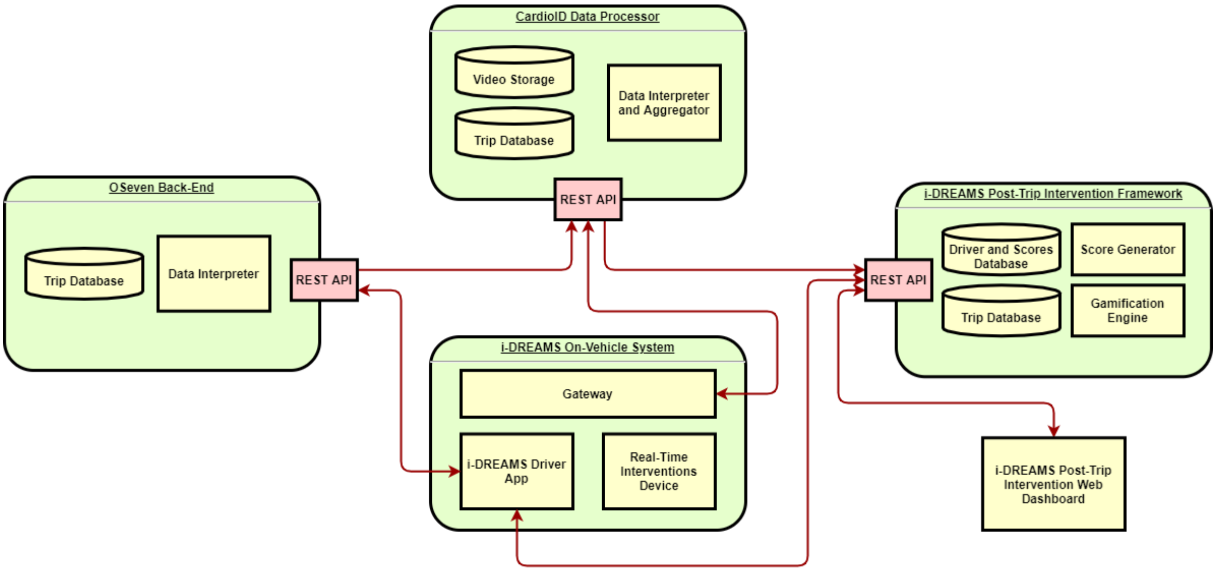

Figure 4: Software infrastructure.

2.1 Transport Modes

i-DREAMS platform will be used in different operational environments - simulator and field trials - to test the concept of the Safety Tolerance Zone (STZ). These trials will comprise different transport modes, and, taking into account the project's budget, available technologies and time for development of customized solutions, the hardware infrastructure was thought to be as much standardized and flexible as possible, to allow its application across the different modes, and hardware in the loop testing. Table 1 provides an overview of the data collection sensors selected for car, heavy vehicles (truck and bus), and rail transport (train and tram).

Table 1: Overview of data collections sensors per transport mode for the on-road field trials.

Car	Truck	Bus	Tram
Mobileye Wearable Dash cameras CardioGateway (GPS, Inertial Sensor) i-DREAMS app	Mobileye CardioWheel Dash cameras CardioGateway (GPS, Inertial Sensor, FMS) i-DREAMS app	Mobileye CardioWheel Dash cameras CardioGateway (GPS, Inertial Sensor, FMS) i-DREAMS app	Mobileye Wearable Dash cameras CardioGateway (GPS, Inertial Sensor) i-DREAMS app

Due to differences between modes, the monitoring perspective, based on data collection sensors, will include alternative technologies (e.g. CardioWheel vs wearable) to allow a better fit to each type of vehicle's operation, technological capability and design, enabling the collection of the same data set across the different modes. Besides these, we also need to consider the simulator setup for each mode.

2.1.1 Cars

In-vehicle technologies include dedicated information system tools to understand driving conditions, environment, and behaviour. They are able to provide real-time interventions to car drivers in order to improve their driving behaviour and promote road safety. Based on the literature review, carried out in WP2, visual, auditory and haptic warnings or combinations of both were found to enhance driving safety. Furthermore, multisensory wearable modules were found to have a robust and statistically significant effect of real-time feedback on both drowsiness and driving performance ratings. Many reviews also proved that there was a strong motivation for drivers to improve their driving style, differentiate their travel behavior from aggressive to normal and reduce their degree of exposure by receiving post-trip interventions and monitoring their driving performance (Katrakazas et al., 2020).

In this perspective, and as shown in Figure 5, private vehicles will be equipped with Mobileye and CardioDashcam, to monitor the road and the driving process, and record events for post-trip analysis, and PulseOn wearable, for drowsiness/sleepiness detection, instead of CardioWheel, as the last one was found to be less acceptable by participants due to aesthetically implications. In the intervention perspective, the intervention device will be installed and will communicate with CardioGateway to receive the status of the STZ, and provide visual and sound alerts in real-time, allowing as well the identification of the driver, in a scenario of multiple drivers per vehicle. Finally, the i-DREAMS application will also be made available to install on personal smartphones, not only to monitor the smartphone usage, as an indicator of distraction, but also for post-trip feedback, to engage drivers on their performance improvement, through a gamification strategy, that includes but is not limited to rating and scores, completing the monitoring dimensions targeted by i-DREAMS platform.

Figure 5: i-DREAMS suite of technologies for light vehicles.

2.1.2 Heavy Vehicles

Several commercial systems and technologies, providing real-time interventions to truck drivers, are focused on collision avoidance, as well as the avoidance of fatigue, distraction or inattention. Truck drivers are willing to accept technology and agree that, if designed and introduced properly, it can provide useful feedback to improve safe driving and efficiency as well. Technologies that were utilized to detect and monitor truck driving behaviour in real-time were non-intrusive, mainly through a web-based safety platform (Katrakazas et al., 2020).

Real-time safety interventions for buses attract a lot of attention nowadays due to the importance of safety, vehicle maintenance and eco-driving for bus operators. The majority of bus interventions exploit CAN bus, GPS and camera data in order to assist drivers in heavy duty navigation, blind spot monitoring, as well as the avoidance of harsh events. Most of the state-of-the-art technologies in real-time bus interventions provide visual and auditory alerts to drivers, representing an advantage for fleet operators in terms of continuous vehicle surveillance and driver compliance to traffic rules (Katrakazas et al., 2020).

In this perspective, and considering that buses and trucks are similar modes of transport due to their dimension and design, the i-DREAMS platform will include, as shown in Figure 6, Mobileye, a collision avoidance system that will monitor the road ahead and the driving process, complemented with CardioDashcam, to record events for post-trip analysis, an intervention device that communicates with CardioGateway to receive the status of the STZ and provide visual and sound alerts in real-time, important for eco-driving behavior improvement, and the i-DREAMS smartphone application for post-trip feedback on safety and driving efficiency, also monitoring the smartphone usage, an indicator of distraction (it may be optional for bus drivers to install the app on their personal smartphones, as it cannot be imposed by the company, depending on their acceptance and cooperation). CardioWheel, already tested in BARRA buses and further fine-tuned for the experiments, will be used as an alternative to the wearable, to monitor fatigue, distraction or inattention, as this last one would require a greater effort from the drivers in terms of usability and charging, which was not ideal in a professional environment. Finally, an integration with the FMS standard was developed in order to use an existing system to simplify the driver’s identification, the tachograph, a device fitted into truck and buses that automatically records speed and distance, in which the drivers’ will have to use their ID cards to log their activity, as a legal requirement from transport authorities to check compliance with work regulations.

