A System for Unobtrusive In-Car Vital Parameter Acquisition and Processing

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Abstract - **In this contribution, a system for unobtrusive acquisition and processing of vital parameters using car-integrated sensors and processing devices is presented for the first time. The system consists of a steering wheel with integrated sensors, sensor processing and wireless communication interface and a portable monitoring unit for wireless data reception, display and interface to the car information system. A great effort is done worldwide to develop technical solutions helping elderly people to keep mobile and thus autonomous, including monitoring vital signs for patients needing continuous medical care or preventive solutions allowing regular health checks. In-car vital signs monitoring is a good approach to solve this problem. This solution focuses on the effective integration of display solutions and few sensors for an improved usability and lowering of the system-related driver's distraction.**

Keywords - vital parameter; car integration; mobility; elderly people; acquisition; processing; display; vital sign; mobile

I. INTRODUCTION

In an aging society, it is very important to enable people to live an independent life for as long as possible. This goal can be achieved keeping people in good health through prevention, early diagnosis and short hospital stays in the first place and assuring that elderly people with cognitive or physical impairments keep self-sufficient. Personal assistant devices are devices designed to achieve both parts of this goal, allowing both motivation to live a healthy life, early detection of changes leading to illnesses and aids to keep independent when illnesses or age-related impairments are already there. Such systems can be embedded in an intelligent home or be portable systems, but they can also be embedded into vehicles. As many people spend a considerable amount of their time in the car, a system able to record vital parameters during the drive could have many benefits. The time spent driving or inside traffic jams could be used for regular health checks. In addition to this, such a system could help people being constricted in their mobility because of the need of continuous monitoring. The monitored data could also be used to detect characteristics about the driver's state and positively influence them, e.g. lowering the music volume or blocking incoming calls if a state of particularly high cognitive stress is detected. After the state of the art overview and task description, this paper will describe the developed system as well as its implementation and two experiments which have been done during and after its development. The first experiment was done to ascertain the basic possibility to embed sensors to acquire vital parameters efficiently during a driving task as well as to explore possible relations between vital parameters and cognitive stress. The second experiment was done to prove the correct functioning of the sensors embedded into the car.

A. *State of the art in in-car vital parameter monitoring*

Especially if blood alcohol concentration and fatigue aren't considered as such, there aren't any car-embedded commercially available devices to measure vital parameters in a car. Thus, the discussion in this section is limited to contributions found among the research area.

The foundations of in-car vital parameter monitoring lie in non-invasive measuring methods which have to be easy to use and dependable. Such systems are common when measuring a person's physical or psychological state without the need of their cooperation, e.g. when they are involved in their normal tasks.

The first approaches in in-car monitoring of vital parameters were motivated in the assessment of the driver's emotional state to determine his driving capability. Against the background of rising traffic volume, driving speeds and related amount of car accidents the assessment of stress determined by the driving task was to shed light on its influencing factors in order to realize counteractive solutions.

The driver's ECG (electrocardiogram) is acquired in [1]. The pulse variability is associated to the activity of the parasympathetic nervous system and is used to ascertain the stress level. To be able to measure the ECG most of the time, electrodes were placed on the steering wheel, on the gear selector and on the left armrest. Reference [2] also presents a system measuring ECG in order to detect the stress level. Here, dry electrodes on the steering wheel are used and compared with electrodes placed on the chest. The signals were digitalized and sent to a PC via Bluetooth. While the ECG was recorded, GPS (global positioning system) was used to protocol the driving speed as a reference for stress. In [3], an expansion of system [1] measuring also body impedance (using electrodes on the steering wheel) and blood pressure (using a self developed optical system on the dashboard) was presented. All sensors are connected directly to a PC for evaluation using an analog to digital converter. The system described in [4] detects

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the stress level using sensor data from ECG, EMG (electromyography), skin resistance and respiratory rate. A reference stress metric was also determined using video cameras recording the driver's facial expression. On most of the observed drivers a strong correlation between stress level and both heart rate and skin resistance was found, and it was suggested to use this data to control non critical car systems. Reference [5] describes a system measuring blood pressure, blood volume and differential skin temperature (on cheeks, nose and finger tips). Reference [6] presents an approach to intervene into the car control based on acquired psychic-physical parameters. Sensors acquiring ECG, EEG (electroencephalogram), skin resistance and temperature directly on the driver's body were applied to be able to detect an inability of the person to drive and, e.g., activate the brakes as a consequence.

