Towards smart working spaces with enhanced well-being and safety of elderly staff

Aliaksei Andrushevich, Martin Biallas, Rolf Kistler
iHomeLab, Institute of Electrical Engineering
Lucerne University of Applied Sciences and Arts
Lucerne, Switzerland
firstname.lastname{at}hslu.ch

Lorenzo Eusebi, Judit Ronai, Massimo Valla
Open Innovation - Joint Open Lab
JOL S-Cube and JOL White, Telecom Italia S.p.A.
Milan and Pisa, Italy
firstname.lastname{at}telecomitalia.it

***Abstract*—Our research explores the possibility to assist employees close or beyond retiring age in the workplace and enhance their, and general, safety by monitoring the personal stress state via wearable and environmental Internet of Things (IoT) sensors and by suggesting proper actions to reduce stress levels and enhance well-being at work. This paper presents the goals and the technological issues, investigated in "AmbienT Response to Avoid Negative Stress and enhance SAFEty" (Trans.Safe) EU AAL JP project, along with the general architecture, the preliminary implementations and some anthropological issues, describing the current state of the research and development.**

***Index Terms*—Internet of Things, Ambient Assisted Living, Stress detection, Workplace safety, Smart Working Spaces**

I. Introduction

Rapidly ageing population in Europe and in other developed countries leads to the increased retirement entry age, and a declining workforce as well. Further, according to the EWCS (European Working Conditions survey) from 2010, more than 22 % of the employees in the EU think that their health or safety is at risk because of their work. This percentage increases when the interviewed employees become older and their jobs demand a high concentration level, long tasks and / or irregular working hours. These conditions especially apply to the transportation and logistics sector: Truck drivers, taxi and public transport drivers, train drivers and control room personnel have to work in very stressful and demanding environments for hours, while keeping constant focus on monotonous tasks. Moreover, public safety can be affected by a single mistake or distraction by this group of workers to a very high degree. For this reason, it is important to understand how these older employees can better cope with stress, before it affects their own and others' health and safety.

The AmbienT Response to Avoid Negative Stress and enhance SAFEty (Trans.Safe) is an European AAL JP research project, co-funded within the Active (Ambient) Assisted Living Joint Program (number 2013-6-064) to assist employees close or beyond retiring, who want, or have to keep working in the high age. The project is addressing one of the biggest rising issues in modern society: the safety and wellbeing of an ageing working population in Europe.

Generally speaking, "stress" is the natural adaptation of the human body in response to a stressor. In other words, in some situations, that could be an environmental change, an intellectual task, or a life-threatening situation, some physiological mechanisms are triggered to help the person to deal with that particular situation. This means that stress is an important survival mechanism, in the first place. If well managed and controlled, it helps to improve human performances ('eustress'). Constant overload, sudden dangers or safety concerns are, on the other hand, strong negative stressors ('distress'), and they can lead to serious consequences. Another source of stress derives from "underload" situations, where the task the person is performing is not an adequate stimulus, resulting in boredom and distractions [1, 2].

The Trans.Safe cyber-physical system aims at detecting and reducing stress and to enhance balance and well-being. Stress detection is based on a combination of wearables and environmental sensors measuring physiological and environmental parameters related to stressful situations. These values then are analysed by an algorithm that decides if the human worker is stressed. The system is able to propose unobtrusively actions that the use can perform in order to improve the stress recovery. Furthermore it offers to adapt controllable parts of the environment for the same purpose.

Multiple issues have to be addressed, starting from the required sensing technology, to physiology and the solution acceptance by the end users. In this paper, the measured physiological and environmental parameters are described together with the foreseen interventions. Finally, the proposed architecture for the system is discussed.

II. Related Work and Measured Parameters

Since stress is related to physiological adaptation mechanisms, the idea is to measure the physiological response of the human body to stressors. To base the state of stress by acquiring indirect physiological signals is being explored in a number of scientific papers [3, 4].

