Review of Human Activity Sensors Applications for Transportation Studies

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Abstract— **Human Activity Sensors (HAS) have become popular in the field of health (Psychology and physiology) and engineering especially in transportation systems. HAS are used in transportation, especially for road users to analyze their behavior. As these sensors are capable of monitoring various human activities, their applications to transportation research are growing. This study aims to provide a comprehensive review on human sensors and associated applications, with a focus on transport research and the trends of research topics. Most previous HAS applications in transportation were to monitor psychological and physical activities by different road users. Recent advances in wireless communication and cloud services have improved data transfer speeds, storage capacity and analysis power in human sensing technology. However, the presence of these benefits with the increase in technical progress is not consistent with the quantity of research in transportation. While previous human sensor studies were mostly limited to drivers, recent studies tend to include various transportation users including pedestrians and bicyclists. This study sheds lights on scientific approaches with HAS in transportation studies.**

Keywords: **sensing technology, human sensors, transportation applications, human activities, human behavior,**

I. INTRODUCTION

Various studies dealing with the sensing of drivers' situations were mainly aimed to develop the potential to reduce accidents and mitigate their harm. The study of traffic accidents caused by humans may provide useful information to researchers and developers if monitored during the event. Fatigue, drowsiness, lack of attention, anger are all major causes of human traffic accidents. As the BLACK BOX equipped with aircraft in the analysis and evaluation of many of the accidents of aircraft, the same role contributes sensors of human activities for drivers [1]. HAS may also had an instantaneous role in preventing accidents if they work in conjunction with Advanced driver assistance systems (ADAS).

Traffic crashes are the leading cause of vast numbers of deaths and injuries on the road reported by annual statistics. Losses resulting from traffic crashes are not only limited to death and injury but also to the economic losses resulting from the cost of treatment and loss of productivity because of person's mortality and disability. According to the World Health Organization (WHO), in 2017 around 1.5 million different road users die every year from traffic accidents and half of them die due to traffic crashes. It is also expected that in the absence of sustainable traffic, traffic crashes will become the leading cause of death by 2030 [2]. According to the National Highway Traffic Safety Administration, from 2009 to 2013, more than 72,000 police-reported crashes involved drowsy drivers, and resulted in more than 41,000 injuries and more than 800 deaths [3] . Another study conducted in 2014 by the AAA Foundation for Traffic Safety estimated that as many as one in five fatal crashes involve drowsy driving. Additionally, a recent AAA survey found that more than 31 percent of highway vehicle drivers admitted driving while so tired that they had trouble keeping their eyes open [3].

The challenge of ensuring safety for different road users is becoming greatest concern and interest for transportation engineers. Some industrialized countries have already taken necessary measures to protect road users, pedestrian, cyclist or motorcycle, and drivers, and those measures could successfully reduce the traffic fatalities. This reduction of deaths resulting from improved safety is not only due to the improvement of the road environment and vehicles but also because of the improvement of the interaction between road users and roads [4]. Warning road users can reduce death and injuries caused by traffic crashes before the moment of accidents. Fatigue, drowsiness, anger, and lack of attention are all causes of accidents. Therefore, the assistive techniques for drivers to stop at risk or to alert when exiting the path is carried out by synchronizing with monitoring and sensing techniques. Some ongoing researches are aiming to reduce accidents of pedestrians and cyclists by using alert techniques as they approach different modes of transportation [5].

It is important to study the essential element of life those are related to transportation engineering especially the way of life and its relation to the risks. The physical activity can be promoted by active transportation (walking and cycling) which are not addressed by the traditional health methods. The benefits of active transportation are not limited to health benefit of road user but also it has environmental and economic benefits in short and medium trips [6]. Devices with sensors or

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known as wearable devices are deployed. These devices create self-awareness among road users, pedestrian, and cyclist, which help to improve the level of physical activity by reducing the inactive behavior. These devices are being used on an equal basis by different aged people and gender [7]. The importance of the use of HAS in the field of transportation is therefore very important and makes the subject fertile ground for research and development.

In the modern era, the world has seen a lot of development in the field of HAS devices through great research efforts and advancement in the industrial community. Reducing accidents, reducing health care costs, and furthering the development of technical systems inside of vehicles are the main interest of using HAS in the field of transportation. This development coincided with the interests of developments in self-driving vehicles and connected-vehicle technologies. The HAS technology market is expected to rise from $20 billion in 2015 to close to $70 billion in 2025, led by the healthcare sector [8].