An overview of the presented systems and their main characteristics is given in table I. Summing up all the mentioned systems contain approaches to measure vital parameters inside a car and to determine the driver's current state. Only in [3] the chances lying into the recording of the state over a long period of time in order to eventually detect abnormal changes in early stages are identified. There is an overall strong focus in the integration of a wide range of sensors in order to detect a state as comprehensively as possible. This has the disadvantage of applying many sensors and electrodes on the user, which will most probably constrain him in his driving task. All systems also evaluate the recorded data on a PC. This solution can be used in experimental setups, but is not suitable for a device which has to be integrated in an automobile for everyday-life recordings.

TABLE I. SENSOR AND DEVICES USED IN THE PRESENTED STATE OF THE ART

	[1]	[2]	[3]	[4]	[5]	[6]
HR Variability	CE		CE			TPP
HR (Heart Rate)	CE	CE	CE		TPP	TPP
ECG	CE	CE	CE	BE		
EEG						BE
EMG				BE		
Body impedance			CE			
Blood pressure			OS		OS	
Blood volume					OS	
Skin resistance				BE		BE
Resp. rate				BHS	BA	
Diff. skin temp.					BT	
Oxygen Saturation					TPP	
Communication	W	WL	W	W	W	W
Processing	PC	PC	PC	PC	PC	PC

CE = Electrodes in car; BE = Electrodes on body; BHS = Hall sensor on body; BA = Anemometer on body; BT = Thermistor on body; OS = Optical system; TPP = Transmissive photo plethysmograph; WL = Wireless; W = Wired; PC = Personal computer

B. *Task description*

The goal of the presented project is to develop a system able to acquire vital parameters focusing on sensors commercially available and which can be integrated into a car without distracting the driver. In addition to this, the goal is to develop a platform able to process the data and display it for the user or transmit it to the car information system during the drive, without the need of integrating an additional embedded PC into the car. Thus, the system should be easy to install even retroactively and easy to use in everyday life. The only sensor considered to be possibly worn by the user is a chest harness for heart rate measurement, as this is an already popular and widespread system.

II. SYSTEM CONCEPT

A. *Static system concept description*

The system can be divided in three components:

Sensor-equipped steering wheel: this is a steering wheel with integrated sensors which are able to acquire the driver's vital signs on contact. In addition to this, it must contain a sensor unit communicating with the sensors in order to acquire their data. The sensor unit also contains a wireless interface in order to transmit the data out of the steering wheel. This unit is powered by the car.

Receiver unit: this is a portable unit which receives all sensor data from the sensor unit inside the steering wheel and is able to further process it. In order to communicate with the sensor unit, it must contain a wireless interface. In addition to this, it must contain data processing, storage and display devices. This unit uses battery power and needs an interface in order to recharge the battery and export the data. This component and the sensor-equipped steering wheel are mandatory and need to be installed into the car.

Car information system: a car manufacturer willing to give the user the option to display the measured data and setup the system more comfortably using the car information system has to integrate as a third component a USB (universal serial bus) interface to the car information system as well as a software extension of this system capable of communicating with the receiver unit.

A scheme showing the system's composition can be seen in Figure 1.

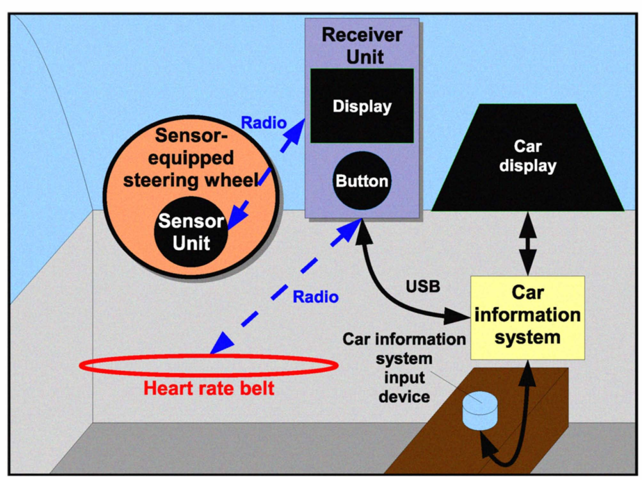

Figure 1. Description of the system's parts and interfaces.

