Using smart materials to monitor physiological signals of driver's inattention

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Abstract

The HARKEN project gathers a consortium of European research centres and enterprises that produce vehicle components, smart materials, and sensors for biomonitoring, to create a physiological monitor integrated in the car. This system is in constant contact with the driver's body through the car seat cover and the safety belt, and it monitors the physiological, mechanical activity related to respiration and the cardiac cycle. Redundant measures of vibrations and artefacts that may distort these signals are used to improve their quality by means of adaptive filters, programmed in a signal processing unit.

Introduction

Road accidents caused by fatigue are an important societal and economical problem. In 2010, there were around 31,000 deaths due to road accidents in Europe (OECD 2012). Moreover, driver fatigue accounts for 20-35% of serious accidents (Hell et al., 1997, Horne and Reyner, 2000, Sagberg, 1999). The projection of these figures means that there are over 6,000 annual fatalities due to fatigue-related accidents in the EU.

Driver fatigue countermeasures may be directed at drivers, companies, road infrastructure and vehicles. Particular countermeasures that should be considered are: publicity campaigns, infrastructural measures, legislation and enforcement, and in-vehicle systems that warn drivers when they are becoming fatigued. The latter type of solution is the most direct countermeasure, and the one that automotive industry and technology component suppliers may contribute to. Many research projects and large cooperation actions have taken place during the 21st century to advance in the development of different solutions (see figure 1).

Among the many projects dedicated to the development of human-machine interfaces (HMI) in the vehicles, to enhance driver's attention and ability to respond to road events, some like AWAKE or DROWSI have focused specially on monitoring and counteracting fatigue. The most common solutions, which are the only currently available in the market, are based on monitoring the driver's behaviour and performance, like lane keeping and acceleration/deceleration patterns.

However, driver behaviour alone may underestimate the loss of ability to respond to sudden risks (Lal and Craig, 2001), so there is a need for more effective solutions, based on the direct evaluation of the psycho-physiological variables that are related to the wakefulness or fatigue of the driver (Barr et al., 2009). There are two main types of developments that follow that approach: camera-based systems, that use face recognition algorithms to measure fatigue indicators, like percent of eye closure or face gestures, and devices that measure the signals of the body which are related to the sympathetic nervous system, like heart rate or respiration. Thanks to recent technological advances, nowadays it is possible to measure such signals and monitor the quality of sleep and fatigue with wearable devices, such as the ones developed in the SENSATION project (Bekiaris and Nikolau, 2004).