In the following paragraphs, the most important physiological and environmental parameters will be presented and explained in relation with stress.

It is necessary to underline the aspect, which is one of the main challenges of the project: Each parameter, both physiological and environmental, transfers different information about the stress of a person depending on the person itself. The variability of the “stress threshold” can vary with people’ by gender, age, job, current health status, personality or form on the day. To develop a solution that can reliably cope with these variables is a challenge the consortium has to deal with.

A. Physiological parameters & stress

Several studies have shown that stress has an impact on the Autonomic Nervous System (ANS) [5, 6]. The ANS controls automated body functions, like the cardiac activity and skin resistance, therefore the monitoring of physiological parameters like Heart Rate (HR), Heart Rate Variability (HRV) [7] and Skin Conductance (SC) [8] is an unobtrusive method for evaluating the stress level of a person. Moreover, in order to better distinguish between situations that are related to a change of stress conditions and the ones influenced by other factors (e.g. increasing/decreasing of physical activity), it is important to investigate parameters related to the movements (e.g. from accelerometers), electromyography activity [9], breathing [10], body and skin temperature [11]. Another factor that is interesting to observe is the brain state, depending on both, external stimulation and internal mental states. It can be described by the electrical activity of the brain (EEG) [12], (i.e. the amplitude of different frequency bands), whereas further information can be also derived from eye blink and gaze analysis [13]. A recent review [14] shows that the aforementioned physiological parameters can be reasonably taken into account to significantly measure people stress levels.

B. Environmental Parameters & stress

All the environmental changes can affect somebody in one way or in another. For the Trans.Safe system, we decided to implement the environmental monitoring using four main parameters:

- Temperature
- Humidity
- Light intensity
- Noise level

These parameters are not only associated with general well-being, but in some cases, they are also regulated by laws about the working environment and, finally they are all parameters that can affect concentration and stress in general [15]. However currently other known dependencies of the ANS from environmental conditions, such as air quality [16] and vibration [17] are excluded. Extending the system with related sensors will be possible.

III. INTERVENTIONS

Understanding how to intervene to maintain a healty level of stress during worktime is not trivial. Here, one of the basic ideas was that the working environment would adapt to the stress level of the worker to help the person relaxation and/or focusing. Changing the lights is probably the easiest and most effective way to reduce stress in a person. The profound connection between lights and physiology has been proved several times. In [18] the lighting condition is set in relation with psychological stress and relaxation, concluding that orange colored pulsating light can help to create a more relaxed atmosphere. In [19] the lighting condition is explored in relation with learning and mental tasks.

Adjusting environmental parameters like light, both color and intensity, temperature and other features of the environment is certainly possible to do from a technical point of view, but in a real environment is not more demanding. There are several reasons for this. The first is that different people could populate a working environment, and it is not possible, for example, to set a temperature for each one. The same is for lighting. It is important to understand that an environmental approach could underline a massive change in the working environment and these changes could not always be possible. The case of a truck cabin or a train cockpit is different, but also there the interventions are limited due to important safety regulations.

Overall, the environmental approach could be very effective, but also limited and not easy to accept, both from the side of the employer and the side of the employee. One crucial aspect, which has to be addressed, is the personal and social acceptance of this kind of intervention.

A possible and easier solution could be to make the person aware of his/her stress status. This biofeedback could vary, it could be a notification at the end of the day, with an easy to read report and some advices, or could be a “live notification”, e.g. the system reveals a state of drowsiness in a truck driver and kindly suggest to the driver to immediately stop for resting.