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B. *Dynamic system concept description*

In this section, the processes running on each system component and their interactions are described. On overview is given in Figure 2.

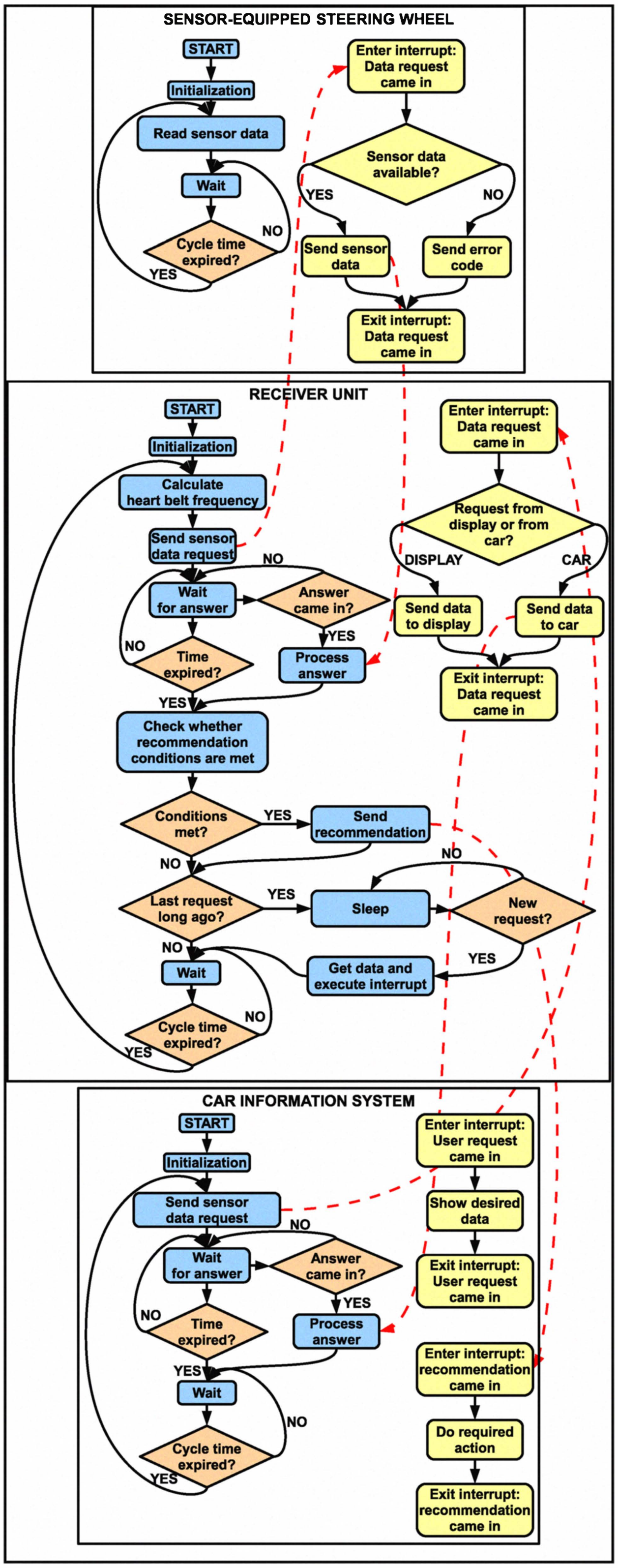

Figure 2. Description of the system's processes.

1) *Sensor-equipped steering wheel*

The process running on the sensor unit reads out the sensor data periodically and listens for requests from the receiver unit. When a request comes in, it sends the requested data to the receiver unit or it sends an error message, in case the sensor data is not available (e.g. because the sensor is not used at the moment).

2) *Receiver unit*

The receiver unit periodically sends sensor data requests to the sensor unit inside the steering wheel through the wireless interface. In addition to this, it calculates periodically the heart rate given by the heart rate belt. When it receives a request from the car, it answers the request sending data or an error message. When the user pushes the button, the display is turned on for a given time. While it is on, the display controller actualizes periodically the shown data sending requests to the receiver unit. With every other push of the button while the display is on the user can cycle through the available sensor values. After a given time without button activation, the display enters a sleep mode. Also the whole receiver unit switches to sleep mode when it doesn't receive requests for a given time.