Figure 6: i-DREAMS suite of technologies for heavy vehicles.

End-of-trip and post trip performance evaluation and feedback are key to develop a proper driver training and coaching program that leads to a visible and lasting impact on professional drivers' safety and efficiency related driving behaviors. In the post-trip intervention framework drivers will receive feedback and scores (not only by means of the smartphone app, but also through a web-based dashboard) on their driving performance under different situations of increased task demand, reduced operator capacity and the departure from conventional/typical user driving profile. The post-trip intervention framework will also adopt gamification techniques to continuously engage and motivate drivers to improve their driving behavior aimed at developing safer drivers (Katrakazas et al., 2020).

2.1.3 Rail (train and tram)

Trains and trams operate differently from the other modes included in the project (car, bus, truck), and trains even more so compared to trams. Both run on tracks rather than on the road, although trams do share the road with other road users along parts of their routes. Trains have signaling systems in place which help to control the environment in which they operate in, and neither trams nor trains have similar dashboards or vehicle controls compared to cars, trucks or buses (Katrakazas et al., 2020).

Certain safety systems are already in place in trains. An example is the “dead-man switch”, that allows to test the attention, presence and health condition of the driver, designed to be activated or deactivated if the human operator becomes incapacitated, such as through death, loss of consciousness, or being bodily removed from control[3]. Most of the systems do not monitor the state of the driver though, and if drivers fail to respond to a warning signal, do not reduce speed, or pass a stop signal, which could be due to inattention, distraction, or fatigue and sleepiness, the brake is automatically applied. In the UK several transport companies have additionally installed driver monitoring systems into their fleets, including in certain trams, for example the Guardian4 system by Seeing Machines, that provide information and monitoring of driver state and just external footage. Currently, no such applications have been used in trains. In terms of applying measures to monitor driver state in trains and trams, it appears that the most applicable and useful measures will be those that comprise of wearable technologies or measures obtained from a driver facing camera (Katrakazas et al., 2020).

Thus said, as shown in Figure 7, the i-DREAMS platform for trams will include the same base equipment as for the other modes. For the context analysis, Mobileye will acquire environmental and contextual information to aid in collision avoidance and improves driver behavior (vehicle information such as lane deviation, longitudinal/lateral movement, headway or collision warnings would most likely not be applicable to tram operations, however speed or braking metrics could potentially be informative; collision warnings may work for trams in shared environments if systems detect other vehicles or vulnerable road users).) Mobileye Shield Plus system, which consists of a Mobileye system with two additional cameras, was evaluated but since trams operate in both directions, it would be very expensive to install. To complement the context analysis, CardioDashcam will record the road ahead, triggered by events, providing valuable information on the driving process for post-trip intervention analysis. The intervention device, will also be available for installation to display the status of the STZ and provide visual and sound alerts in real-time, controlled by CardioGateway unit. The driver monitoring will be conducted based on the PulseOn wearable, as trams do not have a steering wheel, to monitor abnormal driving by focusing on driver states such as distraction, inattention,

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[3] https://en.wikipedia.org/wiki/Dead_man%27s_switch

fatigue and sleepiness through PPG analysis, activity monitoring and sleep quantification. Finally, the i-DREAMS application for smartphones will also be an important tool for post-trip feedback, in order to engage drivers with their performance improvement.

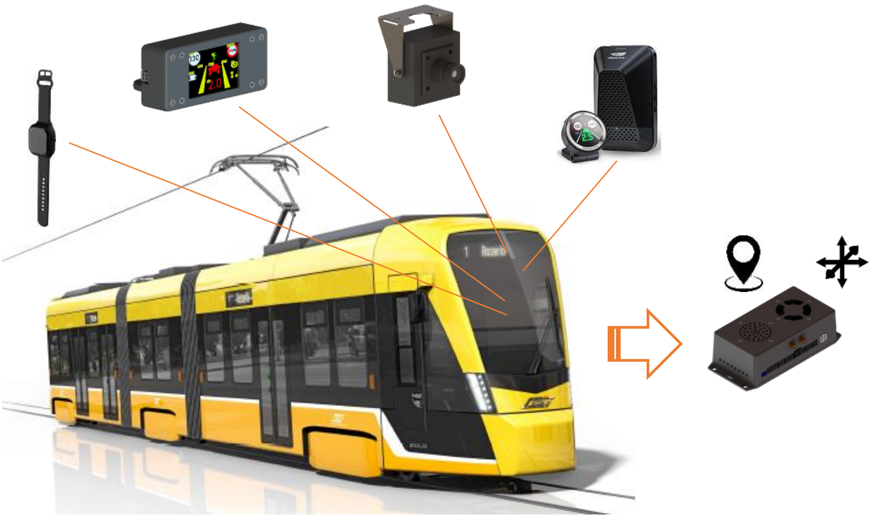

Figure 7: i-DREAMS suite of technologies for trams.

As for the train mode, it will not be possible to instrument such transport with i-DREAMS set of technologies, and so the experiments will be carried out in a simulator environment only.

Nevertheless, and for comparison with the available sensors for the tram mode, systems such as Mobileye, which use forward facing cameras to help with collision avoidance would be less applicable, although it could be useful to detect obstructions on the tracks. However, due to the speed at which trains can travel, by the time an alert has sounded, a driver may not have time to react. In terms of task demand, train drivers may experience stretches of monotonous driving, followed by more active tasks such as stations, busy intersections and crossings. The findings from WP2 indicate that task demand and task complexity can be measured using EEG, vehicle kinematics and skin conductance, as well as eye tracking and ECG, although the most frequent measure of task demand are physiological measures, and so Pulse On would also be applicable to measure fatigue and sleepiness (Katrakazas et al., 2020).

2.2 Simulators

The general purposes of the driving simulator trials in the i-DREAMS project are: to test driving behaviour and validate the STZ mathematical model, to test the monitoring equipment and intervention technologies ability to observe the STZ, and to obtain user acceptance feedback about these technologies. There will be several simulators used for the simulator trials in i-DREAMS including: car simulators in Germany (shown in Figure 8) and Greece, to be used for passenger car simulator trials; large vehicle simulators in Belgium and Portugal, shown in Figure 9, to be used for the trucks and bus simulator trials; and rail simulators in the UK (Pilkington-Cheney et al., 2020).

Figure 8: Car simulator.

Figure 9: Large vehicle simulator.

The data that will be collected from simulator experiments in i-DREAMS comes from various sources such as the driving simulator, i-DREAMS technologies (CardioWheel/Wearable, Mobileye, Intervention Device and CardioGateway, as shown in Figure 10), participants' entry questionnaire, technology acceptance questionnaire and fatigue/sleepiness questionnaires, further detailed in Deliverable 5.2.