IV. SYSTEM ARCHITECTURE

The overall system architecture for the collecting and the elaboration of the measured data are composed by three macro components:

- Sensors (for physiological and environmental signals)
- A smartphone
- A gateway box
- A cloud based server

The data from the physiological sensors are transmitted wirelessly to the smartphone via Bluetooth. The smartphone serves two purposes. One on hand, it aggregates sensor data and forwards it to the gatewaybox by Wi-Fi. On the other hand it can serve as biofeedback device by informing the user about the results of the data analysis. It is performed by a stress detection algorithm. The computation is executed “locally” on the gatewaybox for reasons of efficiency, privacy and data security. Additionally, the gatewaybox gathers the data from the environmental sensors, which are cable bound. In the case of using the system in a truck, a CAN bus adapter provides further situational and environmental data. The cloud based server is used for user management and storage of the history of stress levels. While a WebGUI enables administrators to manage software updates and to add / remove users conveniently, the stress values are stored encrypted and are inaccessible for anybody else except the user.

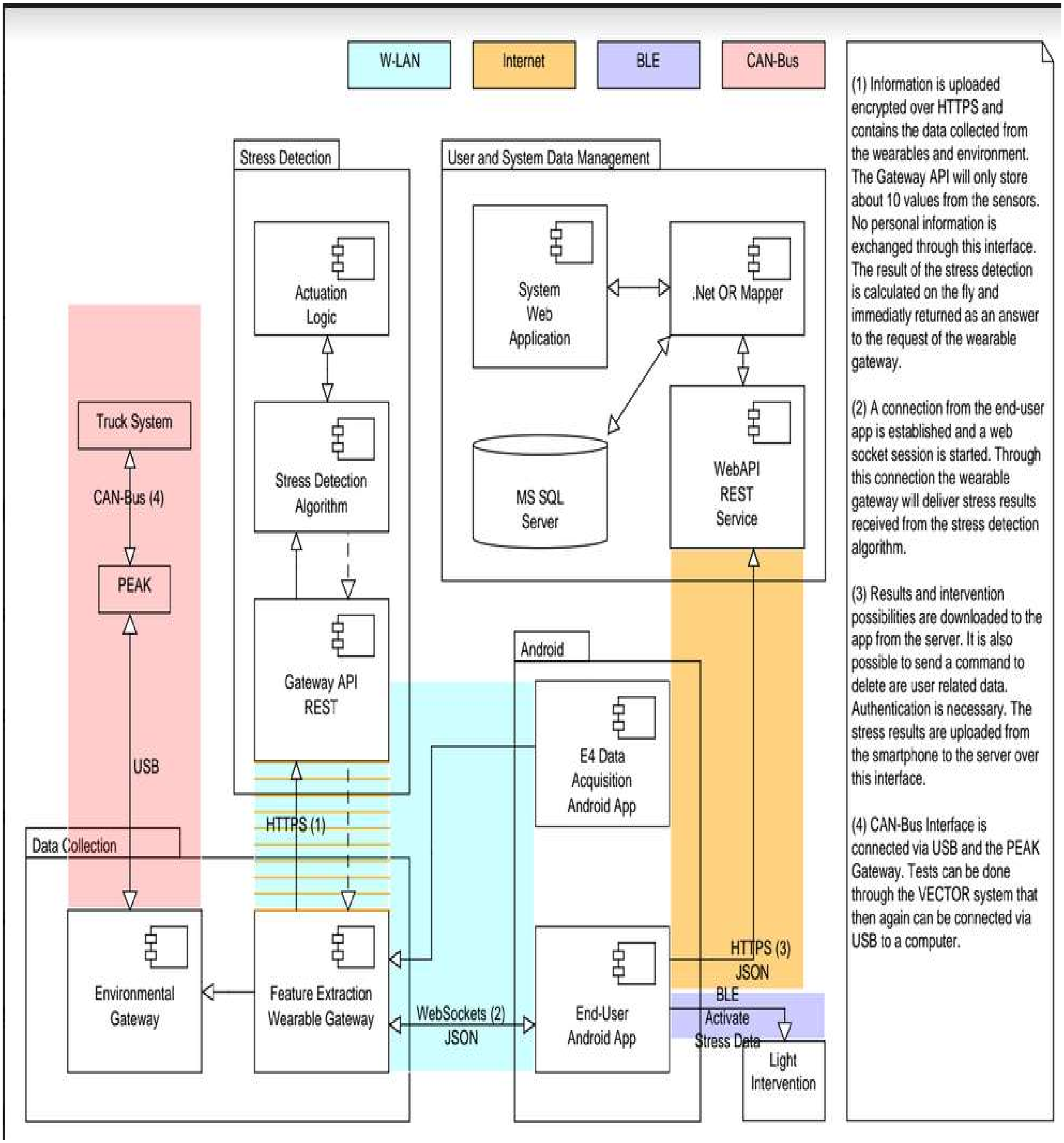

Figure 1 Technical system architecture. TCP/IP based communication between modules grant the system flexibility. Depending on customer requirements (system per workplace or multi-workplace system) specific modules can be integrated in one box, or outsourced to a cloud. As concession to the user as ultimate instance of decision on transfer of personal data, the Android module (being a smartphone), is the only path for physiological or stress related data to enter the storage facilities existing on the User and System Data Management module.

The first, trivial level of stress management is to provide feedback about his stress level by the smart phone. It can also suggest countermeasures, such as breathing exercises or recommendations (e.g. “why not to have a piece of chocolate cake?”). The smartphone enables to control glasses with integrated light sources as alternative intervention. Environmental lights are controlled by the gatewaybox. When it is connected to CAN bus of a truck, further interventions become available - e.g. by invoking driving assistance systems for relieving the driver.

A. *Wearable Sensors*

The choice of the wearable sensors has been performed according to two criteria: accuracy of measures and non-intrusiveness of the sensors. The following sensors compose the optimised set (in earlier stages of the project, more intrusive sensors have been used):