In order to be able to utilize the knowledge about the driver's vital parameters, the receiver unit doesn't just react to sensor data requests. It also calculates a stress level characteristic, which can be used e.g. to control the cabin environment by regulating the music volume or blocking incoming calls. This can be done sending "recommendations" to the car autonomously, whenever the car should be informed about a particular event, like a sudden vital signs change which may require attention. For example, even when the receiver unit is in sleep mode, it wakes up regularly and checks whether a specific sensor is being used by the driver. If this is the case after a given non-usage period, a recommendation to show the sensor's data is sent out both to the receiver unit's display controller and to the car information system. On reception of the recommendation, the receiver unit's display turns on, while the car information system switches to the menu showing the desired sensor data without the driver needing to use its input device to do this.

3) *Car information system*

Apart from the usual processes running within a car information system, a new functionality is added: on activation of the menu item "Fitnessmonitor", the user can display the available sensor information. The car information system sends requests to the receiver unit in order to actualize the sensor data. In contrast to the receiver unit, on the car display it is not only possible to see the current data, but also the devolution of the values over time. As stated above, the car information system also receives recommendations from the receiver unit and reacts accordingly.

III. SYSTEM EVALUATION

For evaluation, the presented system was built in a way described in section III.A and two experiments were conducted. The first one, described in section III.B, had the purpose of measuring the driver's distraction due to sensors attached to the steering wheel. The second one, described in section III.C, was conducted to evaluate the sensor's reliability when integrated into the car.

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A. *Materials and methods*

1) *Sensor-equipped steering wheel*

The sensor-equipped steering wheel is based on a production model steering wheel. Two conductive strip electrodes are attached all around it (Figure 3, bottom right). Between these electrodes, the driver's skin conductivity can be measured placing at least one hand on any part of the circumference. The electrodes are connected to a Nexus-10 SC/GSR sensor (Mind Media B.V.) which has been modified in order to work without the Nexus-10 itself. Thus, the sensor output is a voltage proportional to the driver's skin resistance.

The second sensor is inset in the inside of the steering wheel, left to the horn, in a position where the driver can position his thumb easily during the drive (Figure 3, bottom left). It is a reflective pulse oximetry sensor connected to a OEM III module (Nonin Medical Inc.) for evaluation.

Both sensors are connected to a nanoLOC AVR Module (Nanotron Technologies GmbH) via an A/D converter input and the serial interface, respectively. This module includes an AVR ATmega644 (Atmel Corp.) microcontroller and a nanoLOC TRX Transceiver (Nanotron Technologies GmbH). For the system scheme, see also Figure 3, top.

The whole system is integrated into the steering wheel and is powered by the car's electrical system reaching into the wheel through a buffer spring.

2) *Receiver unit*

The receiver unit is designed as a portable unit which can be taken out of the car by the user and attached into the car like an external navigation system. It is thus powered by an internal battery which can be recharged inside the car or in any USB plug using the unit's interface (Figure 4, bottom).

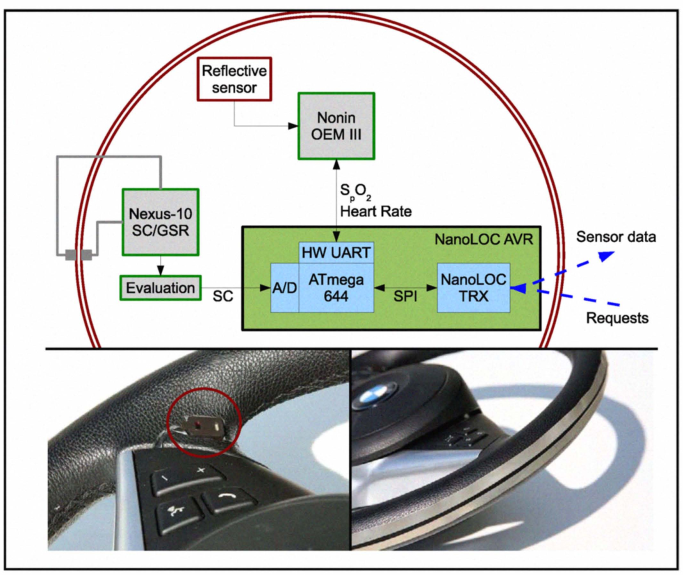

Figure 3. Top: Description of the sensor-equipped steering wheel's parts and interfaces. Bottom left: Detail of the pulse oximeter. Bottom right: Detail of the skin resistance electrodes.