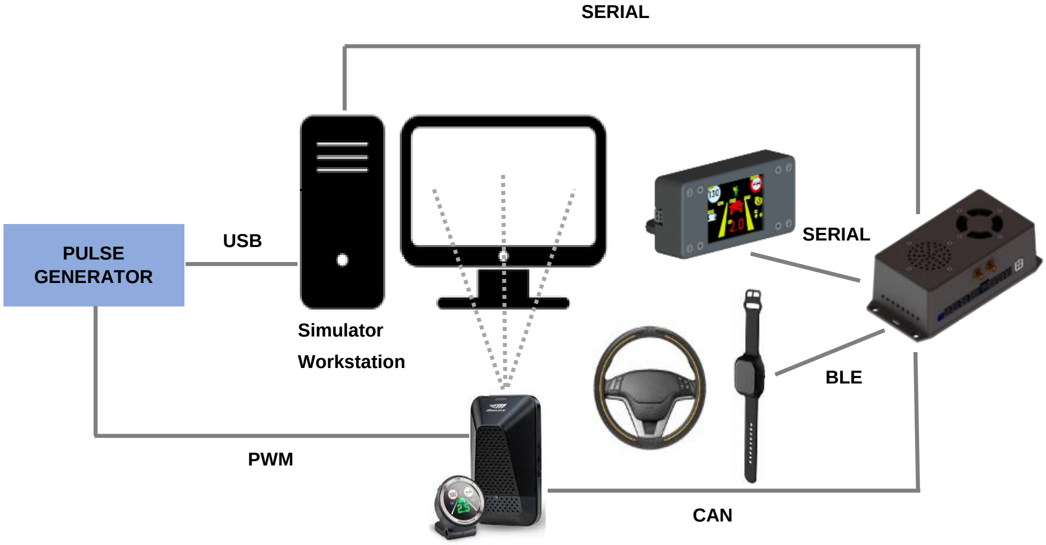

Figure 10: Simulator set up.

3 Data Collection Instruments

This section describes the base hardware used for data aggregation and the outputs that are obtained using these technologies.

3.1 CardioGateway

CardioGateway is designed as a plug & play connection hub and customized IoT edge processing unit that allows continuous aggregation of data from the driver's state monitoring sensors, driving/vehicle parameters, road/context monitoring devices, via BLE, CAN and serial interfaces, and also inertial and GPS information processing, as shown in Figure 11. At the same time, it is an edge computing device that calculates the safety tolerance zone (STZ), allows the triggering of alarms, and or driving of HMI interfaces, and real-time communication with API or storage for post-trip synchronization.

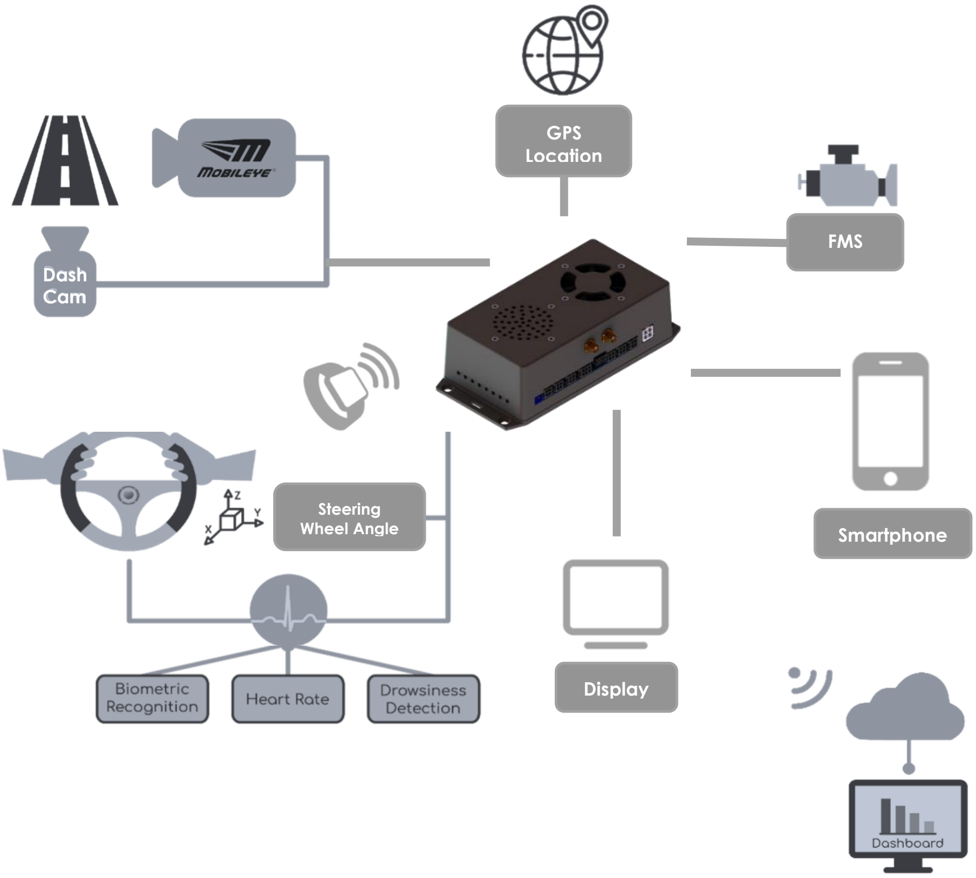

Figure 11: CardioGateway as sensor data aggregator.

A number of iterations were carried out during the development and testing of CardioGateway hardware, as shown in Figure 12, to better respond to the project requirements, and in order to present a reliable and robust solution.

The development started before the beginning of WP4 and was based on CardioGateway version 3. During the initial validation in trucks and light vehicles, the video interface used to connect the dashcam was not robust, leading to the changes to the camera sensor and on the interface.

Figure 12: CardioGateway iterations.

In terms of communication interfaces, the latest version presents an internal 4G modem (with an active antenna), and alternative connection to a Wi-Fi network to ensure connectivity for data transmission, and a GPS with an active antenna outside. Both antennas have to be installed on the windshield.

The connectors that allow the interface with the sensors are automotive grade molex connectors, allowing a greater stability of data collection from the dashcam and the intervention device. CAN interfaces allow connection of Mobileye and FMS (Fleet Management Standard), and there is also BLE connection for CardioWheel and the wearable PulseOn.

The addition of a fan for thermal management and mounting flanges for fixation of the unit under the dashboard were also part of CardioGateway’s design improvement, as shown in Figure 13.

Figure 13: CardioGateway external view.

The system includes an inertial unit composed by an accelerometer and a gyroscope for driver behaviour monitoring. The unit performs a calibration routine after the installation to find the correct orientation of the system in accordance with the vehicle axis. Accelerometer and gyroscope data are processed to obtained events such as harsh-braking, harsh-acceleration, and harsh-cornering and then fused with the speed obtained via CAN bus. The algorithm development and validation was also performed with several types of trips and correlating with other telematics' event detection (in particular with Geotab telematics).

Other features include the capability to control the intervention device, via serial connection, inclusion of an audio interface with an interior speaker (and connection to an exterior speaker), as shown in Figure 14, and the addition of LED's to manage its status, especially important during the unit's installation and for a troubleshooting scenario.

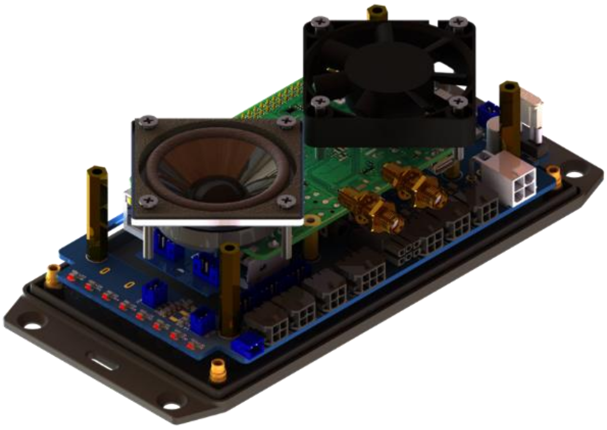

Figure 14: CardioGateway internal view.

CardioGateway computational capability relies on a Raspberry Pi 4, with a Quad core Cortex-A72 (ARM v8) 64-bit SoC @ 1.5GHz processor and a memory of up to 4GB LPDDR4. It has a Linux kernel system, allowing to run several application components, being versatile in terms of programming languages.