The concentration of researchers and developers of HAS technology is developing small-sized, easy-to-wear, fitted with wireless technologies or monitoring, and have remote sensing capabilities devices. The working principle of these sensitive devices is closely related to human conditions, so they vary depending on the physical parameters. They can be used to monitor the several activities by [Electrocardiogram (ECG), brain signal Electroencephalogram (EEG), muscles signal Electromyography (MEG), blood pressure (PPG), eye tracking (EOG), etc]. Most of these sensors necessitate contacting with the human body. However, monitoring, as well as the recording of human temperature, breathing, state of physical activity, and temperament, has become available in two forms: a wearable version like those listed above, and a non-contact version that works via remote sensing. Future developments may produce HAS capable of sensing without the need of contact between device and humans.

Also, some of these studies are concerned of evaluating the performance of road networks and their impact on the cognitive situation as well as the comfort of the physical and psychological of the road users. Many studies have been undertaken to evaluate the effectiveness of road networks by considering the personal evaluation of road user. For this purpose, many researchers used modern technologies such as video imaging, GPS devices, gyroscopes, simulations techniques, and the traditional methods of questionnaire and analysis. The acceptable response of a person depends on individual's personality, perceptions, honesty, etc. during questionnaires and interviews method. Therefore, most of these studies aim to penetrate a field of diagnosing the state of the road users by revealing mental feelings, all physiological vitals, and emotions, directly and objectively.

Generally, in transportation can be used the HAS to 1) monitor psychophysiological activities, 2) manage large crowds or specific situations, and 3) predict crashes. Perhaps one of the most important components of any human sensing related study is the design compatibility of measurement systems. For example, the success of HAS applications does not always depend on sensor's multi-functionality, cost, size, weight, or amount of restrictions. However, letting alone their accuracy issues, some of these devices have problems in creating the need for an appropriate environment where users' observations can be achieved without constraints [9].

Some research papers have been presented on the subject of human activity sensors within the health field and in more than one direction. Most of the health research summarizes developments in this area and describes the mechanisms of work and its association with developments in the fields of communications and data analysis techniques (Zubiete et al., 2011; Patel et al., 2012; Bobade, 2015; Rahman et al., 2015; Nawal and Purohit, 2014; Bassey and Obot, 2016). Other topics of review addressed the HAS in general and focused mainly on the technological aspect. These studies are aimed at detecting developments in the field of sensors and technologies that support them. One of the most important topics that can be discerned in this research is the changes in hardware, software, and the size of data that can be analyzed. Some sensor technologies have also shifted from being wearable to remote sensing or only contact with the body of the human (Duchowski, 2002; Bandodkar et al., 2015; Mukhopadhyay, 2015; Sun and Yu, 2016).

Review's studies on the HAS in the field of transportation are almost less than the reviews mentioned in the health and technical aspects. However, what has been discussed earlier has contributed to the introduction of sensor technology into the transportation system. The decline in the review research of Human Activity Sensors in the transportation system does not mean there are no studies in this area. There is a large number of HAS research within the field of roads, which represents the bulk of the transport system. The Kaplan review discusses the safety issue through the applications of attention-monitoring techniques to drivers caused by drowsiness or distraction. A comprehensive study and classification of drowsiness and distraction cases have been presented. The review also showed suggestions that contribute to safe driving, especially car-to-car communication (C2C) [10]. The other study is for Sylvan, which summarizes safety research via monitoring of fatigue and drowsiness as well. Biological parameters are discussed when driver fatigue is detected through the brainwave, heart rate, or galvanic skin response and other technologies. It can be concluded that the review of Kaplan and Sylvan has shown HAS applications for traffic safety purposes, but one tends to the technical side and the other towards the health side.

This study provides a comprehensive and systematic review of HAS uses and the implementation of such research. The second part of this study presents the most important ideas for applications related to transportation. The third part of the study includes discussion and conclusions.

II. METHODOLOGY

The HAS research has been reviewed and classified through verification of all relevant sources. The literature on transport,

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which formed the database for this study, was determined by the title and abstract of the research. HAS related topics were classified according to the identification of technology type, mechanism of operation and purpose of usage. Matching required research papers with the objectives of the study through identifying keywords related to HAS and transportation, to reduce the time and effort. Figure 1 shows the general plan of research covered by this study and the mechanism in which the publications classification sequence was carried out.