- Empatica E4
- Zephyr BioHarness
- Shimmer GSR Module

E4 is a wristband wireless multisensor device produced by Empatica [20]. It comes on the market as an evolution of the previous model E3. The E4 has four embedded sensors: temperature, electrodermal activity (EDA), 3-axis accelerometer and a photoplethysmograph (PPG). The wristband can operate in two modalities: a streaming mode, that can send real-time data to a mobile phone via a Bluetooth Low Energy connection, and a recording mode, that is capable of recording all the physiological data on the local memory of the device. The parameters detected by the device are: Inter-beat Intervals, Blood Volume Pressure, Body Temperature, Skin Conductance and (x,y,z)-components of acceleration.

BioHarness [21] is a Bluetooth chest belt produced by Zephyr. The device is capable to retrieve signals such Heart Rate, R-R Interval, Breathing Rate, Posture information. In this project, we will use the BioHarness as a Golden Standard to evaluate the accuracy of the PPG sensor on the Empatica E4.

The GSR Module provided by Shimmer [22] is a wearable sensor composed by two special finger electrodes and a main unit that streams data related to the Galvanic Skin Response of the user using a Bluetooth connection.

According to issues about usability and accuracy criteria, a subset of these sensors will compose the Optimized Sensor Set. The Wearable Sensor Gateway is a device that collects data from all the sensors, performs synchronization and data analysis. In the architecture we developed, all wearable sensors are connected with a smartphone that acts as mobile gateway.

The data processing of the wearable sensors is divided in three steps:

- Sensor Interface Module (SIM), aimed to collect data from multiple wearable sensors;
- Data Synchronization Module (DSM), that allows the SPM to process the signals in the same time window;
- Signal Processing Module (SPM), that performs a first processing of the signals in a specific time window, in order to emphasize the meaningful information for the Stress Detection Algorithms in the gatewaybox;

B. *Environmental Data Collection and Control System*

The environmental data collection and control system will be composed by three main components.

The most important one is the gatewaybox. It will have the task to communicate with the actual sensors in the environment, to encapsulate the data in the proper format and to send them to the data collecting service. At the same time, the gateway has the duty to receive a command from the stress algorithm logic and to propagate it to the proper intervention device.