3.2 CardioWheel & Wearable

CardioWheel is an Advanced Driver Assistance System (ADAS) that acquires the electrocardiogram (ECG) from the driver's hands to continuously detect drowsiness, cardiac health problems and biometric identity recognition.

Figure 15: Conductive steering wheel cover.

It is composed by a steering wheel with conductive material, shown in Figure 15, that enables the acquisition of the ECG when both hands are in contact with the wheel. The signal is acquired by CardioWheel processing unit, shown in Figure 16, which acquires the signal using a sampling frequency of 1000Hz, and process the information for extracting patterns and perform biometric evaluation.

Figure 16: CardioWheel PCB with enclosure.

CardioWheel main applications include:

- ECG based biometrics – authentication/identification, personalization (extraction of driver's ID, driver's change alert);
- Drowsiness detection – Heart Rate Variability (HRV) combined with Steering Wheel Angle (SWA) producing Karolinska Sleepiness Scale (KSS), an indicator of sleepiness;
- Distraction indicator – percentage of hands on wheel;
- Wellbeing monitoring – detection of abnormal heart condition.

It integrates several communication interfaces, but in this project only the BLE will be used. GATT profiles available include LOD, Driver Change, Fatigue, IBI and Heart rate. The system has the possibility of being powered both by battery, or constant power supply. On i-DREAMS project, and to ease the installation, it will be powered using a battery. Charging of the battery will be possible using a USB cable connected to the intervention device, after the vehicle arrives to a destination.

A wristband will be used in transport modes where CardioWheel is not applicable, shown in Figure 17. It measures the photoplethysmogram (PPG) and allows HRV analysis, activity monitoring/quantification (based on steps) and sleep quantification.

Figure 17: PulseOn wearable.

PPG (photoplethysmogram) technology is based on optical measurement of blood flow under the skin. PulseOn's patented optical sensor includes LEDs that illuminate the skin and the small capillary vessels close to it, and an electro-optical cell (photodetector) which detects the light which is back-scattered from the skin and tissue. When the heart pumps, the blood flow varies according to the heart’s pumping frequency. PulseOn’s sensor detects this variation from the optical signal and translates the data into an accurate heart rate reading with sophisticated algorithms. It also makes available the raw data for further processing, allowing the validation of this technology in the context of concrete scenarios and i-DREAMS project goals.

Pulse On mechanic design allows firm contact of sensor and skin, essential in ensuring accuracy in optical heart rate monitoring – any movement of the sensor against the skin tissue affects the acquired heart rate signal, by causing increased movement artifacts and ambient light disturbance. Its design is optimized to ensure the best performance in different conditions and use cases. Combined with the intelligent algorithms, all disturbances to heart rate accuracy and reliability can be minimized[4].

The wearable is powered by a battery, and the recharging is performed using a 5V USB power supply.

3.3 Mobileye & CardioDashcam

Mobileye is a collision avoidance system that provides drivers with audio and visual warnings of potential hazards on the road, so that they can take action to correct it (e.g., the driver may need to brake in order to avoid a collision). As shown in Figure 18, it supports a comprehensive suite of Advanced Driver Assistance Systems (ADAS) functions – AEB, LDW, FCW, LKA, LC, TJA, Traffic Sign Recognition (TSR), and Intelligent High-beam Control (IHC) – using a single camera mounted on the windshield, processed by a single EyeQ chip[5].

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[4] https://pulseon.com/tech/technology

[5] https://www.mobileye.com/our-technology/

- Urban Forward Collision Warning
- Headway Monitoring & Warning
- Forward Collision Warning
- Pedestrian Collision Warning
- Lane Departure Warning
- Intelligent High Beam Control
- Speed Limit Indication

Figure 18: Mobileye 6 ADAS functions.

To note that on i-DREAMS project, eyewatch component will not be used, since Mobileye warnings will be combined with other inputs and shown in a separate real-time intervention device, developed to customize/trigger interventions, taking into account operator status information (key element on the project).

CardioDashcam is a camera that records the road environment in front of a vehicle, as shown in Figure 19, providing valuable information on the driving process for post-trip interventions scenarios where the videos can be used to contextualize the events that are used to score the driving behavior. The videos are triggered based on events, such as an accelerometer/gyroscope that monitors harsh acceleration/brakes, Mobileye, that monitors possible collisions as a result of tailgating, lane departure, or other external events. The videos have face and license plates obfuscated for GDPR compliance, as shown in Figure 20.

Figure 19: Mobileye and CardioDashcam fitted in a vehicle's windshield.

Figure 20: Blurring of license plates.

3.4 Intervention Device

Figures 21 and 22 illustrate the intervention device, a customized integration of a capacitive LCD display, with some complementary electronics, that communicates with CardioGateway to receive the status of the safety tolerance zone (STZ) and to provide visual and sound alerts in real-time. Additionally, it will also act as an aggregator of information, e.g. identification of the driver.

Figure 21: Intervention device from view.

Figure 22: Intervention device back view.

The intervention device was designed around a Nextion 2.4 inch HMI display[6], a complete HMI solution combining a touch-sensitive LCD screen with an onboard controller and memory. The device is programmed with a custom routine and pre-defined pictures and screens. Right after the vehicle's ignition has been turned on, the Nextion device boots up almost instantly and can prompt the driver with a message to confirm their ID before the boot up sequence of the i-DREAMS gateway is fully completed.

A custom printed circuit board (PCB) that integrated the electrical connector was designed to guarantee the industrial and scalable replication of the device, shown in Figure 23. It consists of a single-layer PCB interfacing the Molex connector to the display itself through an FTDI circuit.

Figure 23: Intervention device PCB.

The enclosure was decided to be based on an off-the-shelve product which could be drilled accordingly with a custom design. The front cover has different mechanical connections with the display and PCB, while the base case has the mechanical connection with the support. The support allows axial and yaw rotation.

This system will also allow the recharging of CardioWheel, using the USB plug on the side of the case. The unit power on/off is controlled by CardioGateway and, even when the vehicle is off, it can be used for charging CardioWheel.

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[6] https://nextion.tech/datasheets/nx3224t024/

3.5 FMS

In 2002, six major truck manufacturers (Volvo, Scania, Iveco, MAN, DAF and Mercedes-Benz) decided to create a standardized vehicle interface for GPS based tracking systems, that specifies in-vehicle communications of the different types of vehicles, entitled the FMS standard. No matter which OEM produces a particular vehicle, if it is equipped with an FMS interface (FMS Gateway), the interface outputs will be standard. The standard itself was a huge step forward in fleet management, since telematics devices could access vehicle technical information without the need of vehicle specific developments (Inventure Automotive, 2020).

For buses and coaches there was no common interface standard for Fleet Management Systems, so the most significant European bus manufacturers decided to design an interface based on the (Truck) FMS Standard according to the J1939 standard. This common interface was called Bus FMS Standard. These establishing manufacturers were Daimler Buses - EvoBus GmbH, MAN Truck & Bus AG, Scania CV, Volvo Bus Corporation, IrisBus Iveco, VDL Bus International B.V. (Inventure Automotive, 2020).

On digital tachograph equipped vehicles, some newer FMS gateways are able to provide Driver ID information on standard FMS output (as defined in FMS 2.0 Standard documentation), which justified further development on CardioGateway software to resolve the multiple driver scenario in buses and trucks. In that perspective, and taking into account that the unit had an available CAN interface, it was possible to have it connected to the FMS interface in order to retrieve such information, as shown in Figure 24, proving once again its flexibility and high customization capacity.