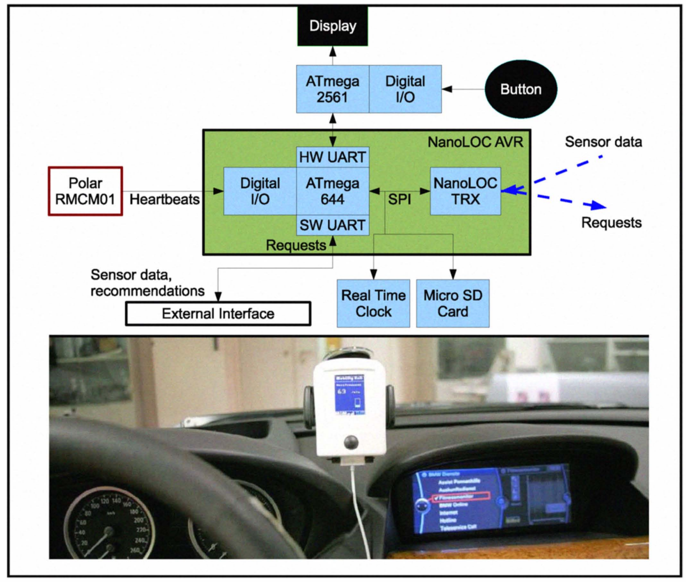

Figure 4. Top: Description of the receiver unit's parts and interfaces. Bottom: Receiver unit in use inside the car. The unit's function is independent from the usage of the external interface.

The receiver unit also contains a nanoLOC AVR Module which is connected to a real time clock, a micro SD card, a RMCM01 OEM Module (Polar) and another AVR ATmega2561 (Atmel Corp.) microcontroller controlling a 2.1" 65536 color TFT display (D012, Speed IT up) (176x132 pixel). The ATmega2561 is connected to the button on the receiver unit. For the system scheme, see also Figure 4, top.

The unit consumes approx. 100 mA when in use and 20 mA when not, operating with a battery voltage of 3.7V. Thus it must be recharged approx. every three days using it for one hour a day. The RMCM01 heart rate belt module indicates every heartbeat received by a Polar Wearlink belt with a trigger pulse on the output line, thus the heart rate must be calculated by the microcontroller. A plausibility check is also necessary, as the heart rate belt module usually sends several pulses for each heartbeat or phantom pulses when receiving noise. As a consequence, the heart rate given by the pulse oximetry sensor is always more reliable and is used exclusively when both heart rate readings are available. In summary, the receiver unit is able to wirelessly request and receive information from the sensor unit to find out whether it is within receiving range. If this is the case, for each sensor it can store a value or an error code indicating that the sensor is not in use. The micro SD card can be used together with the real time clock for long-term, time-stamped data storage and extraction.

3) *Car information system*

To enable external communication with the receiver unit, the serial communication pins of its ATmega644 are connected to the interface. The same protocol to request information employed between the ATmega644 and the ATmega2561 is available to request information through the external interface. A 650i car (BMW Group) was used to demonstrate how this can be utilized by a car manufacturer to embed received data into the car information system (Figure 5, bottom).

