Skadi: Heterogeneous Human-sensing System for Automotive IoT

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***Abstract*—Over the past years, cars' computing, sensing, and networking capabilities have rapidly increased, and the automotive development aims for autonomous driving. However, the driver is still the focal point for decision making. It has to be alert at all times to avoid traffic accidents due to human factors like tiredness, inattentiveness, and intoxication. Therefore, there is a need for a system that monitors the driver and intervenes before human failure can have a negative impact on traffic. A variety of commercially available wearable IoT devices, such as smartwatches, bracelets, and rings, are capable of monitoring human health conditions. However, those devices come with technological differences and manufacturer-specific implementations. This paper proposes a prototype for a human-sensing and health monitoring system based on wearable sensor devices. The aim is to find a solution that ignores the technological heterogeneity of IoT devices and generalises their implementation into the automotive system. Consequently, the data should be available to be analysed together with the data collected from the vehicular sensors. Our solution is compatible with open-source platforms Eclipse Hono and Kuksa.**

***Index Terms*—Internet of Things, Vehicular Systems, Automotive Computing**

I. Introduction

Autonomous and semi-autonomous cars have become more and more popular among many car manufacturers, and they can handle longer highway drives or stop-and-go traffic autonomously. However, there are still no fully autonomous cars on the roads, and it poses a significant challenge to make the vision of fully self-driving vehicles possible. This is mainly because this technology and the needed infrastructures are still unavailable worldwide. Therefore, there is still the need for a human driver responsible for the decision making and handling of the majority of driving tasks. Even in semi-autonomous cars, the driver still has to rely on their skills to a certain extent and be alert if the system fails. This also poses the chance of human failure because car drivers still represent the majority of lethal traffic accidents and passengers [1]. With the help of many actors in the automotive industry, the number of traffic accidents is aimed to be reduced by a further 50% by 2030, even reduce them close to 0% by 2050 in the EU [1]. The reverse case of the car being alert to human errors also needs to be considered to achieve this.

Automatic human (driver) behaviour tracking is proposed as a possible solution for decreasing human failures in traffic [2]. Some studies have to come up with feasible concepts involving mostly self-developed wearable devices or sensor systems that can monitor the test subject's health condition. However, despite achieving high accuracy [3] they have not gotten to the point of being tested outside of simulations. This is because those are either not practical in real-life scenarios or are too conspicuous and uncomfortable. For instance, the number of sensors needed to be attached to the test subject's body [3] can make the system usability insufficient. Some approaches are based on image and motion capture, i.e. Driver Fatigue Monitoring Systems. They usually have limitations regarding computational power, light conditions, and camera angles [4], or can only detect behaviour when shown on the face [5]. In addition, there are concerns regarding privacy and personal data when the face is filmed for face recognition. Therefore, future approaches for automatic driver behaviour tracking and health condition monitoring should be based on products already on the market and preferably inconspicuous.

This paper proposes a prototype for a health monitoring system based on wearable devices for automotive Internet of Things (IoT) solutions. Unlike current commercial automotive systems, our solution is connected to the instance of an open-source cloud. This should ensure the principle of Continuous Integration / Continuous Deployment (CI/CD) in the long term.

II. System Design

Goal of the prototype. This paper proposes a prototype of the human-sensing IoT system with an IoT gateway that controls sensors of a selected IoT device, collects their data and forwards it to the back-end cloud. The cloud service could be replaced by an edge infrastructure closer to the road traffic in the future. The data provided by the prototype can be used for user studies run in the university testbed in the future. In its current form, the prototype can be used to collect data from driver-worn wearables, combine it with the in-vehicular (i.e. the car's own sensors) data, and visualise and demonstrate the data flow in the cloud. Thereby, it should be ensured that the platform is expandable for other wearables and sensing devices either in the vehicle itself or worn by the driver.

Sensors. The sensors included in the prototype could be used for the proposed driver monitoring system as follows:

- Heart Rate. Heart rate is an essential factor in monitoring the mental and physical condition of the user, for example, signs of stress and drowsiness.

