Performance Specifications of Market Physiological Sensors for Efficient Driver Drowsiness Detection System

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Abstract: Significant advances in bio-sensors technologies hold promise to monitor human physiological signals in real time. In the context of driving safety, such devices are knowing notable research investigations to objectively detect early stages of driver drowsiness that impair driving performance under various conditions. Seeking for low-cost, compact yet reliable sensing technology that can provide a solution to drowsy state problem is challenging. The contribution of this paper is to study fundamental performance specifications required for the design of efficient physiological signals based driver drowsiness detection systems. Existing measurement products are then accessed and ranked following the discussed performance specifications. The finding of this work is to provide a tool to facilitate making the appropriate hardware choice to implement efficient yet low-cost drowsiness detection system using existing market physiological sensors products.

1 INTRODUCTION

Till now, the total number of serious car crashes is still increasing regardless of improvements in road and vehicle design for driver safety. Reduced mental alertness due to drowsy state have been identified as the greatest safety danger and the major cause of road traffic accidents (Lal and Craig, 2001). While each day in the United States 80,000 individuals fall asleep behind the steering wheel (American Academy of Sleep Medicine, 2005), 25-30% of driving accidents in the UK are drowsiness related (ROSPA, 2001), about 35% drivers in the Netherlands and 70% drivers in Spain have reported falling asleep while driving (Morales et al., 2015).

The measure of human physiological parameters allows evaluating objectively cognitive-attentive indicators, in reaction to external perceptual stimuli. The study of human physiology has showed that monotone driving task and nocturnal driving mostly lead to sleep deprivation, lacking sleep, and being in a state of low energy (Morales et al., 2015). These symptoms decrease cognitive abilities and make driver more prone to fatal errors. Many drowsiness measurement technologies have been developed to monitor driving behavior and alert drivers when drowsy.

Recently, with the remarkable advance in sensing and communication technologies, Low-cost wearable devices are fast becoming a key instrument on bio-sensors based applications and they have been applied in many fields including industrial, transportation, medical, daily-life, sport, etc. There are a number of tentative promoted by shift-work industries to monitor cognitive state of human-being using these emerging technologies since they hold the promise of being objective compared to other measuring technologies. These bio-signals based technologies make it possible to alert driver at earlier stages of drowsiness and thereby prevent many drastic accidents providing a solution to the driver drowsy problem (Sahayadhas et al., 2012).

In this study, we focus in assessing recent development of bio-sensors technologies in the market that are currently underway to address driver drowsiness issue, and provide a concise hardware specification tool for the design of efficient driver alertness monitoring system. In the following, the key drowsiness detection technologies are presented in section 2. Next, the general architecture of driver drowsiness monitoring system with different modules are explained in section 3. Main performance characteristics that must be met by a drowsiness monitoring technology are discussed in section 4. Section 5 is devoted to review potential market physiological sensors products. Ranking methodology is described in section 6 providing a tool to make the appropriate hardware choice of existing products. Finally, section 7 concludes the paper.

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2 DROWSINESS DETECTION TECHNOLOGIES

A plethora of driver fatigue researches exist spanning different measurement technologies. The most commonly used measurement can be categorized upon the monitoring instrument into: (i) Vehicle-based sensors, (ii) Video-based sensors, and (iii) physiological signals sensors such as electrooculography (EOG), electromyography (EMG), electrocardiography (ECG), and electroencephalography (EEG) signals where the latter is the most used (Sahayadhas et al., 2012; Sanjaya et al., 2016).

Vehicle monitoring focuses on driving and vehicle patterns such as steering wheel angles and reversals, the car position with respect the road's middle lane and the standard deviation of lane position (SDLP), etc. However, this technology can operate reliably only at particular environments (Sahayadhas et al., 2012) depending on the geometric characteristics of the road and to a lesser extent on the kinetic characteristics of the vehicle (Vural, 2009) and they are easily influenced by other factors such as road marking, climate, lighting and traffic conditions.

Video monitoring measures driver's facial expression and detect drowsiness from differentiating its abnormal behavior such as eye closure (PERCLOS), head nodding, etc. The common limitation is lighting. The detection rate using this technology was 59% compared to 85% and 97.5% of EEG and ECG (Sanjaya et al., 2016). (Golz et al., 2010) reported an accuracy around 74% and 66% using PERCLOS compared to 87% and 89% from EEG/EOG.

