Smart Healthcare Monitoring System For Healthy Driving in Public Transportation

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Abstract — **In an age where citizens are constantly moving between different places, transport demand is extremely high, and so, it is important to have sophisticated public transportation systems in place to ensure a sustainable development of urban areas and meet the needs of citizens. Public transport operators consequently need to provide reliable services in order to minimize disruption events that can affect the vehicles and their drivers, such as breakdowns, accidents or illnesses. The project here described focuses on the type of events and approaches related with the vehicle drivers and the identification of both their performance profiles and health condition while in operation. For that purpose, existing non-intrusive technologies present on the vehicle are leveraged, able to collect data related to physiological measurements taken in real-time. Such sensitive data will be processed, stored and shared in a secure manner, using blockchain-based technologies, so that only authenticated and authorized parties will be able to access the data, according to their clearance level, through an Application Programming Interface (API) designed for that purpose. The architecture of the system will be microservices-based, with components deployed at different infrastructure levels—from On Board Units (OBUs) in vehicles up to cloud-based subsystems.**

Keywords - Blockchain; Public Transportation; Security; Reliability; Performance Profile; Microservices.

I. Introduction

Transportation needs of citizens have evolved and have increased over the past few years. Furthermore, the passenger travel demand on public transports is expected to increase even more in several areas of the globe, according to official estimates from Organization for Economic Co-Operation and Development (OECD) [1], as shown in Figure 1. These estimates are based on the fact that public transports are considered one of the most sustainable ways to transport citizens in a transition to a greener future, where one of the main milestones will be to reduce CO_2 emissions as much as possible. This has forced public transportation organizations to expand their business by acquiring new and different (non fossil fuel-based) types of vehicles, to hire additional vehicle operators and to create new transportation routes, in order to cover as many places as possible, in a sustainable manner. With this expansion in mind, it is important for those organizations to maintain a good level of service reliability, in order to ensure passengers arrive to the final destination on time, without any delays or service interruptions. This is a challenging task, as these delays and service disruptions can be caused by multiple factors, including irregular loads, traffic, as well as vehicle and crew availability.

The project here described will focus on the latter aspects (i.e., crew availability), by taking into account a performance profile of each vehicle driver regarding the service they should be operating in and the vehicle they should be driving.

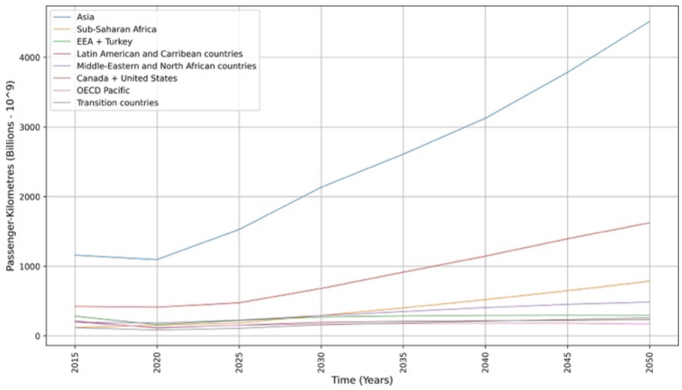

Figure 1. Public Transportation demand (BUS) over the years. Source: [1].

There are certain aspects of the human body and behaviour that can be detected and analyzed, making possible to determine whether someone is feeling specific emotions, such as anxiety, or if they are stressed or tired to the point of not being able to perform their job in a secure and efficient manner. A performance profile of drivers, to be created and updated, will be based on physiological measurements collected in real-time from existing non-intrusive devices in the vehicles, during the operation on a certain service route. The devices, equipped with specialized sensors, use different types of technologies, such as eye tracking cameras (to determine driver fatigue) as described by Singh et al. [2] and a steering wheel with Vital Body Sign (VBS) sensors that allow to collect important data regarding the driver's state as mentioned by Maita et al. [3]. The performance profile will help to reduce the adaptation time for drivers, in relation to the type of vehicles they are going to operate and the routes they are going to operate them on, by providing adequate information for allocating such drivers to vehicles and routes where their performance is expected to be maximized.

This is based on the fact that each defined service route has different characteristics that may influence driver's performance, such as:

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– **Traffic:** Usually, high traffic density may induce stress on vehicle drivers, whereas low traffic density may do the opposite;

– **Route Areas:** Each route passes through different areas, such as streets that are plane or places where the driver is required to employ specialized maneuvers, or areas that may also affect stress levels such as those where the known rate of criminal activities may be higher than usual;

– **Weather:** Weather and environment conditions may also affect the performance of vehicle drivers. For example, higher temperatures inside the vehicle typically make drivers feel more tired than usual.