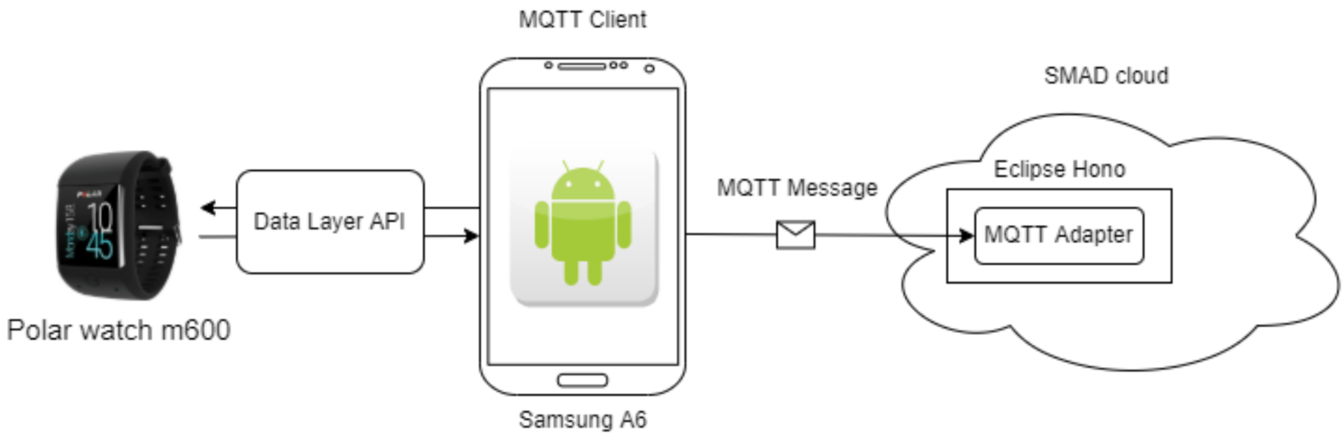

Fig. 1. System architecture of the Skadi prototype using the Polar smartwatch, Samsung smartphone, and Eclipse Hono cloud service called SMAD, that also collects the vehicular data through Eclipse Kuksa service.

- Gyroscope. This sensor can detect changes in the angular movements of the carrying hand during steering.
- Accelerometer. With this sensor, different activities of the driver's hand can be recorded. Depending on the wearing hand, those activities could include steering right or left, shifting gears or activating the windshield wipers. Furthermore, in combination with the gyroscope, it is possible to record the overall movement of the wrist.
- Ambient light. During the nighttime, the likelihood of tiredness and drowsiness increases. In addition, environmental influences like seasonal differences during autumn and wintertime are factors for earlier and longer darkness.

Together, these sensors and others available in the wearable devices should be capable of analysing the driver's stress levels, tiredness, and inattentiveness, maybe even alcohol and drug use. The Skadi prototype is the key for future research to be conducted with real people to gather data for further analysis and algorithmic development.

Architecture. Figure 1 shows the system architecture of the Skadi prototype. It consists of three elements. The first element is a smartwatch to gather the sensor data from, including four different kinds of smartwatch sensors: hearth rate gyroscope, accelerator, and light. The goal is to make the system distinguish the sensor data items from each other, even if coming from different sensors of the same source (smartwatch). The chosen device is the Polar m600 smartwatch. This particular smartwatch was chosen due to its built-in heart rate sensor. The second element is the middleware / IoT gateway that controls the smartwatch's sensors. This is represented by an Android smartphone but could later be replaced as the vehicle's entertainment unit or any suitable computer locally. Any Android smartphone with at least API level 25 can be used for the Skadi prototype. The chosen smartphone is a Samsung Galaxy A6 SM-A600FN/DS with 3GB RAM.

The third element is the cloud that will receive the sensor data, SMAD. The most important part of the cloud is an instance of Eclipse Hono. This system's endpoint receives the incoming data and forwards it further into the cloud. The driver-based sensor data is the most beneficial when analysed with the vehicular data. Thus we are using the same cloud-platform Eclipse Hono, which is also used in Eclipse Kuksa [6]. Kuksa introduces a software and cloud stack for in-vehicle IoT applications that can be used to develop and test vehicles with a specific hardware interface. The developed prototype Skadi uses the MQTT protocol to connect to Hono.

Implementation. Skadi, in its current form, requires both the smartwatch and the smartphone to be paired by the Wear OS Android app. This will enable them to access the Wearable Data Layer API. Skadi includes two Android apps that are used by the devices paired via the Wear OS. The first app is a standard Android app installed on the smartphone. The second one is an Android Wear app that is installed on the Polar m600 smartwatch. Both have to be installed through an SDK like Android Studio. The apps in combination will be referred to as companion apps in the further course.

The companion apps communicate through the Wearable Data Layer API that uses Bluetooth as a proxy for data exchange. Alternatively, the devices would be able to communicate through a network via Wifi or mobile data, but that could cause a higher battery drain. Moreover, the communication via the Data Layer API is easier to implement. Once the devices are paired via the Wear OS app and the google services are added to the dependencies of the wearable app, the services can be accessed without any further explicit implementation. The mobile app works as the middleware between the IoT device (smartwatch) and the SMAD cloud. On the one hand, it registers and connects itself as the MQTT client to an active Hono tenant. On the other hand, it enables and disables sensors of the smartwatch.