Bio-sensors measure physiological signals from organs such as brain, eyes, muscles, and heart which have visual correlation with fatigues/drowsiness. Researchers observed via EEG that drivers had sleep bursts accompanied by theta waves and K-complexes while they still had their eyes open, something video-based monitoring might have missed. Physiological signals have been shown to be reliable and accurate since they are less impacted by environmental and road conditions and thus may have fewer false positives than other measures (Zilberg et al., 2007).

3 SYSTEM ARCHITECTURE

Due to the increasing interest in the use of wearable bio-sensor systems, many communication architectures have been proposed depending on the target application (Lee et al., 2013). The general architecture of bio-sensor system is composed by three main modules: (i) signal acquisition, (ii) data processing, and

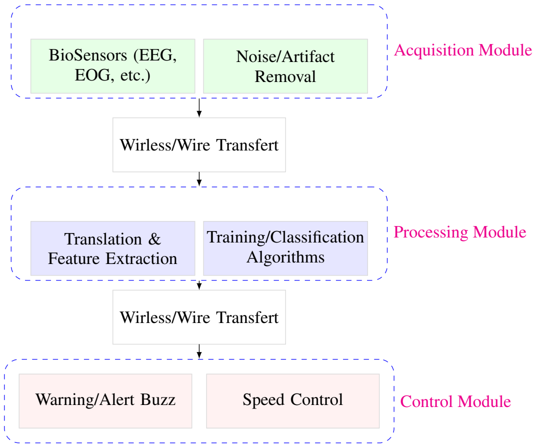

Figure 1: Logical view of different modules of the system.

(iii) control modules as depicted in Fig. 1.

3.1 Acquisition Module

This module is composed of different physiological wearable sensors such as EMG, ECG, EOG, EEG, etc. attached to the body which measure physiological signals. These sensors form a network and communicate with the network coordinator to send data. The measured signals are then filtered and transformed to remove any noise and artifact that may affect the quality of sensed data values.

3.2 Processing Module

Signals are received from acquisition module after filtering noise and removing artifacts. As second stage, signals are processed to extract the main features that reflect different states of the target application (e.g. the cognitive states of driver). These features are then passed to the training and classification algorithms to determine the new measured states. As for driver drowsiness, the features can be used to determine in which level of alertness the driver is.

3.3 Control Module

Driver alertness is monitored in real time using acquisition and data processing modules. Whenever a drowsy state is identified, the detection event is then triggered by the control module to make the appropriate action in time. This action may be an alarm or buzz inside the vehicle to alert or wake-up the driver. The action may take control of the vehicle in order to speed-down or stop the vehicle.

Many portable systems propose to incorporate the acquisition and the processing modules into the same component to compact the system. Hence, there is a

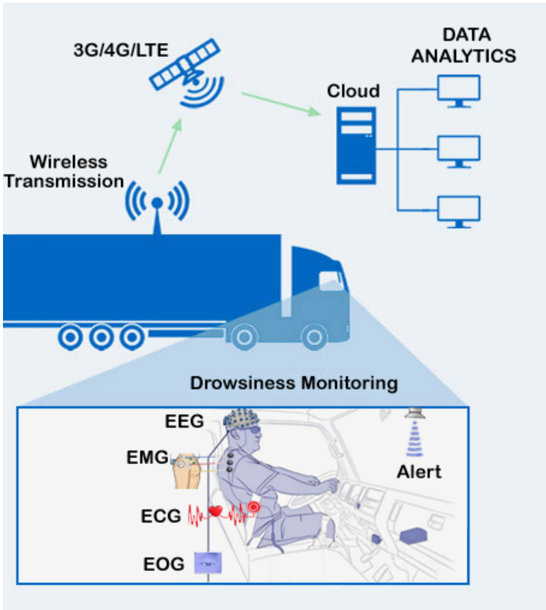

Figure 2: Driver Drowsiness Detection System Architecture.

serious issue with the battery lifetime. In the context of driver drowsiness detection, the acquisition module is attached to the driver and the processing module is installed on the vehicle which has sufficient power supply. This allows extending the battery lifetime and keep monitoring for long periods. The control module is mounted on the vehicle to trigger warning messages and sound alerts. This module can be even enabled to control some actions of the vehicle such as acceleration and speed. The system can be extended to support multi-tiers cloud-based architecture (Zao et al., 2014). As depicted in Fig. 2, some of data can be transmitted via 3G/4G/LTE connections to the remote servers where data analytic algorithms can be used to train and extract new knowledge. This enables monitoring cognitive states during real driving tasks from large number of drivers and may be explored by the research community to enrich training sets and improve the accuracy of existing detection algorithms.