The main purpose of the project is, therefore, to develop a **Health Monitoring System** to promote **Healthy Driving in Public Transportation** that allows to identify the performance profile of a vehicle driver. The required methodologies and technologies to be used will be described in Section II together with the analysis of related works. The proposed solution for this project is then described in Section III, together with the methodology for its development and evaluation.

II. Background and Related Work

There are several approaches regarding the ways physiological measurements can be collected, as well as how that data should be transported, stored and accessed. This includes, but is not limited to, blockchain-based Distributed Ledger (DL) for storing the secure and decentralized data structure, information system architectures for the adequate processing of the data, such as microservices, and techniques that are already used in different sectors and for many similar purposes, such as Messaging and Message Broker Systems. The key VBSs to measure are the Movement of the Eyes, the Pression exercised on the steering wheel, and the Heartbeat.

A. Physiological measurements

As stated by Maita et al. [3], it is important that this layer of the system is as transparent as possible to the drivers, so that they are able to behave and perform their tasks in a normal manner, and to avoid discomfort. Thus, it is crucial to distribute the sensors on the vehicle rather than force the driver to use wearable devices. The minimum set of VBSs to be considered are **Fatigue** and **Heartbeat**:

Eye tracking and Fatigue monitoring: The project described by Singh et al. [2] intends to reduce the amount of accidents and service disruptions caused by the drowsiness state of the vehicle driver (which is directly related to driver fatigue, in most cases). One of the physiological measurements that is collected is the movement of the eyes of the driver, a measure referred to as “PERCLOS” as “a standard for drowsiness detection” as it corresponds to “the percentage of eyelid closure over the pupil over time and reflects slow eyelid closures rather than blinks” [2]. For that purpose a camera is placed in front of the driver seat to cover all the face. The project also takes into account the abrupt changes in the speed of the vehicle, due to the fact that driver drowsiness can cause irregular acceleration or deceleration. The system is also able to alert the driver for danger situations, before they take place, by means of an “Alerter subsystem” that triggers a *seat belt vibration* (with a frequency between 100 and 300 Hz, and a *sound alarm* (to make the driver aware that there is imminent danger). Those components cannot be turned off automatically. There is a Driver’s Safety Device (DSD) manual mechanism in place to enable/disable those components of the “Alerter subsystem”, such as a switch (commonly designated as “Dead Man’s Switch”), which must be toggled by the drivers, for security reasons, to ensure they were alerted and are aware of the situation.

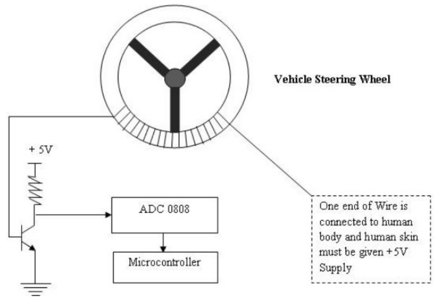

Figure 2. Steering Wheel components. Source: [2]

Steering wheel pressure: Another component of the system in [2] is shown in Figure 2. and corresponds to a steering wheel that is capable of detecting the pressure the driver exercises on it, at a specific moment, based on the fact that the human body conducts current. A similar solution is implemented and described by Maita et al. [3], but using a method to detect whether the driver is exercising adequate pressure on the wheel, by means of elastomeric sensors and the movement of the hands of the driver. Both systems alert the driver whenever the pressure is below a static threshold value, to prevent possible accidents.

Heartbeat: In order to detect the heartbeat of the driver in an efficient and accurate manner, it is important to take into account the state of the vehicle, since the vehicle noise increases with its speed, and it changes according to the vibration of the vehicle and the movements of the driver, on the seat. The project described by Hideki et al. [4] makes use of a contact electrode on the steering wheel of the vehicle and a capacitive electrode on the seat of the driver. The signal from the steering wheel electrode contains both the heartbeat and the noise, while the signal from the seat electrode only contains the noise. This allows the system to apply a noise reduction technique, by taking into account the difference between both signals amplitudes and by calculating the average from both signals and subtracting these values from the seat electrode and the steering wheel electrode, after adjusting the gain of the signal coming from the seat electrode, since it is the one with a lower amplitude (as illustrated in Figure 3. According to the authors, it was possible “to obtain 80% or more of the heartbeat signal while driving at high speed, with one hand.” [4].