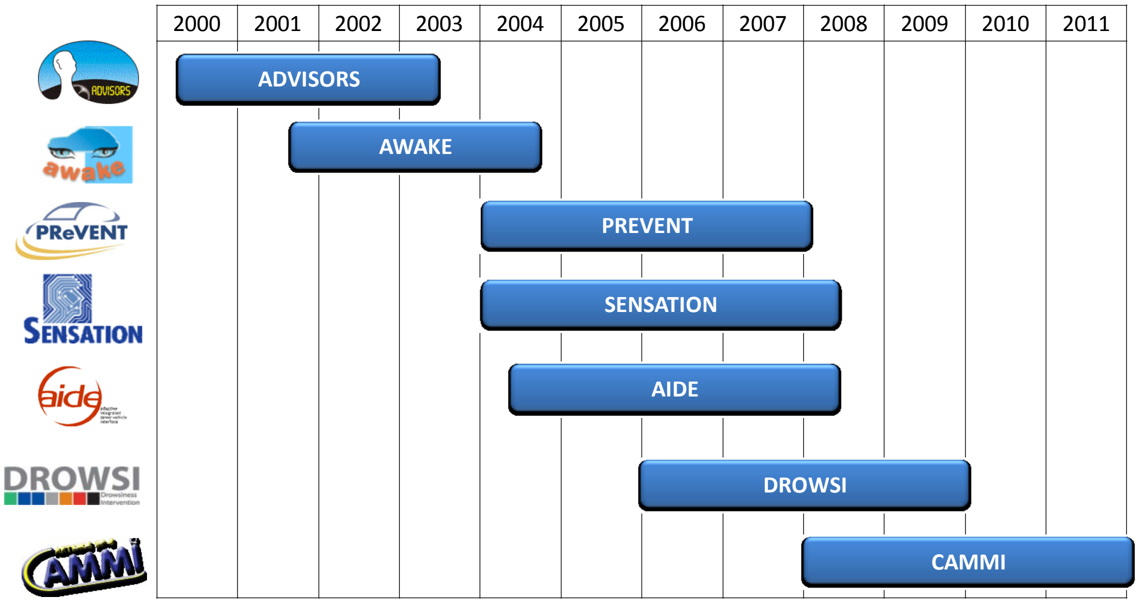

Figure 1 **Main European projects related to monitoring sleepiness, driver vigilance, and developing advanced automotive HMI**

The creation of the SFIT cluster (Smart Fabrics Interactive Textile) has also promoted the creation of smart textiles and wearable microsystems to measure physiological signals through different research projects (Luprano, 2006). The main challenge, however, remains in the difficulty of measuring such physiological signals in a totally unobtrusive manner, without carrying devices or special clothes. To achieve this goal, the HARKEN project has gathered a consortium of enterprises and research centres to develop an unobtrusive physiological monitor, based on sensing materials that are directly integrated in car components.

Figure 2 shows the structure of the HARKEN consortium, formed by small and medium enterprises (SME) that will produce the product, research and technological development (RTD) centres that are doing the necessary investigation to obtain it, and a large enterprise that works as road to the market.

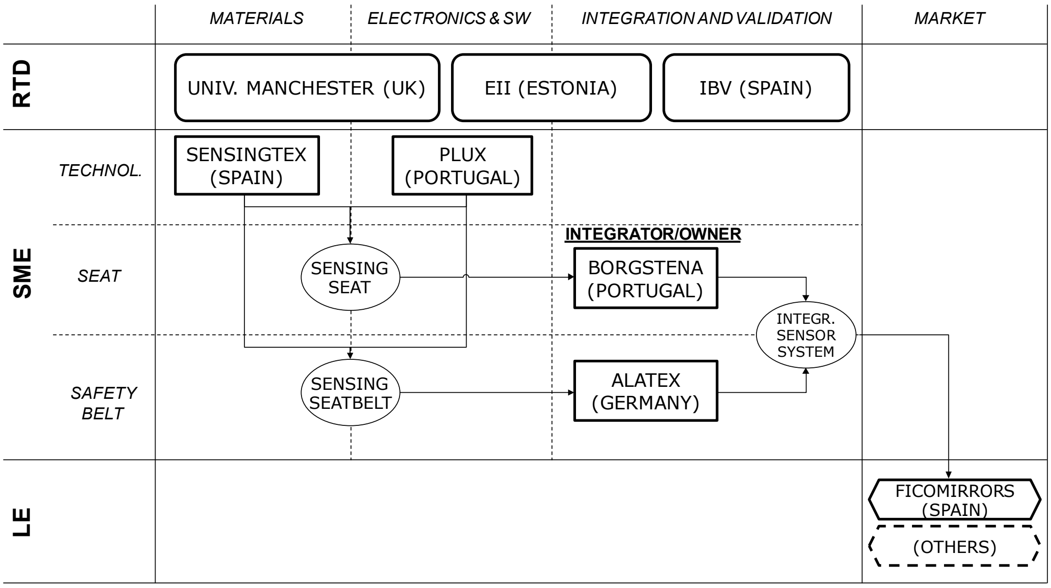

Figure 2 Structure of HARKEN development and value chain

Solution concept

The proposed solution is a nonintrusive sensing system of driver's heart activity and respiration, embedded in the seat cover and the safety belt of a car. The rhythm of heart beats, specially heart rate (HR) and heart rate variability (HRV), are good indicators of concentration and wakefulness (Lal and Craig, 2001), whereas the decrement of respiration rate has been also been proved to be correlated with increasing fatigue in monotonous driving (Milosevic, 2010), such that slow and deep breathing can indicate a relaxed resting state (Hadjileontiadis, 2006).