4 PERFORMANCE SPECIFICATIONS

If any bio-sensors system is to prove suitable for detecting driver drowsiness, it must meet some performance specifications. These specifications are essential in making the appropriate bio-sensors hardware choice for design consideration. In the following, the major specifications are discussed:

4.1 Multi-sensors Support

Single signal measurement such as EEG may necessitate dense electrode placement in different locations to accurately capture cognitive states. Hybrid signal acquisition through simultaneous recording of different bio-signals can yield higher accuracy of the system. Combination of multiple bio-signals measurements, such as ECG, EMG, EOG with EEG, the system can measure not only brain waves but also heart rate, eye movements, etc. Research results have showed that adding either EOG or ECG measurements, there is further improvements in reduction of error rates in drowsy state detection (Warwick et al., 2015).

4.2 Type of Electrodes

The choice of electrode technology is very important since it represent the sensing component. With respect EEG measurement, wet electrodes known as silver-chloride electrodes (Ag/AgCl) are widely used by current market products. These electrodes are low-cost, and have low contact impedance, and good stability in time. Wet electrodes requires removing outer skin layer of the scalp and filling a special conductor gels which take long time to prepare and are uncomfortable to users. Dry electrodes are other technology which do not need to use gel and skin cleaning. However the bad signal quality is their main disadvantage. Fig. 3 shows an example of wet and dry electrodes available in the market.

(a) (b)

Figure 3: (a) Wet electrodes vs. (b) Dry electrodes.

4.3 Electrode Placement

Capturing as much as data from strategically locations is critical to pinpointing the drowsy related causes. For each bio-signal, there exists suitable locations where may be placed to efficiently measure signal reflecting the drowsy state of driver. For EOG, electrodes are attached to the eye skin (up/down/left/right) whereas for EMG, they may be placed on the left bicep, right bicep, left forearm flexor, right forearm flexor, frontal muscles, or on the deltoid, trapezius Hostens and Ramon (Hostens and Ramon, 2005).

While 5 & 12 lead electrode placements are generally used for ECG recording. For EEG, the electrode placement according to the 10-20 Standard defines which brain location that serves a specific function (see Fig. 4). More specifically: Prefrontal Cortex (Fp) for emotional inhibition and attention; Frontal Lobes (F) for working memory, metaphorical thinking, sustained attention and judgment; Central Strip (C) for sensory-motor functions; Temporal Lobes (T) for language comprehension and long-term memory; Parietal Lobes (P) for language processing and procedural memory; Occipital Lobes (O) for visual processing. Thus, locations concerning various forms of attention which reflect alertness/drowsiness states must be covered by the hardware.

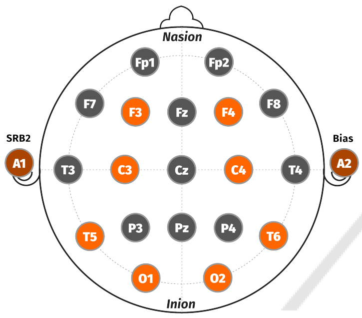

Figure 4: The 10-20 system of EEG electrode placement.

4.4 Number of Channels

An electrode capturing bio-signal activity is called a channel. Typical Bio-sensor systems can have as few as a single channel to as many as channels (256 for EEG) depending on the required density. The system must trade-off between capturing as much as bio-activities with some performance metrics. For instance, increasing the number of channels will have significant delay for data processing. Second, more channels mean higher costs and more difficult experimental setups. Lastly, by increasing the number of channels, the huge amount of signals will be transmitted that impairs reliability and battery usage especially for mobile and low-power systems. On the other hand, very few channels impair the accuracy of detection.

4.5 Portability & Mobility

Conventional bio-sensors systems such as *actiCHamp* (Brain Products), *Neuroscan NuAmps Express* (Compumedics Ltd.), and *EDVTCS* (Neurocom) are wired. The acquisition part of wired systems generally comes with bulky and heavy amplifiers and preprocessing units. Connecting wires is usually complicated with a large number of cables between the electrodes and the acquisition part. For these reasons, preparation time for measuring signals is typically very long. In addition, user movement is limited due to cable constraints. Therefore, the application of drowsiness detection based on these systems is difficult to escape from laboratory scale experiments. With emerging wearable technologies, biopotential measurements, such as EEG, ECG, EMG, and EOG can be delivered in real-time via wireless and Low-energy connections such as WiFi, Bluetooth, ZigBee, etc. Therefore, these provide the advantages of mobility and long-term monitoring. Portable systems facilitate the implementation of driver drowsiness detection systems and enable in-field experimentation instead of simulation environment. However, huge volume of signals may be sampled and need to be transmitted wirelessly in real-time. Hence, the system must prove energy-efficient operation for long period to be accepted for continuous monitoring. for example, compression algorithms can be used to alleviate big data transfer since it is time and energy consuming (Hussein et al., 2015).