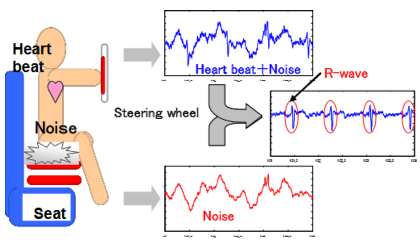

Figure 3. Driver seat Noise Reduction system. Source: [4]

B. *Messaging and Message Broker Systems*

A flexible manner that allows the components of a distributed system to communicate reliably in a loosely coupled form is by means of a "message broker", where the information exchange is achieved by translating messages between different formal messaging protocols, and so, message brokers serve as a distributed communications layer to allow applications spanning multiple platforms to communicate among themselves as if directly connected to each other.

There are two message distribution patterns for message brokers: 1) "Point-to-point messaging" for message queues with a one-to-one relationship between the sender and the receiver, and where each message in the queue is sent to only one recipient and is consumed only once; 2) "Publish/subscribe messaging" for message queues in which the producer of each message publishes it to a topic, and multiple message consumers subscribe to topics from which they want to receive messages.

In the other hand, certain types of information that are considered to be highly sensitive, must be protected, as stated by Lebepe et al. [5], when referring to the system they developed. So, these systems must ensure that the information is transmitted in a secure and efficient manner.

Among the many protocols and technologies available to achieve the goals for this project, the ones considered as the more effective and adequate are: Apache Kafka, RabbitMQ [6] and Message Queuing Telemetry Transport Protocol (MQTT).

Kafka: is a project of the Apache Software Foundation (https://www.apache. org) and it is an open-source distributed stream platform (publish/subscribe system) which was designed for "low latency and high throughput", as described by Shree et al. [7] and is being integrated in systems that use massive amounts of sensors and mobile devices, "as a real-time messaging system", as stated by Wu et al. [8].

RabbitMQ (https://www.rabbitmq.com): It is also an efficient and scalable publish/subscribe system, which supports Advanced Message Queuing Protocol (AMQP), by default, and other protocols. Messages are forwarded to specific queues, by the "exchange" component, according to a set of established rules (called bindings), and the queues store such messages and send them to the consumers, as it is based on a push approach, while Kafka is based on a pull approach.

According to Naik et. al [9], "MQTT is one of the oldest Machine-to-Machine (M2M) communication protocols". MQTT is a standard messaging protocol of the Organization for the Advancement of Structured Information Systems (OASIS), specifically designed for the Internet of Things (IoT). MQTT is designed as a lightweight publish/subscribe messaging transport for connecting remote devices with a small code footprint and minimal network bandwidth. One advantage of this system is that it is very lightweight and "is most suitable for large networks of small devices that need to be monitored or controlled from a back-end server" [9].

C. *Distributed Ledger and Technologies*

DLs are highly available, append-only distributed databases that can work on untrustworthy environments in which Byzantine failures can happen, such as crashed or unreachable nodes, large network delays, as well as malicious behavior of nodes. The use of Distributed Ledger Technology (DLT) and a Blockchain-based DL can help to ensure the security constraints related with the sensitive physiological data of the vehicle drivers and their performance profiles. Generically, a Blockchain can be defined as a structure of data, with inherent security qualities, built as "a sequence of blocks which hold complete lists of transaction records, like conventional public ledger", according to Zheng et al. [10]. Furthermore, it is "nearly impossible to delete or rollback transactions and data once they are included in the blockchain. In personal health data sharing systems, the data collected is usually controlled by multiple service providers, device manufacturers or healthcare systems. This is a barrier for data sharing and poses a threat to privacy and data security, as stated by Zheng et al. [11]. However, the authors mention that a blockchain can help prevent these risks, by encrypting user data, using asymmetric cryptography for authentication, and allowing users to be in control of their own data (being able to track where such data is used, by owning it).

The base tool to be considered for developing Enterprise Blockchain-based applications and solutions with modular architectures, is the Hyperledger Fabric (https://www.hyperledger.org), an open source, extensible and Permissioned blockchain framework that does not depend on cryptocurrencies. As stated by Androulaki et al. [12], it allows to manage identities by having a membership concept, supports the "execution of distributed applications...consistently across many nodes", and the transactions can be executed not "only by a subset of peers" but also executed in parallel.