The HARKEN system will detect the mechanical effect such physiological activity, filter and cancel the noise and artefacts expected in a moving vehicle (vibration and body movements), and calculate parameters like the intervals between heart beats, or the amplitude and frequency of the respiration signal, which will be delivered in a readable format to integrate it in a fatigue detector (see figure 3).

The HARKEN system introduces two main innovations, which solve important limitations. First, the conventional electrodes to monitor physiological signals are replaced by smart textile materials, composed by a combination of fibres and yarns with electrical properties, supported by the standard textile of the seat and belt. This imposes some conditions on the type of signals that will be gathered. The solution concept of the safety belt is technologically similar to the plethysmography monitors that are usually employed to measure respiration, through the strain of a couple of thoracic and abdominal strips. On the other hand, the placement of the safety belt strap on the chest and abdomen on the driver, and the pressure exerted on the body, are usually inadequate for physiological monitoring purposes. Thus, besides the integration of the sensitive material in the strap, there is the challenge of adapting the structure of the safety belt and its anchorages to improve these conditions. A study of driver anthropometry is currently being conducted, in order to determine the optimal location of the sensors, and design a system of tensors that will help get a better control of the placement and pressure of the sensor.

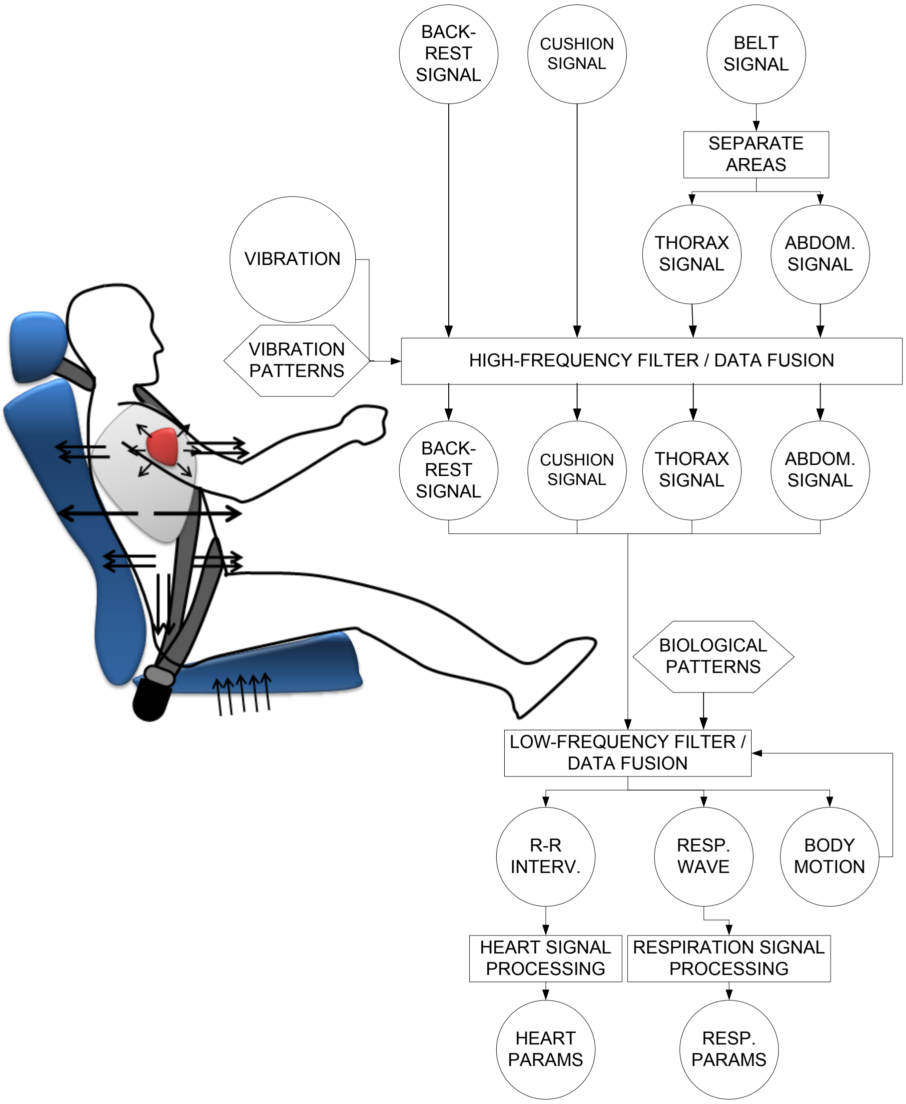

Figure 3 Scheme of the HARKEN concept

The solution concept of the seat differs from most types of physiological monitors, in the sense that the parts of the body that are in contact with the sensors, are not the closest ones to the organs whose activity is monitored (heart, lungs, or abdomen). However, the pressure exerted by the driver's body weight on the seat cushion and backrest improves the sensitivity of the materials for certain types of signals. Regarding