Use Case of Smart Textiles Bio-Sensors Development and Integration for the Automotive Industry

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Abstract. As smart clothing is reaching a commercial level of maturity, the technology beyond bio-monitoring is being explored for other fields such as the automotive industry. In this case, the textile sensors integrated into a seat must remain contactless to allow for layer of clothing, seat cover, and such. The use of conductive textile materials is a key in creating an electromagnetic field which allow for contactless sensing. The data gathered by the biosensors can be used as prevention tool for detecting driver’s over-tiredness and stress or to monitor discomfort among passengers.

1. Introduction
Smart textiles may have been around for only a few decades but it is one of the fastest growing markets in the world; reaching 2.03 billion dollars in 2018 and expected to double these figures by 2025 [1]. Offering various active functions such as lighting, heating and sensing, smart textiles are mostly present in the garment industry and more specifically for workwear and sportswear applications. However, few products are actually commercially available due to important technical challenges related to the wear of the garment such as stretchability and washability. On the opposite end, while the automotive industry is usually perceived has highly innovative and cutting-edge in terms of technology, there are very few applications of smart textiles in cars; despite the fact that an average car is composed of approximately 30 kg of textiles [2].

However, the recent development trend showed a clear emphasis on the driver’s safety and comfort. The autonomous cars, which are to be the next generation vehicle, would not only need to perform their main function of driving by assessing its surrounding environment but will also be required to maintain the current entertainment functions encountered in many vehicle: music, lighting, and so on [3]. The same way, no human action is needed to control an autonomous vehicle, it is expected no more actions will be necessary to control accessories in the vehicle cabin. Being able to adjust its surrounding such as ambient temperature, volume of the music, or even engine functions (slow down or stop) based on the monitoring of the driver’s physiological state is tomorrow’s main innovation for the automotive industry.

2. Context and State-Of-Art Review
Long-distance travels have been known to often be a source of discomfort for both passengers and drivers, independently of the mode of transportation: plane, bus or train. Moreover, tiredness and psychological stress can affect the reflexes of drivers, putting at risk all passengers using public transport system. Professional drivers are considered a vulnerable occupational group due their exposition to environmental stressors and adverse work conditions. Furthermore, studies have been
able to create direct correlation between work-related stress and health outcomes such as cardiovascular disease, aggressive driving and fatigue leading to unsafe vehicle operation.

Reports of bus accident are fairly common, though they do not often get as much attention at plane crash much rarer but also involving a higher number of casualties. However, the statistics displayed by the National Transportation Safety Board (NTSB) reached 250 fatal casualty and 20 000 injuries sustain during a bus accident [4]. In over 20% of the cases, the driver was found to be at least partially responsible. These numbers does not take into account the percentage of accidents which may have been averted by the driver, if he would have been in a better state of focus.

Therefore, for safety reasons as well as for insurance purposes, many public transport companies require a check-up of their drivers before letting them on board [5,6]. The regular check-up relies mostly on questions given to the drivers and is solely based on his perceptions and self-evaluation of his condition. Therefore these measures are fairly ineffective as any driver who would want to take on his shift can do so, regardless of his physical and psychological state.

Several projects, such as Harken in Europe or EPIC [7] have looked into integrating sensors in cars; more specifically in the seat, seatbelt or even the steering wheel to monitor variation in heart rate and respiration rate. Indeed, these parameters are good indicators of stress or onset drowsiness and fatigue. However, the constraints related to the integration of such sensors into a vehicle are complex as it requires the car to be built consequently to be able to exploit the data gathered by the sensors [8].

Moreover, most sensing technologies, especially the ones used in smart textiles application, relay on direct electrical resistance variation, and require a very good contact with the human body in order to get a viable signal.

Contactless technologies are a more suitable option for use in transportation system where clothes are a factor to consider [9]. However, because these technologies are still under development, their maturity level is significantly lower and there are no commercial or ready-to-use examples available for direct integration at this stage.

Some major car manufacturers such as Ford and Toyota have contributed to developing DSM systems (Driver Status Monitoring) based on commercial medical technology such as electrocardiogram (ECG) and photoplethysmogram (PPG) [10]. These systems are usually fairly cumbersome, rigid and not compatible with a flexible textile structure. By miniaturizing these electronic devices, applications were found on the steering wheel.