Figure 24: FMS connection to CardioGateway.

4 CardioGateway Embedded Software

The embedded software running on the CardioGateway is a fundamental component of the i-DREAMS system. Therefore, great care and thought went into its design, taking advantage of open-source, well-supported software components, with the goal of having a robust, modular, and easily maintainable system.

The major tasks of the gateway software are as follows:

1. Sensor Data Collection – Data from all on-vehicle sensors must be collected in parallel and distributed to downstream modules that need it.
2. Safety Tolerance Zone Computation – Collected data is fed in real-time to the STZ algorithm, triggering driver interventions when needed.
3. Driver User Interface Control – Real-time driver interventions trigger both an auditory and a visual warning, shown on a display.
4. Data Upload – To support post-trip driver interventions and analysis, collected data is stored locally and then uploaded to the i-DREAMS database server.
5. Diagnostics and Maintenance – Tools and modules to monitor system performance, deploy software updates, configure gateway parameters, and provide remote support.

The gateway runs on a Debian Linux operating system, with the gateway software being developed in Python 3, combining the robustness of a Linux environment with the versatility of the Python language. In the following sub-sections, each software component is described in more detail.

4.1 Sensor Data Collection

The i-DREAMS on-vehicle system collects data from a variety of sensors, obtained through various hardware interfaces. Each sensor produces data with its own communication protocol, its own data format, and its own data rate. Moreover, data collection must be done in parallel, i.e., the system must be able to read from multiple sensors at the same time. On the other hand, data transmission is time-critical, in the sense that important messages (e.g., a collision warning) must be processed in the shortest possible time. Additionally, collected data needs be distributed among several computing modules, which themselves produce output that needs to be sent elsewhere (e.g., to trigger a driver intervention or start a dashcam recording).

The chosen approach to tackle this challenge was to run each sensor module in a separate operating system process, thus parallelizing data acquisition. Inter-module data communication (an N-to-N problem) relies on the ZeroMQ (ZMQ[7]) messaging library, which is a high-speed, open-source networking protocol, supporting multiple messaging patterns (publish/subscribe, push/pull, client/server). In this case, the publish/subscribe pattern is the most appropriate, given we have a set of publishers (the sensors) that need to send data to a set of subscribers (the data processing modules). Specifically, a publish/subscribe Proxy is used, which is a ZeroMQ construct that allows to build an N-to-N network topology (see Figure 25).

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[7] https://zeromq.org/

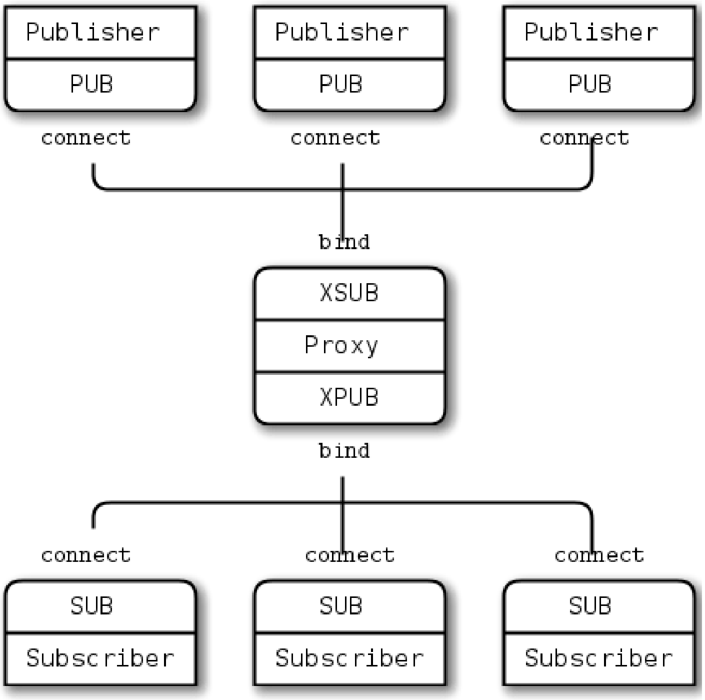

Figure 25: ZeroMQ publish/subscribe Proxy.

The advantages of this Proxy are that both publishers and subscribers connect to one well-known network address, with data being seamlessly replicated to all subscribers, with minimum delay.

ZeroMQ messages themselves are just streams of bytes. Therefore, a data protocol is needed to actually transmit information. For this, each message is a JSON[8] object, prepended with a topic identifier which labels the source of the message (e.g. GPS data). The message JSON objects are encoded to bytes with msgpack[9], a fast library producing small byte streams.

Figure 26 provides an overview of the CardioGateway sensor network, with each module connecting to the ZeroMQ proxy, and Table 2 lists all ZeroMQ topic identifiers.

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[8] https://www.json.org/
[9] https://msgpack.org/