III. SOLUTION ARCHITECTURE

For this project, it is considered that there are different non-intrusive devices that collect physiological measures in order to create the performance profile of a vehicle driver. The data collected by those devices must be sent to a cloud-based platform in order to be processed and stored. Since such data is sensitive, a Blockchain-based technology is used to store cryptographic pointers to the data, while the data is stored off the blockchain in a secure and anonymized way. The cloud-based platform of the solution is architected with a containerized microservices-based approach, and deployed in scalable, highly-available and orchestrated clusters, such as Kubernetes (https://kubernetes.io).

The high-level architecture of the Proof of Concept (PoC) for the proposed solution is shown in Figure 4.

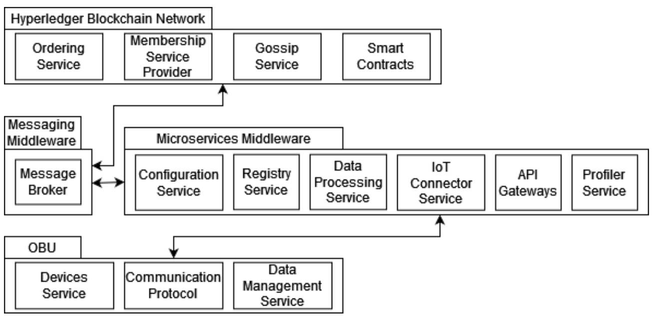

Figure 4. High-level architecture of the proposed solution.

The architecture considers a Service Platform Middleware Layer comprising a Messaging Broker and a modular Microservices middleware that includes a Data Processing Service and a Profiler Service, as well as the Application Programming Interface (API) Gateways (for User-oriented external Applications interactions and for internal interactions between modules and components of others layers). For this project, the most important data to be collected in order to build the profile of a vehicle driver are the **Heartbeat** [4] and **Fatigue** [2]. Additional data may be added to the profile of a vehicle driver in the future, should that be deemed necessary, as the solution is modular and will have support for that. The collected data will be processed at the On Board Unit (**OBU) Computer** in vehicles, which corresponds to the edge component connected to local sensors, and may process some of the collected data, to a certain extent, and communicate that pre-processed data to the **Cloud-based Service Platform** that corresponds to the core services that will fully process the received data. The network communication protocol to be used related with VBS signals will mainly be MQTT. The Microservices Middleware follows a modular microservices approach and includes (v. Figure 4. : a **Registry Service** to register entities and users in the system, with custom identifications, roles and secrets; a **Configuration Service** to register, change or maintain the configurations of the platform at several levels; a **Data Processing Service** responsible for receiving the data from the OBUs, processing them according to adequate rules and adequately storing such data, ensuring confidentiality in order to prevent the data from being tampered with; a Profiler Service to analyze, convert and characterize the data in order to create/update the profile of a vehicle driver; the API Gateways to interact and communicate with and between the different components of the platform, and the other services; and IoT Connectors that allow the adequate communication flows with the OBUs and convert messages from different edge devices (OBUs) to a standard protocol. Those microservices will be deployed on a Kubernetes cluster, which will be provisioned on a public cloud such as Google Cloud Platform (GCP). Each component of the project will be evaluated, according to their specific functionalities. Furthermore, the interactions between the components of the system will also be tested, as it is crucial that all components be able to communicate with each other properly. The scalability of the system will be evaluated, to a limited extent, as it will be expected to collect multiple data from several vehicles at a time, which will be tested through simulations, e.g., for OBUs, as described by Zelkowitz et. al [13].

IV. Conclusion

This documents describes a solution for a Healthcare Monitoring System for healthy driving in public transportation. The system will allow to monitor specific health signals of vehicle drivers, which will permit to create a profile for each driver and allocate them to a vehicle and route where their performance can be maximized. Furthermore, it enables vehicle drivers to react fast in case of imminent danger. The motivation of this project is related with the urge of smarter methods to maintain a good level of service reliability in public transportation in order to minimize delays and service disruptions, that are due to vehicle and crew availability, determined in near real-time from smart monitoring implemented in the vehicles. The most important physiological signals to be collected and analyzed were described, as well as the devices that can be used. The technologies for the implementation of the system were also presented, including those for data transport, storage and virtualization. The high-level architecture of the proposed solution contains the necessary components that enable the system to fulfill its purpose and enables such components to communicate.

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