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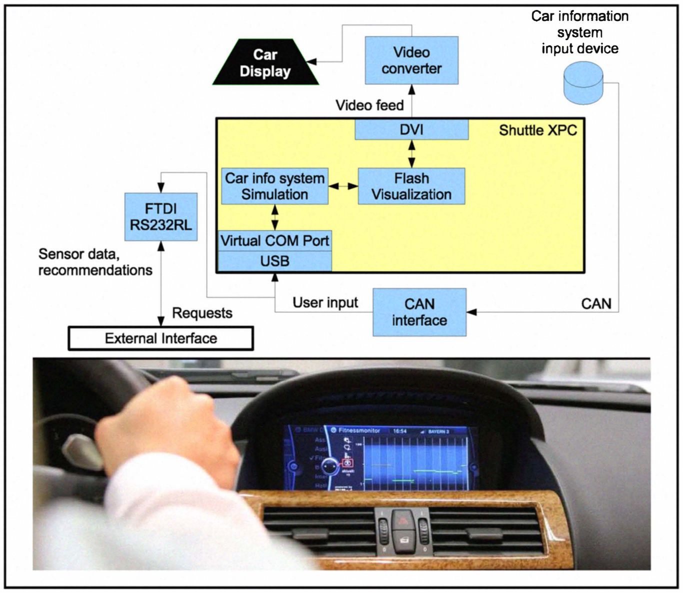

Figure 5. Top: Description of the car information system's parts and interfaces. Bottom: Detail of vital parameters displayed on the car information system.

The car was modified in order to have a USB plug in the driver cabin, so the receiver unit can be connected to the car's information system. Cars will most probably have such an interface in near future. If not, the system can easily be adapted expanding the serial interface with a Bluetooth module, as most cars already support Bluetooth communication with e.g. mobile phones. To implement the new functionality into the car information system, a flash simulation of this system running on an XPC System (Shuttle Computer) was modified. The XPC System is connected to the car's display and CAN bus in order to visualize the simulation and to get user input from the information system input device. This is a common approach for prototyping new features of a car information system. For the system scheme, see also Figure 5, top.

B. *Preliminary experiment*

1) *Motivation*

In the run-up to the system development it was necessary to determine which sensors are capable to acquire vital parameters without distracting a driving user. Furthermore, possible realistic usage scenarios and correlations between cognitive stress and driving situations had to be explored.

2) *Setup*

The experiment took place inside a static driving simulator (Figure 6, left) with 21 male and 3 female subjects, 36 year old in average. Every subject was asked to drive through 5 simulated scenarios:

- Scenario "sparse traffic".
- Scenario "heavy traffic".
- Scenario "dynamic heavy traffic".
- Scenario "dynamic heavy traffic and secondary task".
- Scenario "interurban and city drive".

Figure 6. Left: Experimental setup. Right: Frame of the four recorded views during the tests.

The secondary task in the fourth scenario consisted in counting down loudly in steps of seven. During the drive, the subject's vital parameters were recorded with a sampling rate of 50 Hz using the following sensors:

- Skin temperature and skin resistance sensor attached on the back of the steering wheel's left radius arm (iSense, Werfen Austria GmbH).
- Skin temperature and skin resistance sensor attached to the left hand's forefinger (iSense, Werfen Austria GmbH).
- Transmissive pulse oximeter attached to the right hand's forefinger, measuring heart rate and oxygen saturation (PEARL, medlab GmbH).

The test subjects were asked to use the sensor fixed to the steering wheel whenever it was possible without being distracted from the driving task. Before the first and after the last scenario, a baseline reading was taken. Between the scenarios the following questionnaires were filled out to acquire subjective data:

- Basler existential-orientation-scale (Befindlichkeitsskala) [7].
- NASA Task Load Index [8].
- Simulator sickness questionnaire [9].

In addition to the objective and subjective driver data, several internal simulator values were recorded with the same sampling rate. These values included speed, acceleration, attitude angle, yaw rate, driven distance, differential lane angle, lateral position, steering wheel angle, steering rate, throttle pedal setting, braking pedal setting, turn indicator state, overall vehicle position and orientation and motor rotation speed. Regarding the driving situation, the number of available lanes, the distance to the next car, the number of cars on the driver's lane before and behind the driver and the overall traffic density were recorded.

In the dynamic scenarios the simulator generated and recorded two critical driving situations:

- Situation "merger".
- Situation "braker".

The "merger" situation occurs when a vehicle suddenly changes to the driver's lane, while the "braker" situation occurs when a vehicle suddenly brakes sharply in front of the driver. However, those situations are recorded even if the situation doesn't influence the test subject (e.g. happens too far away).

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The overall test duration averaged to 60 minutes and was recorded as video footage including a view of the driver cabin, a detail view of the steering wheel sensor, a view of the foot space and a 3rd person simulator view of the test subject's vehicle (Figure 6, right).