4.6 Artifact Removal

Bio-sensors are prone to various sources of noise and artifacts. Signal conditioning is essential to enable transmission of precise bio-signals. Many noise sources are likely present from physiological interference and power line noise. Physiological interference occurs between EEG, EMG, ECG, EOG and others. The amplitude of EMG, ECG and EOG is relatively lager around 50uV and 20-30mV while that of EEG is much smaller around 10 100uV. Thus, the EEG signals are easily buried by these physiological signals unavoidably. Power line noise (Outlet, USB, etc.) can also contaminates the EEG signals in the range of 50 or 60Hz. Furthermore, the measured bio-signals of mobile systems are also subject to heavy motion and vibration artifacts. Hence, the presence of noise and artifact removal mechanism is essential in such systems.

4.7 System Autonomy

Another important specification is the need of energy-efficient and long-term wearing system. For systems that use battery powered bio-sensors, the lifetime of the system is the critical challenge to ensure continuous driver monitoring. In fact, wireless transmissions consume the largest amount of device's energy. Indeed, the battery autonomy may go from 4 hours to 24 hours or even more depending on the wireless

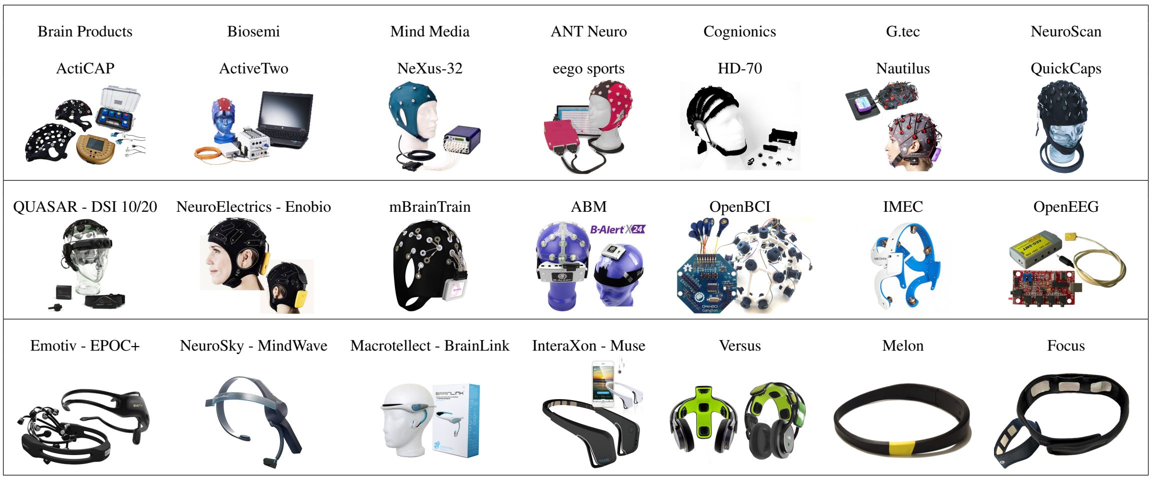

Figure 5: Overview of biosensors market products.

technology (e.g. Bluetooth, Wifi, etc.) and on the sampling rate. The system must be designed with efficient usage of sensory and radio components to ensure reasonable monitoring lifetime.

4.8 Software

The software is one of the main part of the system. Thus it is fundamental to have access to data in order to manipulate and/or analyze the recorded signals. The market product may provide software development kit (SDK) as bio-signal acquisition software or an application programming interface (APIs) compatible with some known commercial or open source bio-signals software platforms (e.g. BCI 2000, OpenVibe, LabVIEW, etc). This enables to facilitate and speed-up the development of efficient detection algorithms.

4.9 Product Cost

Making a choice between products must trade-off system performance with its cost. Many of existing market devices are designed for clinical and research purpose and provide multi-sensor acquisition with a large number of electrodes/channels and with incredible sensitivity. The cost of such systems is visibly high due to the full provided functionality. Depending on the application need like driver drowsy detection, the system cost may be reduced and can be determined by the performance specifications such as number of channels, sensors' type, portability, wireless technology, flexibility, and comfort.