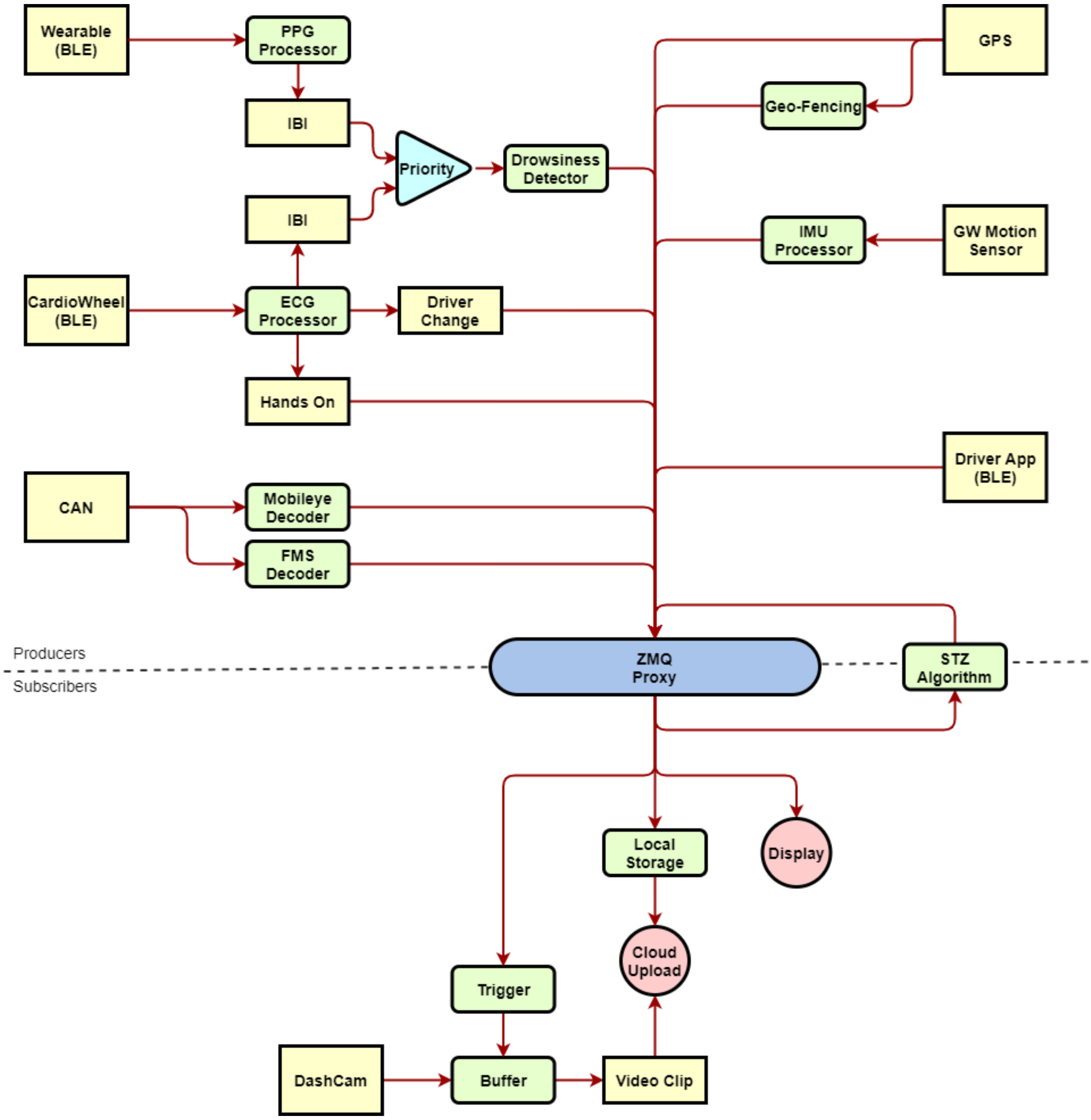

Figure 26: Embedded software flow-chart.

Table 2: Sensor network modules and identifiers.

Module	Identifier	Description	Upload
Gateway	Ignition	Ignition on/off event	✓
CardioWheel	ECG	Raw electrocardiogram signal	
	LOD_Event	Hands on wheel detection event	✓
	IBI	Cardiac Inter-beat intervals	✓
Wearable	IBI	Cardiac Inter-beat intervals	✓
Drowsiness Detector	Drowsiness	Drowsiness detection event (KSS level)	✓
Gateway Motion Sensor	GW_AG	Filtered acceleration and gyroscope signals	✓
	DrivingEvents	Harsh driving detection events	✓
Mobileye	CAN	Raw CAN sensor data	✓
	ME_AWS	Decoded Mobileye AWS message	
	ME_TSR	Decoded Mobileye TSR message	
	TSR_Info	Interpreted Mobileye TSR message	
	ME_Car	Decoded Mobileye Car message	
GNSS	GPS	GPS location message	✓
	Region	Country geo-fencing message	
Driver App	Distraction	Use of mobile phone event	✓
Display	DriverChange	Driver ID selection event	✓
	iDreams_Display_REQ	Intervention display request	
	iDreams_Display_REP	Intervention display response	
STZ	iDreams_Fatigue	Driver fatigue intervention warning	✓
	iDreams_Headway	Headway monitoring intervention warning	✓
	iDreams_Overtaking	Illegal overtaking intervention warning	✓
	iDreams_Speeding	Speeding intervention warning	✓

4.1.1 Driver Identification Module

The i-DREAMS system needs to keep track of the identity of its drivers, especially in scenarios where a vehicle is shared among multiple participants. On one hand, the STZ algorithm takes into account certain driver parameters (e.g. age), with the possibility of having a user-tuned model. On the other hand, personalized post-trip interventions and analysis are only possible if there is a way to know the identity of the drivers.

In the case of professional vehicles (buses and trucks), the FMS interface described earlier has access to the driver identification from the tachograph that, by law, must be installed in these vehicles.

In the case of personal cars, the Gateway takes advantage of the on-board display to ask the driver for their identification. This procedure is done at the start of a trip, requiring, at most, two taps on the display, given the display first asks if the current driver is the same as the one from the previous trip (if known). If the driver does not select an identity, the trip will be discarded, thus the i-DREAMS system continuously verifies participant consent to record trips and personal data.

Once a driver identity is known, the gateway can then connect to the appropriate Wearable device (for cars) and to the driver mobile application, both via BLE. The driver mobile app detects driver distraction periods, which is fed into the STZ algorithm. For this data transfer, the Gateway works as a BLE Peripheral device, meaning that it advertises itself and waits for connection attempts from the mobile app. The Gateway advertisement information includes the driver identifier, allowing the correct driver app to connect. This is important when multiple participants (with the driver app installed) are is the vehicle at the same time. An overview of this driver identification and BLE communication scheme can be seen in Figure 27.

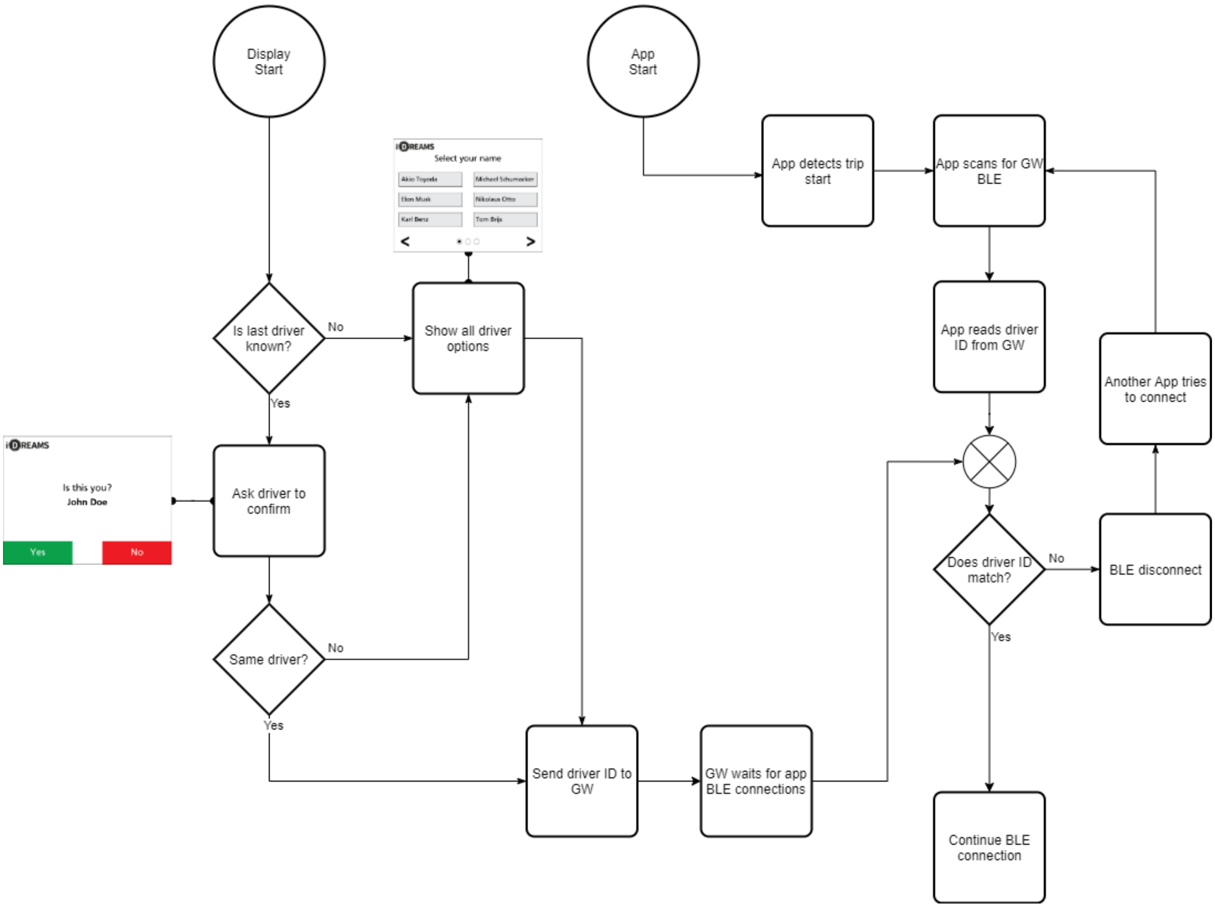

Figure 27: Driver identification workflow for cars.