To be able to do so, the gatewaybox will have specific plugins to communicate with the sensors and the devices. This part can be considered the “southbound” of the gateway. The modules that control the gateway and communicate with the Cloud Service compose the “northbound” part. The main modules here are the REST server, which is able to send the request information to the cloud and, in general, to consume the commands and information received by the cloud.

The rule engine will provide some simple and easy to implement automatic rules, similar in concept to an “if-this-then-do” logic. The role of this module is to allow simple settings in the environment without sending constant messages from and to the cloud logic. Finally, the software framework also includes a module that enable the exchange of messages inside the software modules inside the gateway.

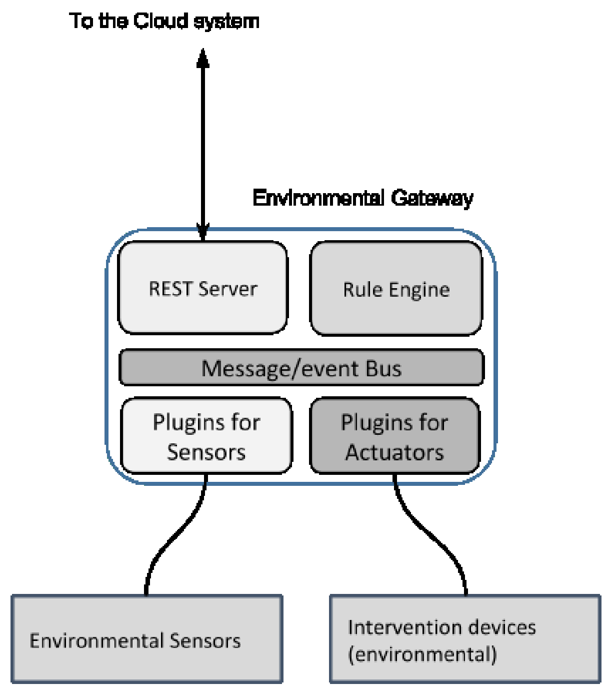

Figure 2 Environmental Data Collection and Control System

For the sensors used, we decided to deploy a system based on commercial boards for fast prototyping (Arduino and Arduino-like) with a set of discrete sensors.

The reasons for this choice are that the normal devices that collect these kind of values are not easy to connect to a web service to retrieve the data. There are some commercial devices that allows a remote reading of multiple environmental values (e.g. Netatmo), but they usually rely on their cloud services and the time between readings is not entirely configurable. They could also not be suitable for installation in a particular environment such as the cabin of a truck. Professional devices have also been considered, but they suffer the same problem as the regular devices: they are not IoT ready and not easily to interface in a M2M paradigm. Using the chosen kind of approach allows to prototype rapidly the whole system with an IoT approach using a configurable and easy to upgrade hardware.

C. Cloud Server

The Cloud Server is the remote component of the whole system. It will host the software modules for communication and the resources to store the data.

The stress algorithm retrieves data from the database and performs the analysis to detect the stress level of the user. The results are sent back to a specific section of the database that keeps track of the stress history.

First, the User Management module is in charge of controlling the access to information and to retrieve the correct data from the database for a given user. All this information will be then be shown using a web application that could be access via browser.

At the same time, the system will implement a module with APIs to act as a bridge between a mobile app, and the database. The presence of this layer is necessary also because a possible course of intervention could be a live alert on a mobile or wearable device during a stressful situation; therefore, a layer that keeps the connection between the Cloud Service and a mobile app is needed.

All these modules all run in an independent way from each other. No centralized control module has been deployed to reduce the overall complexity of that module for the possible states and connection it should have had to keep the system in a functional state.

In the way we proposed, each module will be able to communicate directly with the modules it has a functional connection with and, at the same time, it will be able to answer the requests the same modules will ask to it. Examples of this concept will be provided in the following chapter.

The modularised system developed in a rapid manner simplifies the introduction of a maintenance friendly IoT platform, which is planned with respect to a future commercialisation. Several platforms (e.g. openstack [23], or platforms based on openstack, such as Stack4Things [24], and platforms dedicated to healthcare or medical appliances [25], [26]) are under consideration.