5 MARKET PRODUCTS

With the growing progress in sensing technologies, more smart, compact and user-friendly products have been increasingly introduced to the market. Each of existing bio-sensor products provides specific monitoring functionality of human physiological states. For example, MySignals[1] provides e-Health platform that includes several bio-signals measurements such as ECG, EMG and X-Y-Z Accelerometer but not EEG and EOG.

ActiCHamp cap from Brain Products is destined for EEG signal acquisition. ActiCHamp exists with different channel and sampling rate configurations ranging from 32 to 160 channels and from 10 to 100 kHz receptively. **ActiCAP** express is light head cap version with 16 channels with active electrodes. Biosemi developed **Active Two** which is a 8/16/32 channels acquisition cap system with wet electrodes. The **ego/rt sports** from ANT Neuro is a portable head cap with up to 64 channels for rehabilitation mental states studies, and can work without conductive gel electrodes. **NeXus-32** and **Nexus-4** (Mind Media) are 32 channels (heavy) and 4 channels (portable) biosensors head cap with wet electrodes. ANT Neuro developed wireless **eego/rt sports** with 7-32 channels and dry electrodes.

Cognionics developed 64 channels headset Dry electrodes for general signals measurement. **Quick-20/30** is light version with 20 channels and possibility to integrate 8 channels from auxiliary EOG/ECG/EMG/PPG bio-sensors. Cognionics also designed **Sleep HeadBand** with 10 channels for sleep monitoring. G.tec designed **g.nautilus** with 8/16/32

[1] http://www.my-signals.com/

channels and wet/dry electrodes for clinical and research bio-signals measurement. **Quick Cap** is 256 wet electrode head cap from NeuroScan capable of measuring EEG, ECG, EMG, and EOG bio-signals. QUASAR designed **DSI-10/20** head cap with 21 dry electrodes. While **Enobio** from NeuroElectrics is a bio-signals acquisition head-cap with 8/16/32 channels. mBrainTrain designed 24 channels EEG wireless cap with wet electrodes as a research tool for Psychology, Sport, sleep, and Serious gaming/VR studies. ABM realized **B-Alert X10** (13 channels) and **B-Alert X24** (24 channels) which are portable biosensors headsets that can measure EEG combined with some other bio-signals such as ECG and provide quick and valuable insight into the cognitive function and mental state of the user.

OpenBCI is an open-source bio-sensors board capable of measuring EEG, EMG, and ECG signals. OpenBCI can support 4/8/16 and wet/dry electrodes which are sold separately. **IMEC** developed EEG headset with 8 channels to monitor Emergency Room and Intensive Care Unit patients. Omilex sold ModularEEG which is a 2 channels open-source hardware known as **OpenEEG**. Neurosky designed **MindWave**; a single channel EEG using one dry electrode on the forehead (FP1) for everybody use. Emotiv is another company that developed mobile bio-sensors. **EPOC+** is a 14 channels and **Insight** is a 5 channels from Emotiv that use dry electrodes and are capable of providing the following metrics to the users: (i) Engagement/Boredom which reflects long-term alertness and the conscious direction of attention towards task-relevant stimuli, (ii) Excitement (Arousal) that reflects the instantaneous arousal towards stimuli associated with positive valence, (iii) Stress (Frustration), and (iv) Meditation (Relaxation). **Versus** is EEG headset with 5 channels and dry electrodes designed for athletic peak-performance neurofeedback training through customized exercise protocols to improve mental acuity, concentration, and sleep management. **Muse Headset** from Interaxon is an easy-to-use 4 channels headband for concentration and meditation training. **Melon** is a slim EEG headset with 4 dry electrodes for focus neurofeedback. **iFocusBand** is a neoprene headband with 3 flexible woven electrodes targeted primarily for sports performance training. Table 2 provides a review of existing market bio-sensors and highlights the main performance specifications including the number of channels, electrode placement, data transfer technology and sampling rates as well as the battery autonomy and the corresponding cost whenever provided.