4.1.2 Dash Camera

Dash camera recordings are triggered by certain events, described in Table 3. In order to also record the period before the trigger, a buffer is continuously kept in memory, being discarded on system shutdown. To ease implementation, the amount of recorded time before the trigger is always the same (10 seconds), with each event specifying the amount of time to record after the trigger.

Table 3: Dash camera triggers and recording durations.

Trigger	Duration (seconds after trigger)
Fatigue Warning	10
Forward Collision Warning	10
Harsh Acceleration	5
Harsh Braking	5
Harsh Cornering	5
Headway Warning	20
Lane Departure Warning	5
Overtaking Warning	10

To comply with local regulations related to the use of dash cameras, the camera module is disabled when the vehicle is in a country where these recordings are not allowed. This geo-fencing is done based on the GPS coordinates and country borders obtained from OpenStreetMap[10].

With the purpose of minimizing video upload time and size (and thus cost), after recording, the videos are compressed locally on the Gateway. After upload, the videos go through an automated process to blur any faces and license plates that may be visible.

4.2 Safety Tolerance Zone Computation

The Safety Tolerance Zone algorithm and its real-time interventions, as described in Deliverable D4.2, act both as a subscriber and publisher in the ZeroMQ sensor network, consuming the sensor data needed to compute the STZ phase and issuing warnings to be shown on the display. The STZ code is implemented in Python as well, taking advantage of widely used data science packages: NumPy[11], SciPy[12], and scikit-learn[13].

4.3 Driver User Interface Control

The driver-facing display runs a user interface application, as described in Deliverable D4.4. This application is controlled by a module in the ZeroMQ network, handling the results from the STZ algorithm. This display controller is also responsible for obtaining the driver identification selected on the display, at the start of the trip. In addition, there is also a controller that drives the speaker on the Gateway, for auditory warnings.

4.4 Data Upload

Data upload is processed asynchronously from trip recording, being done either via Wi-Fi or 4G internet connection. For this, a local trip database is maintained on disk. Upload attempts

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[10] https://www.openstreetmap.org/
[11] https://numpy.org/
[12] https://www.scipy.org/
[13] https://scikit-learn.org/

are robust to connectivity interruptions, resuming as soon as connectivity is re-established. After upload, trip data is kept on the gateway for 10 days, after which it is deleted. In case the Gateway is not able to upload data for a long time, to avoid running out of disk space and thus crashing the system, old trips will also be deleted.

4.5 Diagnostics and Maintenance

Several mechanisms and tools have been implemented on the Gateway to help verify its correct installation and functioning, as well as to assist in issue debugging. Additionally, the Gateway periodically checks for software updates.

An installer application has been developed, which connects via BLE to a Gateway. Once connected, the app allows the installer to verify if all hardware interfaces and sensors are working properly – more details in section 5.

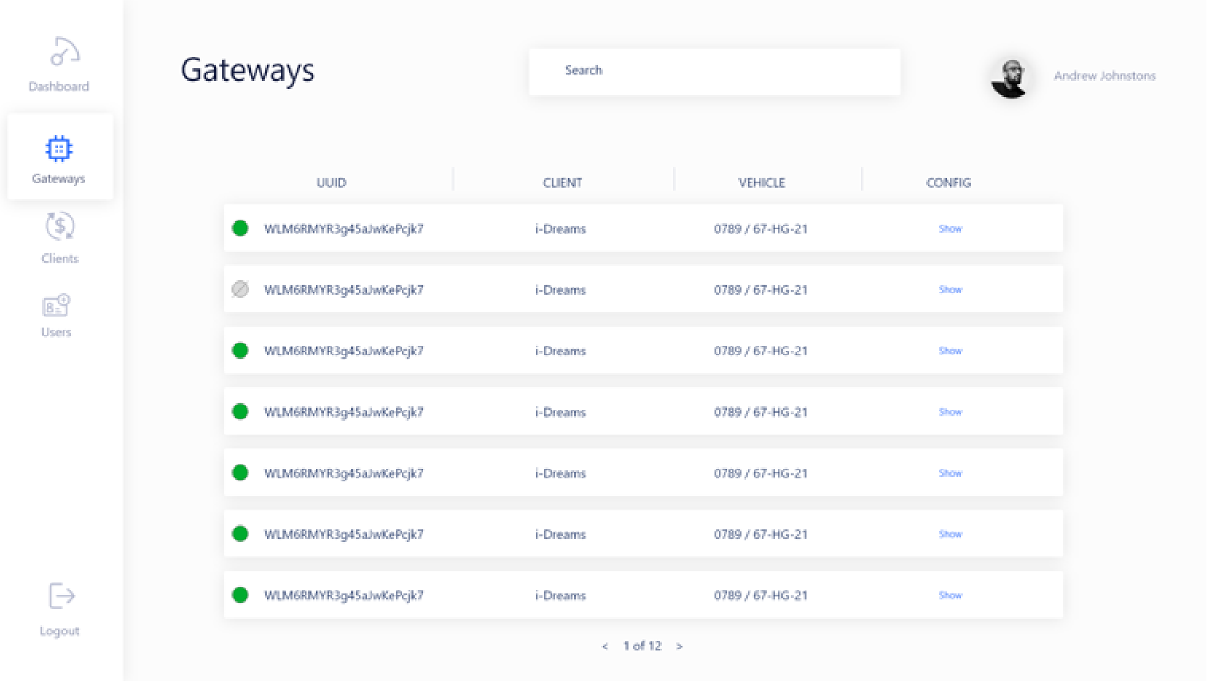
On the Gateway itself, a series of software-controlled LEDs indicate the functioning of core components of the gateway, specifically the gateway software itself, the GPS module, the CAN interface, and the dash camera connection.

While running, software logs from all modules are kept, including informational as well as error messages. Additionally, system performance parameters are periodically recorded and uploaded, namely CPU temperature and load, remaining disk storage, and memory usage.

Finally, on system crash or with a remotely triggered command, a reverse SSH service is started, allowing CardioID’s support team to remotely access the Gateway system, to manually assist in resolving any issue.

5 BackOffice Support Software Infrastructure

To support the installation of CardioGateway, and management of the installed equipment in each vehicle, a web back-office was created. The back-office allows each country coordinator to list all the vehicles and verify the status of each CardioGateway, see Figure 28. The platform also allows the creation of users, according to their roles: installer, supervisor, etc.