the measurement of heart activity, the most used physiological signal in medical applications is the electrocardiogram (ECG), but the HARKEN concept takes advantage of the abovementioned condition, and measures heart activity by ballistocardiography (BCG), a mechanical measurement of the blood flow driven by heart beats, which has successfully been measured in normal chairs (Baek et al., 2012). Although the BCG signal does not show the specific patterns of the ECG waves that are used in clinical assessments, the heart beats are clearly marked and are correlated in both signals, so salient features like HR or HRV are equally measurable by this alternative.

The second innovation consists in the redundancy of physiological and dynamic measures of the driver's body, which will allow using data fusion strategies to improve the reliability of the outcome, and also applying adaptive filters to cancel the effect of vibrations and artefacts in the processed signal. Due to those noise factors and filtering effects, the finer details of the physiological signals cannot be retrieved from such a system, but it still possible to look up the main features like heart beats, and the intervals between successive breaths, that may be used to feed fatigue detection algorithms.

Current status of development

During the first nine months of the project HARKEN, the consortium has completed a definition of the system that will be used to measure heart and respiration activity by means of unobtrusive textiles. After a thorough revision of the state-of-the-art about unobtrusive physiological sensing, the variables and parameters that must be extracted have been specified, as well as the type of filter algorithms that will be used to cancel the effect of vibrations, motion artefacts and other sources of noise. This definition has been done on both theoretical and practical grounds, after experimental measures with users that carried physiological sensors in vibratory platforms and in vehicles, in order to characterise the signals that shall be measured by the sensors, and the error sources that shall be dealt with by our system (figure 4).