6 PRODUCTS RANKING & DISCUSSION

Notable efforts are taking place to promote biosensors technologies for pioneer applications. To our knowledge, there exists practically very few biosensors product intended for driver drowsiness detection on the market. Most of existing products provide bio-signals monitoring for general research usage or for medical and neurofeadback applications such as training, sport, gaming, etc. In the context of driving monitoring, more efforts are needed to meet performance specifications to develop efficient drowsiness detection system. For instance, high precision products are bulky and rely upon a large number of channels (e.g., 64-256), which is cost non-effective and makes it difficult to do fast artifact removal. Furthermore, electrode placement is too technical due to the requirement for electrodes, gel, wiring, etc. The use of dry electrodes is promising to reduce the cost and time required for data collection but novel techniques are needed to improve the accuracy of measured signals. Lower cost products come with reduced resolution (e.g., 4-16 channels) but with increased portability. Although, these devices are cost effective and more comfortable, they either suffer from low accuracy and require additional signal inputs such as EOG, ECG, EMG to maintain high accuracy.

In the context of driver drowsiness detection, it would be preferable that the bio-sensor system is less obtrusive and composed with multiple bio-sensors especially EEG and EOG (Golz et al., 2010), with few but sufficient number of channels, active electrodes, low-power communication technology with acceptable sampling rate and battery autonomy. To facilitate the choice of suitable hardware for drowsiness detection, we have ranked the reviewed bio-sensor products in Sec. 5 using the performance specifications discussed in Sec. 4. As multiple bio-sensors are needed, we ranked with (1,2,3,4) whenever EEG, ECG, EMG, EOG are supported. Electrode type is ranked with 1 for wet and 2 for dry. Electrode placement is ranked only for EEG from 1 to 6 for (Fp) (F) (C) (T) (P) (O) locations. We ranked the number of channels with 1/2/3/4/5 for 64-256/32-64/16-32/8-16/1-8 channels. Portability is ranked following the data transfer technology as 1/2/3/4 for USB, Wifi, BLE, RF[2]. Artifact removal is ranked with 0 or 1 for the existence of the mechanism. Battery lifetime is ranked as 1/2/3/4/5 for 1-4/4-8/8-12/12-16/16-24 hours autonomy. The

[2]BLE: Bluetooth Low Energy marketed as Bluetooth Smart. RF: Proprietary RF refers to any radio frequency specific to an original equipment manufacturer OEM and it is under 928MHz.

software is ranked with 0/1/2 when the signal processing software is provided and wither is commercial or open-source software. Finally, the cost is ranked with 1/2/3/4/5 for price ranging in [50k 100k]/[25k 50k]/[10k 25k]/[1k 10k]/[0 1k]$.

Table 1 shows the results of existing bio-sensor products ranking. It can be observed that OpenBCI, Enobio, and DSI10/20 are the top ranked products that met the required performance specifications among others. This ranking is based on our study of physiological based-sensors technologies and we believe that it is not the only evaluation and ranking method to access the performance of such technologies. Although some performance metrics were not taken into consideration in our ranking (e.g., device comfort), we think that the proposed ranking tool help in choosing the most appropriate hardware products to develop efficient drowsiness detection system.

7 CONCLUSION

Driver drowsiness poses a major danger for public safety. Monitoring driver's alertness is of high importance to prevent grand number of incidents. Existing drowsiness detection technologies such as vehicle and video-based have limited accuracy and work well in specific conditions. Recently, a number of portable bio-sensor devices have rapidly attracted the research interest to circumvent the drive drowsy problem under any condition. These promising devices can objectively capture the drowsiness state by monitoring physiological signals of drivers and alert them in real-time. However, the choice of the hardware must trade-off some performances such as signal quality and the cost. This paper discusses a number of performance specifications required by such systems and rank the existing market physiological sensor products following these specifications providing the research community with a tool to make the appropriate hardware choice for design consideration of efficient yet low-cost driver drowsiness detection. We plan to perform experimental comparison tests between some existent market platforms in our research agenda.

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Table 1: Bio-Sensors Products Ranking.

