flourish

EMPOWERMENT THROUGH TRUSTED SECURE MOBILITY

Human State Monitoring System

Executive Summary: Evaluation Report

May 2019

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1. Introduction

Human State Monitoring (HSM) adds an extra dimension to Connected and Autonomous Vehicles (CAVs), by allowing machines to have a greater depth of understanding about their user. Whilst certain information can be very easy for computers to capture and begin to comprehend (such as date of birth, and name) and provide the user with a more customised experience (like welcoming by name) this is reliant on 'hard coded' information rather than dynamic updating.

By proposing a Human State Monitoring System, it is hoped that through advanced, non-contact, physiological sensing, it will be possible to gain insights into a user's state – for instance are they relaxed, or feeling anxious. By taking this into account in real-time the CAV can adjust its behaviour to provide a more responsive and satisfying journey.

This document outlines the objectives which were set at the beginning of the work, and then an evaluation of how well the completed system supported the overall objectives.

2. Objectives

The following set of objectives were laid out to guide the creation of the system.

OBJ1. Data should be gathered on human users in real-time
this is necessary to ensure that such a system can provide insights to the CAV system in a timely enough manner to be useful to wider decision making.

OBJ2. Sensors should be non-invasive
this is a key requirement, as all previous systems had involved requiring users to wear intrusive or contact sensors. This caused a major block to implementation / exploitation, both in terms of the targeted user group (older adults would have been less comfortable to submit to these tests), as well as practical considerations (a system could not rely on inexpert users to be able to ‘wire themselves up’, nor would the inconvenience of this before each use be acceptable).

OBJ3. COTS Availability
whilst research should be innovative and on the cutting edge, the objective of this project was to examine the aspects of integration and data analysis, not on delivering cutting edge sensing modalities.

OBJ4. Suitable for physical and cognitive stress assessment
Any system developed should be able to consider both physical and cognitive forms of stress.

OBJ5. Automated analysis should provide insight into user state
at the heart of the system is the capability for automatic analysis to derive information about the user state, i.e. the system should not merely present sensor read-outs to a domain expert for their interpretation, but should add additional analysis and insight to support indicators of user state.

OBJ6. An extensible platform for HSM Research
Previous work had focussed on creating ad-hoc solutions for specific sensors. Whilst this delivered the necessary results, it offered a short-sighted view that didn’t support rapid sensor evaluation and deployment. It is proposed instead that a framework should be deployed to support the flexible and reliable connection and assessment of multiple sensing modalities.

3. HSM Strategy

With these objectives defined, a sensor survey was undertaken to understand what sensing modalities could work given these objectives and constraints. The following were considered amongst others:

1. Heart
    a. Electrocardiography (ECG)
    b. Photoplethysmography (PPG)
    c. Eulerian Video Magnification (EVM)
2. Brain - Electroencephalography (EEG)
3. Movement
4. Facial Expressions
5. Voice and Sound

The right selection of sensors was the first task of this category. An initial analysis was completed. Following on from this, sensor and middleware vendors were invited to give demonstrations of their technologies. After these demonstrations, three sensors were selected.

1. Microsoft Kinect 2.0 (face, EVM, voice, movement)
2. Plessey Epic Sensor (ECG)
3. Samsung & Huawei Wristband (PPG)

After extensive evaluation, whilst these sensors demonstrated value in different ways, the Plessey Epic Sensor (ECG) was chosen as the primary sensor, as it represented the most appropriate method for achieving the required objectives, whilst maintaining an acceptable level of performance.

4. HSM Framework

At the core of this HSM system is the HSM Framework – a modular software architecture which acts as the 'technical glue' to bind together each of the components within the system. Sensor connections, data flows, analytics, communications, and administration are all enabled through this framework.

The Human State Monitoring (HSM) framework consists of three high-level applications (see **Error! Reference source not found.**).