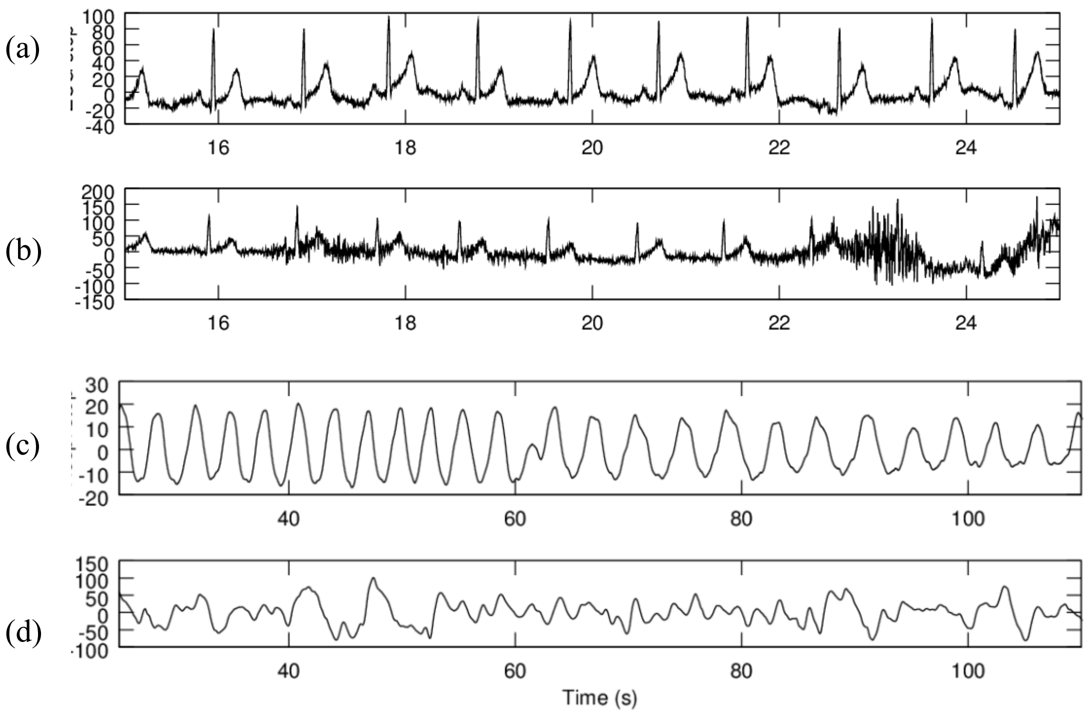

Figure 4 **Reference signals taken with medical monitors: (a) ECG in ideal conditions; (b) ECG of a person driving; (c) respiration in ideal conditions; (d) respiration of a person driving**

We have also defined a preliminary design of the hardware components that will be used. Sampling rates, voltages and other hardware specifications, including the characteristics of the front end, have been defined, and a Failure Modes and Effects Analysis (FMEA) has been conducted, to ensure that all the potential problems that may be encountered are under control (Passey, 1999). The algorithms of the Signal Processing Unit (SPU) are also structured, with an outline of the hardware and software requirements to implement them in the microelectronic devices.

The most important investigation carried out in this period is related to the creation of the sensors. Sensing Tex's state-of-the-art technology has been studied by the experts of the University of Manchester, and in this moment there is a technological solution based on their materials, that is capable of measuring the target signals, with the sensors on the subject's thorax an abdomen, but no direct contact with the skin. As seen in figure 5, the output signal reflects clear peaks o both respiration and heart (BCG) signals, that will allow to extract information about their rhythm and variation.

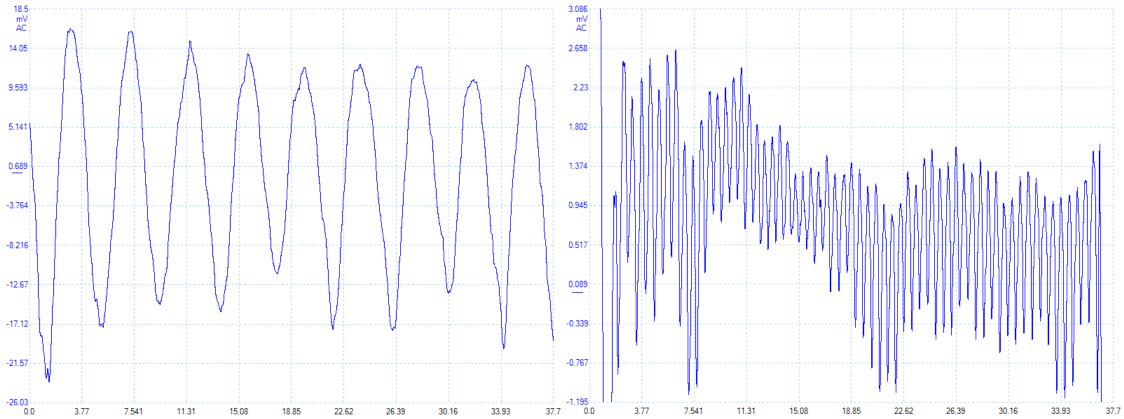

Figure 5 Signals of respiration (left) and heart activity (right) picked up by the sensors

The next challenge is the integration of the sensors in the car components, that has been already initiated. Even though the sensing materials are created for textile applications, the aesthetic, functional and safety requirements of the automotive industry for the materials that are used in car seats and belts are very specific, and it is necessary to find the optimal trade-off. Besides, solutions made out of the new materials entirely would be unaffordable from an industrial perspective, since their price is substantially higher, and the production processes of the manufacturer companies should be totally changed.

In the present moment, the project consortium is studying the most suitable location of the sensing elements in the car components, and how to introduce them in the production processes of the manufacturers in order to obtain a really unobtrusive integration, that minimizes the aesthetic and functional impact of including the new materials. After that, the different components shall be assembled in an integrated prototype with the SPU, to build a fully functional device.

Acknowledgements

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