Product	Number of Channels	Electrode Placement	Type of Electrode	Multi-Sensors	Portability	Artifact Removal	Battery Autonomy	Software	Cost	Total
ActiCHamp-64	2	6	1	1	1	1	2	2	2	18
ActiCHamp-32	3	6	1	1	1	1	2	2	2	19
ActiCap	4	6	2	1	1	1	2	2	3	22
eego/rt sports	2	6	1	3	1	1	2	1	2	19
Active Two-128	1	6	1	3	1	1	2	2	2	19
Active Two-64	2	6	1	3	1	1	2	2	2	20
Active Two-32	3	6	1	3	1	1	2	2	3	22
Active Two-16	4	6	1	3	1	1	2	2	3	23
Active Two-8	5	6	1	3	1	1	2	2	3	24
Cognionics-70	1	6	2	3	3	1	2	1	2	21
Cognionics-40	2	6	2	3	3	1	2	1	2	22
Cognionics-32	3	6	2	3	3	1	2	1	3	24
Cognionics-24	3	6	2	3	3	1	2	1	3	24
Quick-20	3	6	2	3	3	1	2	1	3	24
Sleep Headband	4	3	2	1	3	1	2	1	4	21
G.tec SAHARA-32	3	6	2	1	4	1	2	1	3	23
G.tec SAHARA-16	4	6	2	1	4	1	2	1	3	24
G.tec SAHARA-8	5	6	2	1	4	1	2	1	4	26
Q. DSI10/20	3	6	2	4	3	1	5	1	3	28
Enobio-8	5	6	2	4	3	1	2	1	4	28
Enobio-20	3	6	2	4	3	1	2	1	3	25
Enobio-32	3	6	2	4	3	1	2	1	3	25
B-Alert X10	4	3	1	4	3	1	2	1	4	23
B-Alert X24	3	4	1	4	3	1	2	1	3	22
Quick Caps	1	6	1	4	1	1	1	1	1	17
NeXus-32	3	6	1	4	3	1	5	1	3	27
mBrainTrain Cap	3	6	1	1	3	1	2	1	4	22
OpenBCI-4	5	4	2	3	4	1	5	2	5	31
OpenBCI-8	5	6	2	3	4	1	5	2	5	33
OpenBCI-16	4	6	2	3	4	1	5	2	5	32
IMEC	5	4	2	1	3	1	5	1	3	25
OpenEEG	5	2	2	1	1	0	1	0	5	17
Emotiv EPOC+	4	4	1	1	4	1	3	1	5	24
Emotiv Insight	5	3	2	1	4	1	1	1	5	23
NeuroSky	5	1	2	1	4	1	2	1	5	22
BrainLink	5	1	2	1	3	1	1	0	5	19
Muse	5	3	2	1	3	1	2	2	5	24
Versus	5	2	2	1	3	1	2	0	5	21
Melon	5	1	2	1	3	1	2	0	5	20
Focus	5	1	2	1	3	1	3	0	5	21

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Table 2: Review of well-known Bio-Sensors market products with major performance specifications.