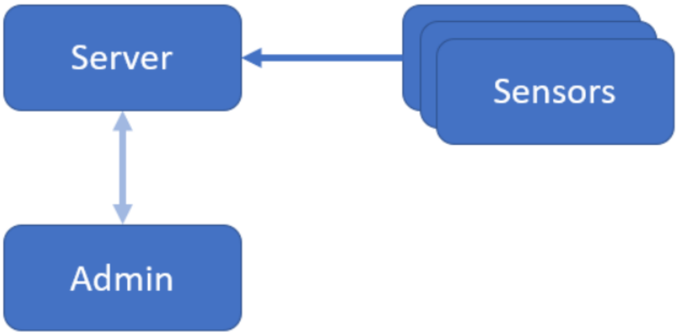

Figure 1: High-level HSM framework components

The Server Service is the centre of the HSM framework. The main functionality is:

1. Manage sensor data
    a. Receive sensor data from sensors
    b. Store the sensor data
2. Classify stress from sensor data
3. Publish results of the classification to subscribed consumers
4. Log messages, warnings, and errors
5. Manage communications
    a. Service announcement and publication via broadcast UDP
    b. Listening for sensor and admin connections

The admin console can control the server. The main functionality is:

1. Server and sensor execution control (start / stop)
2. Input
    a. Settings user interface
    b. Consumer user interface
3. Output
    a. Server console events
    b. Server sensor data

The sensor applications each interface with an external sensor and relay the sensor's data. The main functionality of these interfaces is:

1. Collect raw sensor data
2. Process the raw data if processing is needed
3. Send the sensor data to the server

During the trials the framework itself operated in a reliable manner. The framework experienced one bug in the sensor coding, this was reported in the error system and later corrected in code. The core framework component proved to be stable during the trials, and provides a useful extensible and consistent way for gathering and analysing human physiological data.

5. HSM Data Gathering

Data Gathering was the first stage in the HSM process and was necessary for the training and testing of a Machine Learning system. Once developed, it could then be used to undertake the ‘real-time’ gathering of data from the passenger in order to carry out the analysis.

There were a number of challenges to this process: working with cutting edge sensors; maintaining a legal and ethical approach to data acquisition (particularly with the introduction of the GDPR within the timeframe of the project); and creating a ‘clean’ enough signal to enable statistical analysis.

Multiple phases of data gathering took place:

1. Desk based
2. Simulator based (in the FLOURISH simulator)
3. Virtual Reality based (used in a custom developed system)
4. Trial based (during the FLOURISH trial campaign)

Whilst the Plessey sensor showed promise for an operational sensor, it proved a challenge to generate quality data during the trial phases (particularly given the contending requirements of all the other FLOURISH components being evaluated during the trials). Therefore, for the statistical analysis data was captured from a backup sensor (an Empatica wristband) and resultant systems tested on Plessey data.

6. HSM Signal Processing & Initial Metrics

Once captured, there was a requirement to carry out extensive signal processing and to derive some low-level metrics. This required some novel approaches to be developed, in particular with approaches to peak detection in an ECG trace. The Pan-Tompkins algorithm is considered the ‘state of the art’ approach at present, and during FLOURISH an enhanced system was proposed which initial tests suggest offers increased performance and more accurate detection of heart beats from ECG data.

7. Algorithmic Development

Where there were a number of key innovations across the FLOURISH HSM project, the ‘hardest’ to achieve was the algorithmic development that would allow insight to be gained into a user’s state at a deeper level than currently possible.

Data was analysed from a number of scientific experiments which took place in partnership with subject matter experts from the school of Psychology at the University of the West of England. A variety of statistical features were derived which allow the system to make promising insights into the user’s state.

More ‘cutting edge’ Artificial Intelligence (AI) approaches were examined for developing more accurate approaches, however, the quantity of data was not sufficient to be able to accurately assess the performance of these systems.

While we haven’t achieved the fully-automated system we would have liked to have, we have gained much insight into these approaches, and paved the way for future researchers to build on and refine our system.

8. Conclusion

Overall, much has been learned from the work undertaken during the FLOURISH project. We have created a cutting edge framework utilising the latest sensing technologies to effectively and autonomously gather physiological data. We have advanced the state-of-the-art in analysing these datasets to provide some high level insights into user state, and hopefully this informs the future development and deployment of HSM systems in a variety of use cases, beyond solely CAVs.

Returning to the objectives specified above, an assessment was undertaken of how well each was met by the resultant system:

- Data should be gathered on human users in real-time
    - *Fully met*
- Sensors should be non-invasive
    - *Partially met*
- COTS Availability
    - *Partially met*
- Suitable for physical and cognitive stress assessment
    - *Fully met*
- Automated analysis should provide insight into user state
    - *Partially met*
- An extensible platform for HSM Research
    - *Fully met*

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