D. System Functioning Example

For a better understanding of the architecture described above, we can assume the case of a truck driver who is driving along a highway. The environmental and the wearable gateways are collecting data from the deployed sensors. It is a normal day on the street and driver is well focused and rested. The system reveals that everything is fine. At some point, the driver notices that the traffic density is increasing and starts to worry about being late for the delivery. The algorithm detects a shift in the stress values and the Actuation logic decides to take action and activate an environmental change to help the driver to relax.

Consequently, the gatewaybox is invoking an additional driver assistance system. In the next break of the driver, when he checks his messages on the smartphone, it will provide the feedback that a stress period has been passed and recommend a light shower to better recover in during the break. If the user decides to follow the recommendation, the gatewaybox will adjust the colour and intensity of the cabin lights. At the end of the shift, the system notifies the driver that, during that day, he had a number of episodes of stress, and suggests him to do simple, relaxing exercises before going to sleep.

V. CONCLUSION

The holistic approach of developing a system, able to detect changes in the ANS based on physiological parameters and environmental sensor data, for classifying the current stress level remains – despite the growing body of scientific literature on the topic – challenging, especially in the light of user acceptance of physiological sensors and the data quality required by the automatic analysis. For the project that is based on a user centred design process, i.e. including relevant stakeholders, ranging from potential customer to users of the system, the addressing of social questions must also be taken into account. Questions concerning the privacy / data protection by design, to empower users to be the authority on their data, allowing them to benefit from new technology, while to avoid becoming transparent to the employer and / or providers of ICT infrastructure (e.g. sensors providing data only via servers of manufacturer). This, in conjunction with data protection regulations (partially different from country to country) and open questions of specific domains (e.g. “could / should the physiological data of the driver be made available for law enforcement in case of an truck accident?”), should be solved before successful deployment of applications, as the one presented here, can achieve comprehensive relevance for a wide market penetration.

ACKNOWLEDGMENT

The authors of this paper would like to thank their partners in the Trans.Safe project and acknowledge the financial support given to this research by the European Union in the AAL Program (Call 6 – Supporting occupation in life for older adults).

VI. References

[1] R. Viner, "Putting Stress in Life: Hans Selye and the Making of Stress Theory". Social Studies of Science. 29 (3): pp. 391–410, ISSN 1460-3659, JSTOR 285410, June 1999

[2] D. S. Goldstein, I. J. Kopin, "Evolution of concepts of stress". Stress: The International Journal on the Biology of Stress. 10 (2): pp. 109–120, PMID 17514579, January 2007

[3] The Efficacy of Psychophysiological Measures for Implementing Adaptive Technology - Mark W. Scerbo, Frederick G. Freeman, Peter J. Mikulka, Old Dominion University, Norfolk, Virginia - Raja Parasuraman and Francesco Di Nocero, The Catholic University of America, Washington, DC Lawrence J. Prinzel III, Langley Research Center, Hampton, Virginia

[4] MONITORING DRIVER DROWSINESS AND STRESS IN A DRIVING SIMULATOR Maria Rimini-Doering, Dietrich Manstetten, Tobias Altmueller, Ulrich Ladstaetter, Michael Mahler, Corporate Research Division Robert Bosch GmbH Stuttgart, Germany E-mail: maria.rimini-doering@de.bosch.com

[5] T. F. of the European Society of Cardiology, the North American Society of Pacing, and Electrophysiology. Heart rate variability: Standards of measurement, physio-logical interpretation, and clinical use. European Heart Journal, 17(2):1043{1065, March 1996

[6] W. W. Grings and M. E. Dawson, Emotions and Bodily Responses A psychophysiological Approach: Academic Press, INC, 1978

[7] Vrijkotte, T. G., Van Doornen, L. J., & De Geus, E. J. (2000). Effects of work stress on ambulatory blood pressure, heart rate, and heart rate variability. Hypertension, 35(4), 880-886.