3) Results

a) Sensor availability

The average sensor availability (percentage of recordings with valid values) was minimal in the scenario with dynamic heavy traffic and secondary task. Here, it was 91% for the pulse oximeter, 99% for the finger-attached skin sensor and 73% for the steering wheel-attached skin sensor.

b) Significant vital parameter variations

On average, the test subject's heart rate is significantly higher in the scenario with dynamic heavy traffic and secondary task, both as absolute value and as difference to the average value (Figure 7). After a critical situation, in most cases a heart rate rise can be found (Figure 8). This effect does not happen consistently and features a high variance, nonetheless it must be taken into account that vital parameter changes can occur due to the driving situation and not due to pathological reasons.

The change of skin resistance in consequence of critical situations was less consistent. No significant effects could be found on the skin temperature or on the comparison of the baseline measurements before and after the test.

c) Subjective results

Evaluating the existential-orientation scale, a rise of the excitement from the first to the fourth scenario was found as intended. At the same time, concentration and balance dropped. The values in the last scenario were similar to the ones in the third. The evaluation of the task load index showed that the test subjects classified the progression of scenarios as increasingly demanding both mentally and physically. Concurrently, the estimated quality of task fulfillment and well-being dropped. In the course of the test single subjects reported increasing indisposition (3 subjects had to abort the last scenario) within the expectancy for static simulators.

C. Sensor evaluation experiment

1) Motivation

To verify the validity of the data delivered by the sensors embedded into the steering wheel and adapted to be evaluated by a microcontroller, a second experiment was done. Thus, the experiment can be divided into three parts:

- Skin resistance (3 test subjects, average age 26)
- Heart rate and oxygen saturation (2 test subjects, average age 25)
- Heart rate (Polar) (2 test subjects, average age 25.5)

For every test subject, 20 different measurements were taken.

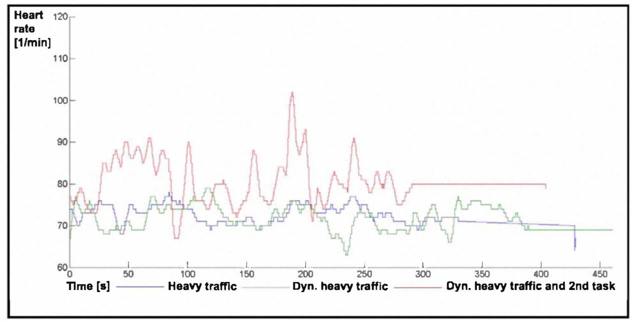

Figure 7. Measurement of heart rate characteristics during different driving simulator scenarios.

2) Setup

For every sensor, the sensor data was requested from the receiver unit through the external interface and stored on a PC. At the same time, the same value was measured on the test subject using a conventional sensor. The conventional sensors used as reference were:

- Skin resistance: Nexus-10 (Mind Media BV) connected to the output of the SC/GSR sensor together with the system's sensor unit.
- Heart rate and oxygen saturation: OnyxII (Nonin Medical Inc.) attached to the ring finger of the test subject, on the same hand activating the steering wheel sensor.
- Heart rate (Polar): OnyxII (Nonin Medical Inc.).

The sensors were evaluated based on the error value e:

$$e = \left|(V_S - V_R)/V_S\right| \cdot 100\% \tag{1}$$

, where V_S is the value provided by the developed system and V_R is the value provided by the reference sensor.

3) Results

a) Skin resistance

The Nexus-10 system has a measuring range from 1kΩ to 10 MΩ, whereas the developed system has a range from 170kΩ to 1MΩ, as the developed system is bound to the restrictions of the ATmega644's built-in A/D converters. Thus, within the system's range the maximal error was 18%, while it reached a maximum of 76% in one of the test subjects having a skin resistance out of the system's measuring range.