However, it requires the driver to have both hands on the steering wheels at all time. Moreover, not only the degree of accuracy may be reduced but it also limits the type of signal as, for instance, the respiration is out of range.
Lately, attention was brought to optical system linked to a camera integrated in the middle rearview and able to capture the blinking rate of the driver \cite{11}. This system is fairly dependent of the quality of the recognition software coupled with the hardware to be effective. Practically, as many drivers wear sunglasses, the technology becomes somewhat irrelevant. After investigation, it appears the more efficient surface to be used at all time by the drivers, independently of any external circumstances is the seat and therefore the seat covers.

In order to bridge this gap and bring forward the opportunities offered by smart textiles, CTT Group has developed contactless sensors using a combination of conductive and electromagnetic materials combined with piezoresistive membranes.

3. Context and State-Of-Art Review

3.1. Heart rate sensing

Two independent technologies were used to measure respectively the heart rate and the respiration rate. The electrical impulse emitted at each heartbeat is initiated in the brain and travels through the nervous system to the muscle, in this case the heart. The displacement of such current and its alternation (on/off) lead to the creation of an electrical field and therefore an electromagnetic field. \cite{12-13}

At first, a conductive nonwoven structure, composed of 90% polyester fibers and 10% silver plated polyamide fibers, entangled in a random dispersion to create a 3D effect, was evaluated, as seen in Figure 2a.

However this prototype required to have electrodes in order to connect it to an electronic acquisition system; which involved additional processing steps and a longer production time. Moreover, a nonwoven structure is, by nature somewhat random and therefore the repeatability of the electrical surface resistivity between several samples of a same production roll can vary between 10 to 20%. Lastly the 3D shape of a nonwoven also creates a variable as the electrical conductivity will also vary based on the level of compression.

Research also showed the shape of the textile could influence the sensing sensitivity \cite{10}. Since antenna are usually made in circular spiral shape, a new prototype was designed using a conductive core-spun yarn, made of aramid spun core and cover with very thin copper flat lamella, embroidered according to a spiral pattern, as seen in Figure 2b. The results obtained were similar to the ones with the 3D-conductive nonwoven.

Though, distinct peaks were visible on the oscilloscope signal, an important work was done by
Thales Systems Inc in developing suitable algorithms and filters in order to obtain a clear and exploitable signal. Indeed, any flexion or friction resulting from person’s motion on a seat can lead to background noise and drown out the signal emitted by the heart.

Figure 2. a. on the left: conductive nonwoven with embroidered electrodes; b. –on the right: conductive yarn embroidered antenna structure.

3.2. Respiration rate sensing
The respiration rate was measured by using a flexible piezoresistive membrane, placed in-between two highly conductive fabrics. During a respiration, the volume changes of the thorax can be translated in an increased pressure against the backrest of the seat. By using pressure sensing technologies such as piezoresistive materials, it is possible to identify the respiration signal. However, the system must be suitable for various morphologies, meaning both different level of pressure and different positioning of the sensors. The number of sensors, their shape and their position within the seats were tested under multiple configurations.

The sensitivity of the piezo-membrane had to be tailored to the range of pressure applied solely by body contact. The choice of conductive fabric: silver-plated conductive woven fabric, sandwiching the membrane was key to controlling the variation of electrical resistance to the appropriate level; as shown in Figure 3. Results for the measurement of the respiration rate were very good and were used directly, without software transformation.

Figure 3. Semi-assembled seat cover with six respiration sensors located at the level of the backrest.

4. Integration, connexion and validation
Each respiration sensor is connected to the others using conductive yarns acting as electrodes. Conductive yarns were embroidered on the surface of the sensor, all the way down towards the connector, using a technique called tailored yarn placement. It allowed for optimal positioning of the
All conductive yarns, all parallels and close to each other without risk of short-circuit. All sensors were integrated in the backing of a seat cover where the conductive yarns were soldered to a connector allowing plugging the system onto its own circuit board. The connection was made underneath the junction between the backrest and the seat in order to minimize any mechanical strain on the cables. The validation of the system was made by six persons, having various morphologies and wearing different type of clothes, from tee-shirt to winter jacket. The data analysis confirmed that different sensors were triggered for the respiration dependently on the height of the person.

5. Conclusion
The emergence of autonomous cars, already involving numerous on-board technologies, will help launch forward and democratize the integration of bio-sensors in seats. Moreover, it will also provide a structure in which such data can be put to use.

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