Skadi is designed with an assumption that the SMAD cloud is actively running on a computer or cloud. Furthermore, an Hono tenant has to be set up in advance. The mobile app was designed so that there must be a successful connection to an Hono MQTT tenant to unlock its other functionalities.

The Hono receiver acts as the MQTT adapter, which receives incoming messages and forwards them to the rest of the cloud.

Data Processing. Once a smartwatch sensor is activated, the initial value shown is 0. Once an activated sensor updates its data, the wear app sends its most recent value via SendThread. To differentiate which sensor the data is from, the wear app sends a unique prefix character for each sensor together with its updated value. The mobile app 'removes' the prefix by initialising a new sub-string without the prefix character, containing only the sensor value. This sub-string is then forwarded to the MQTT adapter.

III. Discussion and Results

Heterogeneity of Manufacturer Specifications. As the main requirement of this system suggests, there needs to be a middleware that ignores the technological heterogeneity, and different implementation approaches of each included IoT device. Some manufacturers require proprietary software or APIs for their devices. Therefore, they cannot be combined with other IoT devices systematically, especially if all devices are aimed to be controlled by the same middleware. For example, the Oura API needs to be used to access the data of the Oura ring. Bosch's XDK sensor device is also only programmable with its corresponding prototyping platform. Furthermore, integrating a device using a different programming language can also be challenging. Therefore, only devices can be combined if their manufacturers offer open-source libraries and frameworks.

Processing Power of Mobile Phones. One of the limitations of the Skadi prototype is the processing power of smartphones. While it is easy to use a smartphone as the IoT gateway, it cannot handle the massive amount of data sent from the smartwatch's accelerometer and gyroscope sensors. As proposed, their data flow had to be reduced by a running average or waiting for sufficient change in the value before sending a new reading into the gateway. Otherwise, the mobile app crashes due to the "constant" change on the slightest movement of the smartwatch. Once other IoT devices and sensors are included to the system, performance testing with other smartphones should be conducted for comparison.

Pre-Processing and Accuracy Loss. The collected data is aimed to be used to train machine learning algorithms, such as neural networks. These algorithms should handle the decision making how the car should react following the driver's state. In the current state, limiting the data flow from the gyroscope and accelerator sensors can lead to the loss of accuracy. The future work focuses on not only adding new sensors but also validating the existing data readings.

Improvement of Companion Apps. Both companion apps need improvement and optimisation. For instance, once the connection to Hono is established, the mobile app assumes a constant connection. The user will not be informed if the connection is interrupted and the UI elements are not updated. Furthermore, the mobile app does not have an always-on mode yet. If the mobile phone's screen turns off, any data transmission will be interrupted. Therefore, it needs to be implemented so the screen will always be on while the app is used. Another possible way to improve both companion apps would be to replace the sending threads. Threads have a considerable overhead, and therefore, the messages between the coupled devices should be exchanged in a more optimised way.

Extension of the System with more Devices and Sensors. Above all, the system would need to be extended by adding more devices and sensors. For instance, in the scenario of driving, the eSense earables could additionally detect the movement of the driver's head. Furthermore, sensors from a smartphone could also be included. For example, the GPS sensor could determine the car's position in case of emergencies. Moreover, the smartphone's accelerometer and gyroscope sensors could detect the car's movement and the tilting of the phone. In addition, the more contextual information about drivers and their background should be known. For instance, the research in mental and biophysical monitoring should include sensor data from test subjects whose medical conditions deviate from a generally healthy person [7]. In addition, while earplugs like the eSense earables are less conspicuous than a full headset, it should be studied with real users whether it could still feel unnatural to wear them while driving.

IV. Conclusion

This paper proposes a prototype for human sensing and health monitoring system for automotive context. The prototype Skadi includes a smartwatch as an IoT device with different sensors that can be controlled remotely via a smartphone. The smartphone connects to a cloud, collect different sensor data and forward it to the cloud. Skadi also demonstrated how smartphones and other mobile devices could be added to the SMAD cloud as MQTT clients. In addition, Skadi provides a way to distinguish which sensor the data comes from. Despite the limitations the prototype presented, it shows how IoT systems could be implemented on a larger scale using open-source software in the future. Lastly, we discussed how future research could combine the aspects of wearable IoT systems and automotive applications in a more efficient way.

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