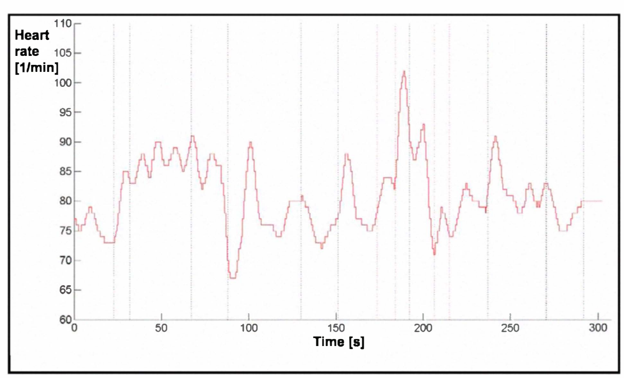

Figure 8. Measurement of heart rate change after critical situations (vertical dotted lines).

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b) Heart rate and oxygen saturation

In the heart rate, the error reached a maximum of 15% in one single measurement. The average error was 3% for the first test subject and 7% for the second. The oxygen saturation could be measured with a maximal error of 5%, while the average error was 1% in both subjects (Figure 9).

c) Heart rate (Polar)

In the first subject the heart rate was detected with a maximal error of 15% and average error of 3%. On the second the effects of noise were detected, thus the maximal error was 20%, with an average of 6% (Figure 10).

IV. CONCLUSIONS

A prototype of a system for unobtrusive in-car vital parameter sensing is presented for the first time. In an experiment exploring the usability of embedded sensor in the car and possible correlations between vital parameter changes and driving situation it was shown that sensors embedded in the steering wheel are easily usable without distracting the driver, and a correlation between heart rate and cognitive stress was detected. A second experiment ascertaining the accuracy of the system showed that the developed system has acceptable error values, as they lay within or below the error rates of conventional systems for the measurement of those parameters.

The system has the advantages of being able to measure vital parameters without distracting the driver and of evaluating the sensor data on a microcontroller, thus allowing an easy integration as small handheld device. Additionally, it offers an external interface and a communication protocol allowing car manufacturers to expand their car information system in order to utilize the information. Thus, it provides a basis for several pervasive applications supporting the mobility of elderly people, from regular in-car health check-ups to the adaptation of the car to the driver's current state. As next steps, an improvement of the user interaction for data visualization and extraction on the handheld device and the implementation of additional recommendations sent by the system to the car depending on the user's state are planned.

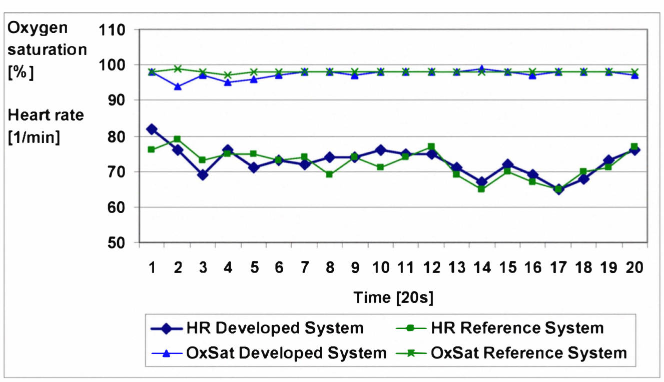

Figure 9. Measurement of heart rate and oxygen saturation with developed system and reference system.

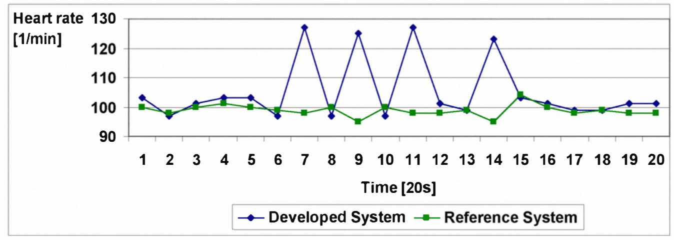

Figure 10. Measurement of heart rate with developed system using heart rate belt and reference system. The higher values result from noise-related phantom pulses.

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Within the research consortium of the Bavarian Research Foundation (BFS) „FitForAge“ a team of scientists and engineers affiliated to 13 departments of the Bavarian universities Erlangen-Nürnberg, München, Regensburg and Würzburg works together with 25 industrial partners on the development of products and services for the aging society.

The scope of the research consortium is to develop technology based solutions which will help elderly people in their future living environment comprising home and workplace as well as in communication and transportation. Eventually not only elderly people but also all social groups should profit from these solutions.

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