[8] Tang, T. B., Yeo, L. W., & Lau, D. J. H. (2014, November). Activity awareness can improve continuous stress detection in galvanic skin response. In SENSORS, 2014 IEEE (pp. 1980-1983). IEEE.

[9] Lundberg, U., Kadefors, R., Melin, B., Palmerud, G., Hassmén, P., Engström, M., & Dohns, I. E. (1994). Psychophysiological stress and EMG activity of the trapezius muscle. Internationaljournal of behavioral medicine, 1(4), 354-370.

[10] Rottenberg, J., Wilhelm, F. H., Gross, J. J., & Gotlib, I. H. (2002). Respiratory sinus arrhythmia as a predictor of outcome in major depressive disorder. Journal of affective disorders, 71(1), 265-272.

[11] Karthikeyan, P., Murugappan, M., & Yaacob, S. (2012). Descriptive analysis of skin temperature variability of sympathetic nervous system activity in stress. Journal of Physical Therapy Science, 24(12), 1341-1344.

[12] Seo, S. H., & Lee, J. T. (2010). Stress and EEG. INTECH Open Access Publisher.

[13] Haak, M., Bos, S., Panic, S., & Rothkrantz, L. J. M. (2009). Detecting stress using eye blinks and brain activity from EEG signals. Proceeding of the 1st driver car interaction and interface (DCII 2008).

[14] Sharma, N., & Gedeon, T. (2012). Objective measures, sensors and computational techniques for stress recognition and classification: A survey. Computer methods and programs in biomedicine, 108(3), 1287-1301.

[15] Hori, K., Yamakawa, M., Tanaka, N., Murakami, H., Kaya, M., & Hori, S. (2005). Influence of sound and light on heart rate variability. Journal of human ergology, 34(1/2), 25-34.

[16] C. P.; Verrier, R. L.; Lovett, E. G.; Larson, A. C.; Raizenne, M. E.; Kanner, R. E.; Schwartz, J.; Villegas, G.; Gold, D. R. & Dockery, D. W. (1999). Heart rate variability associated with particulate air pollution, American Heart Journal, 138, 890 - 899

[17] FÄRKKILÄ;, M.; PYYKKÖ;, I. & HEINONEN, E. (1990), Vibration Stress and the Autonomic Nervous System, The Kurume Medical Journal, 37, S53-S60

[18] The Influence of Lighting Color and Dynamics on Atmosphere Perception and Relaxation - S. H. Wan, J. Ham, D. Lakens (Eindhoven University of Technology, Eindhoven, the Netherlands), J. Weda, & R. Cuppen (Philips Research, Eindhoven, the Netherlands)

[19] Illuminating the Effects of Dynamic Lighting on Student Learning - Michael S. Mott, Ashley Walden, Jodie Burnette, and Angela S. Rutherford (The University of Mississippi, USA), Daniel H. Robinson, (The University of Texas, Austin, USA)

[20] https://www.empatica.com/

[21] http://zephyranywhere.com/

[22] http://www.shimmersensing.com/

[23] https://www.openstack.org/software/

[24] Merlino, G.; Bruneo, D.; Distefano, S.; Longo, F. & Puliafito, A. (2014), Stack4Things: integrating IoT with OpenStack in a Smart City context, Smart Computing Workshops (SMARTCOMP Workshops), 2014 International Conference on, pp.21-28

[25] Rolim, C. O.; Koch, F. L.; Westphall, C. B.; Werner, J.; Fracalossi, A. & Salvador, G. S. (2010). A Cloud Computing Solution for Patient's Data Collection in Health Care Institutions, Second International Conference on eHealth, Telemedicine, and Social Medicine, pp.95-99

[26] Zhang, X. M. & Zhang, N. (2011). An Open, Secure and Flexible Platform Based on Internet of Things and Cloud Computing for Ambient Aiding Living and Telemedicine, International Conference on Computer and Management (CAMAN), pp. 1-4