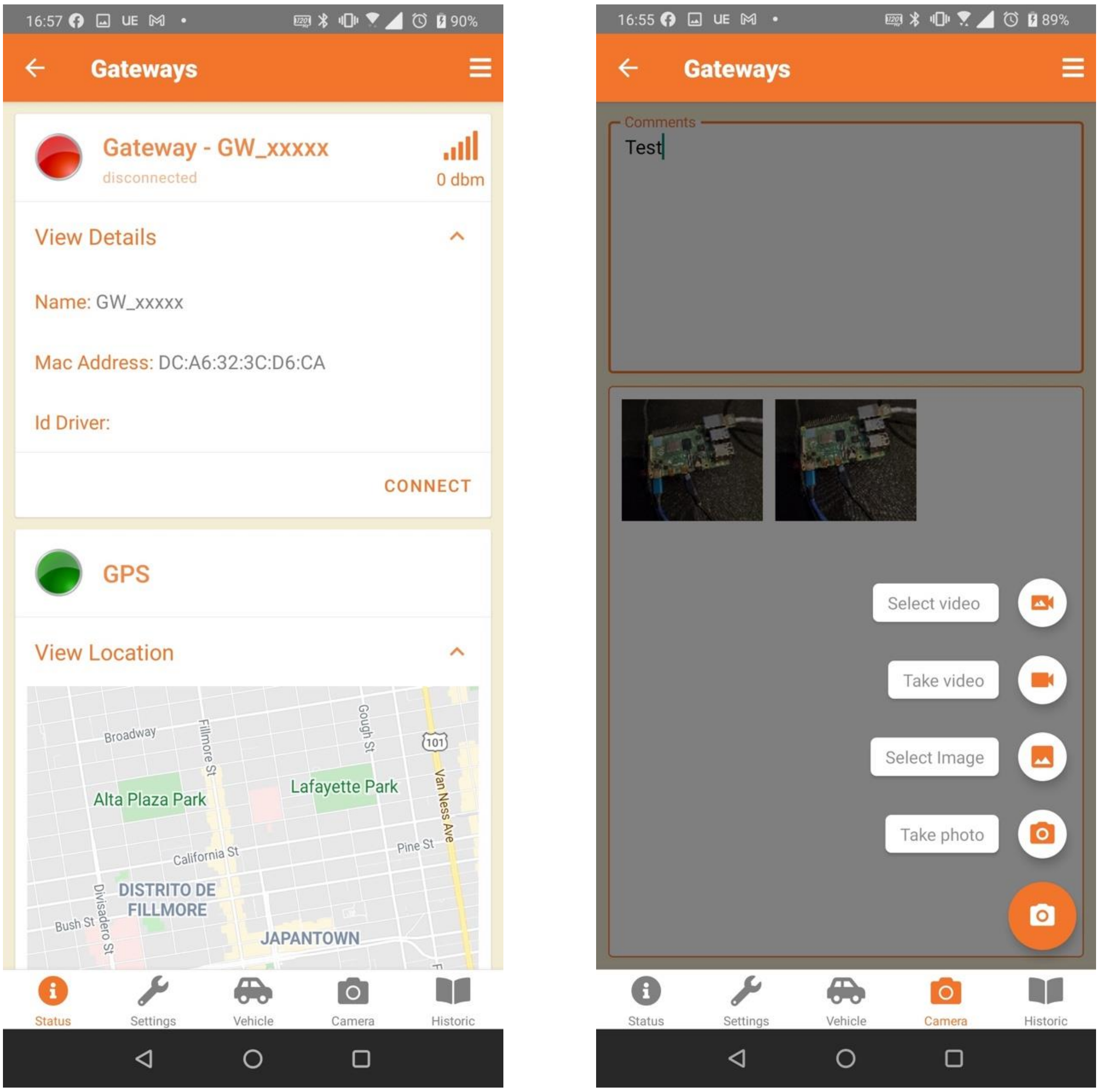


	UUID	CLIENT	VEHICLE	CONFIG
●	WLM6RMYR3g45aJwKePcjk7	i-Dreams	0789 / 67-HG-21	Show
⊘	WLM6RMYR3g45aJwKePcjk7	i-Dreams	0789 / 67-HG-21	Show
●	WLM6RMYR3g45aJwKePcjk7	i-Dreams	0789 / 67-HG-21	Show
●	WLM6RMYR3g45aJwKePcjk7	i-Dreams	0789 / 67-HG-21	Show
●	WLM6RMYR3g45aJwKePcjk7	i-Dreams	0789 / 67-HG-21	Show
●	WLM6RMYR3g45aJwKePcjk7	i-Dreams	0789 / 67-HG-21	Show
●	WLM6RMYR3g45aJwKePcjk7	i-Dreams	0789 / 67-HG-21	Show

Figure 28 – Back-Office Front-end.

Additionally, an Android application was created to help the installer verify that each system is properly installed – see Figure 29. This application will also be used to capture photos of the installed equipment, to guarantee that each of the systems was correctly installed and that the vehicle was not damaged after the procedure. A User Guide will be made available, with instructions on how to navigate the app (CardioID Technologies, 2021).

The information between both systems is synchronized, since both communicate with a central API.



Name: GW_xxxxx

Mac Address: DC:A6:32:3C:D6:CA

Id Driver:

Comments

Test

Figure 29 – CardioGateway Installation Application.

6 Conclusions

The implementation of i-DREAMS project framework is based on a set of technologies to monitor the context, the operator (driver) and the vehicle, and with them assess the 'Safety Tolerance Zone' (STZ). The estimate of the task complexity and coping capacity has to be performed in the vehicle, using an edge computing device in real-time to provide timely interventions to keep drivers in a safe driving zone.

The aim of this deliverable was to describe all the modules for monitoring, integration, real-time processing of information and aggregation in the cloud, collectively entitled as ***i*-DREAMS platform**.

CardioGateway, the central and coordinating element of this platform, has evolved, since the beginning of the project, with multiple versions and improvements after testing and validation in simulation and real world context. The specifications of this system have advanced to allow the robustness required to accommodate trials in 5 countries and cover different modes of transportation.

The i-DREAMS architecture was indeed conceived in a way that enables the integration of different sensor technologies, and the implementation of different instances for different transport modes, proving its high flexibility and customization. In that sense, it is for instance possible to install either CardioWheel, that acquires the ECG, or Pulse On wearable, that acquires the PPG, for physiological signals acquisition. Moreover, and to allow compatibility between modes, CardioGateway was designed to acquire inertial information and GPS, and also read the FMS CAN information, especially important for buses and trucks. Mobileye and CardioDashcam allow the collection of contextual information for real-time and post-trip analysis, the last one being completed with the i-DREAMS app, providing not only useful information on smartphone usage, an indicator of distraction, but also engaging the drivers to improve their behaviour in an interactive way.

In addition, the embedded software that supports CardioGateway was developed in a modular perspective, having time-critical and distributed concepts as concern. The ZeroMQ messaging library allows the parallelization of data acquisition and inter-module communication. The system also includes a driver identification module to keep track of the identity of the drivers, to effectively respond to the multiple driver scenario, using the intervention device as input, or in the case of professional vehicles, the FMS interface. The data upload can successfully be performed via 4G or Wi-Fi internet connection, allowing the synchronization of a local database with the cloud API.

Finally, to support the installations, several mechanisms and tools have been implemented, including a back-office platform for field trial countries' coordinators and an Android application for local installers, in order to help verify the correct installation and functioning of the systems and store evidence for traceability purposes.

On a last note, it is important to highlight once again that at the time of writing this deliverable there has been a global COVID-19 pandemic, with implications on the deployment of i-DREAMS project. It led to a distributed scenario where the technological development had to be coordinated and performed remotely, with big challenges. Additionally, stock shortages and increased lead times from the suppliers of components led to changes on the final designs and demanded a redefinition of suppliers. The manufacturing process was also affected, with constraints on the lead time from assembly partners, affecting therefore the finalization and distribution of i-DREAMS hardware infrastructure to the field trial countries, and causing delays in training and installation activities.

The recurrent lockdown periods on each of the countries, with unknown extension, are a big challenge. In the technological point of view, all the efforts are being made to mitigate, as much as possible, delays with the experiments, with close evaluations on the progress of the COVID-19 pandemic and discussions between partners on solutions to avoid higher deviations to the project's original timeline.

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