Company	Product	Channel	Electrodes	EEG Placement	Bio Sensors	Data Transfer	Sampling rate (kHz)	Battery Autonomy	System Cost ($)
Brain Products	ActiCHamp	160	Wet	(Fp) (F) (C) (T) (P) (O)	EEG	USB	10-25	6 hr	96,500
		128	Wet	(Fp) (F) (C) (T) (P) (O)	EEG	USB	10-25	6 hr	80,000
		96	Wet	(Fp) (F) (C) (T) (P) (O)	EEG	USB	10-25	6 hr	66,200
		64	Wet	(Fp) (F) (C) (T) (P) (O)	EEG	USB	25-50	6 hr	49,900
		32	Wet	(Fp) (F) (C) (T) (P) (O)	EEG	USB	50-100	6 hr	35,600
	ActiCap	16	Wet/Dry	(Fp) (F) (C) (T) (P) (O)	EEG	USB	2-20	6 hr	11,375
ANT Neuro	eego/rt sports	64+24	Wet	(Fp) (F) (C) (T) (P) (O)	EEG EMG EOG	USB	2.048	6 hr	$>25,000$
Biosemi	Active Two	256+7	Wet	(Fp) (F) (C) (T) (P) (O)	EEG ECG EMG	USB	2-16	5 hr	75,000
		160+7	Wet	(Fp) (F) (C) (T) (P) (O)	EEG ECG EMG	USB	2-16	5 hr	52,000
		128+7	Wet	(Fp) (F) (C) (T) (P) (O)	EEG ECG EMG	USB	2-16	5 hr	45,000
		64+7	Wet	(Fp) (F) (C) (T) (P) (O)	EEG ECG EMG	USB	2-16	5 hr	27,000
		32+7	Wet	(Fp) (F) (C) (T) (P) (O)	EEG ECG EMG	USB	2-16	5 hr	21,000
		16+7	Wet	(Fp) (F) (C) (T) (P) (O)	EEG ECG EMG	USB	2-16	5 hr	17,000
		8+7	Wet	(Fp) (F) (C) (T) (P) (O)	EEG ECG EMG	USB	2-16	5 hr	13,500
Cognionics	Dry Head Set	16+8	Dry	(Fp) (F) (C) (T) (P) (O)	EEG ECG EMG	BLE	0.262	6 hr	∼15,500
		24+8	Dry	(Fp) (F) (C) (T) (P) (O)	EEG ECG EMG	BLE	0.262	6 hr	∼20,500
		32+8	Dry	(Fp) (F) (C) (T) (P) (O)	EEG ECG EMG	BLE	0.262	6 hr	26,500
		64+8	Dry	(Fp) (F) (C) (T) (P) (O)	EEG ECG EMG	BLE	0.262	6 hr	42,600
	Quick-20	20+8	Dry	(Fp) (F) (C) (T) (P) (O)	EEG ECG EMG	BLE	0.262	6 hr	20,600
	Sleep Headband	10	Dry	(Fp) (F) (T)	EEG	BLE	0.262	6 hr	3,800
G.tec	g.sahara/nautilus	8	Wet/Dry	(Fp) (F) (C) (T) (P) (O)	EEG	RF	0.25/0.5	8 hr	4,500
		16	Wet/Dry	(Fp) (F) (C) (T) (P) (O)	EEG	RF	0.25/0.5	8 hr	∼9,500
		32	Wet/Dry	(Fp) (F) (C) (T) (P) (O)	EEG	RF	0.25/0.5	8 hr	$\leq 25,000$
QUASAR	DSI10/20	21	Dry	(Fp) (F) (C) (T) (P) (O)	EEG ECG EMG EOG	BLE	0.24/0.9	24 hr	22,500
NeuroElectrics	Enobio	8	Wet/Dry	(Fp) (F) (C) (T) (P) (O)	EEG ECG EMG EOG	BLE	0.25	8 hr	4,995
		20	Wet/Dry	(Fp) (F) (C) (T) (P) (O)	EEG ECG EMG EOG	BLE	0.25	8 hr	14,495
		32	Wet/Dry	(Fp) (F) (C) (T) (P) (O)	EEG ECG EMG EOG	BLE	0.25	8 hr	24,995
ABM	B-Alert X10	9+4	Wet	(F) (C) (P)	EEG ECG EMG EOG	BLE	0.256	8 hr	9,950
	B-Alert X24	20+4	Wet	(F) (C) (P) (O)	EEG ECG EMG EOG	BLE	0.256	8 hr	19,950
NeuroScan	Quick Caps	256	Wet	(Fp) (F) (C) (T) (P) (O)	EEG ECG EMG EOG	USB	02/0.5	0	81,396
Mind Media	NeXus-32	21	Wet	(Fp) (F) (C) (T) (P) (O)	EEG ECG EMG EOG	BLE	2.048	20 hr	23,995
mBrainTrain	EEG Cap	24	Wet	(Fp) (F) (C) (T) (P) (O)	EEG	BLE	0.25/0.5	5 hr	6,925
OpenBCI	Head Set	4	Wet/Dry	(Fp) (F) (C) (T)	EEG ECG EMG	RF/BLE	0.20	26 hr	199+60
		8	Wet/Dry	(Fp) (F) (C) (T) (P) (O)	EEG ECG EMG	RF/BLE	0.25	26 hr	499+60
		16	Wet/Dry	(Fp) (F) (C) (T) (P) (O)	EEG ECG EMG	RF/BLE	0.25	26 hr	899+60
IMEC	EEG Headset	8	Dry	(F) (C) (T) (P)	EEG	BLE		22 hr	25,000
Olimex	OpenEEG	2	Wet/Dry	(Fp) (F)	EEG	USB	0.19/0.5	0	119
Emotiv	EPOC+	14	Wet	(F) (T) (P) (O)	EEG	RF	0.128	12 hr	799
	Insight	5	Dry	(F) (T) (P)	EEG	RF	0.128	4 hr	299
NeuroSky	Mind Wave	1	Dry	(Fp)	EEG	RF	0.25	8 hr	130
Macrotellect	BrainLink	1	Dry	(Fp)	EEG	BLE	0.512	4 hr	373
InteraXon Inc.	Muse	5	Dry	(Fp) (P) (O)	EEG	BLE	0.22	5 hr	299
SensLabs	Versus	5	Dry	(F) (C)	EEG	BLE	0.25/1.28	5 hr	399
Melon Inc.	Head band	1	Dry	(Fp)	EEG	BLE	0.25	8 hr	149
Focus	IFocusBan	2	Dry	(Fp)	EEG	BLE	0.25	12 hr	500

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