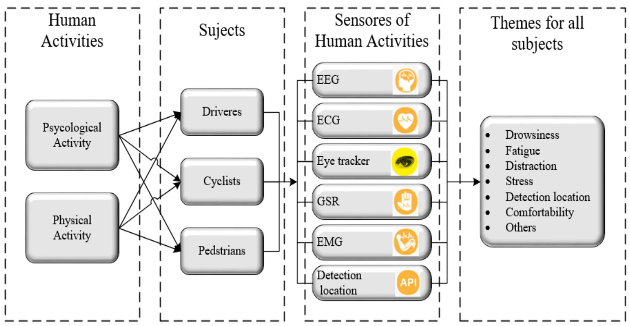

Figure 1 General data collection for transportation users based on Human Sensing (HAS)

In this study, the review is only concerned with HAS related to human activities. What is meant here is not to focus on sensors that sense the materialistic components.

Table 1 shows the classification of the equipment used in the field of transport for sensing the various human activities. The international codes for these techniques were presented with a brief explanation and detail of the mechanisms used.

Table 1. Human Sensors (HAS) used for transportation, whether wearable, non-wearable or available in both cases

Human Sensors (HAS)	Description	Type
EEG (Electroencephalography)	The devices that are monitoring and recording the electrical activity of the brain [11].	Wearable
fMRI (functional magnetic resonance imaging)	It is another device to monitor brain activity, but its mode of operation depends on changes in blood flow. Where the brain's neurons and their emotion are associated with blood flow.	Non-wearable
Heart Rate/ ECG/EKG (ECG/EKG: Electrocardiography)	It is a set of techniques designed to monitor the activity of the heart muscle by recording the path of electrical pulses. These devices measure the activities of the human heart in various situations, whether at sleep, rest, or movement.	Wearable or Non-wearable
Eye tracker	The devices that are monitoring eye movement of the head, direction, and length of time of concentration [12].	Wearable or Non-wearable
Skin Sensors/GSR (GSR: Galvanic Skin Response)	(GSR) Galvanic Skin Response: It is adopted as one of the signs of emotional arousal or sensitivity, as the positive signs mean happiness and negative indicate the sad [13].	Wearable
Blood pressure/PPG (PPG: Photoplethysmography) sensors	It uses a light-based technology to sense the rate of blood flow as controlled by the heart's pumping action	Wearable
EMG (Electromyography)	It is an electro-diagnostic technique for evaluating and recording the electrical activity produced by skeletal muscles.	Wearable
Others	These are the different technologies used in transportation such as radar, scanners, laser, or devices that rely on optical vision systems with motion detection algorithms such as ADAS technology developed by Mobily (One of Intel companies). Adas provides warnings to drivers to prevent collisions and reduce risk.	Wearable or Non-wearable

III.RESULTS

In our study, abbreviations were used for each type of human sensor technology according to what is approved in the most relevant research in the field. For example, abbreviations for sensing equipment on the brain are EEG and fMRI (Table 1) which differ completely regarding hardware, software, and usage between the two. A portion of studies involving HAS used only one technology, while others used multiply. Also, research has been classified into those involving intrusive and non-intrusive sensors. The technology used in each technique varies from one device to another regarding the freedom it gives the user and the ease of carrying the device. Although some HAS devices such as those used for walking and cycling are considered intrusive/wearable, which may not be comfortable for the users, HAS devices been frequently used and do not cause inconvenience to users. Some manufacturers have sought to develop intrusive products to become more aesthetically pleasing products, and users take pride in utilizing them.

A. The Trends of Categories

The classification of the collected studies of the subject of HAS included more than one method. The studies were classified according to the type of road user: pedestrians, cyclists, and drivers. Figure 2 shows the distribution of these studies without differentiation between road users. Beginning from 1988 to 2017, it is clear that the largest amount of research was done in the years 2002, 2009, and 2012. Figure 2 distributes research with differentiation between road users (pedestrians, cyclists, and drivers).

It can be seen that the greatest interest was in research related to drivers, followed by cyclists in 2007, and late interest in pedestrian research. Interest in pedestrian research started low and had been increasing until 2012 where it witnessed the largest amount of research. The most studies of cyclists were completed in 2016.

Recent years indicate that research across all road users is equal in some studies conducted due to increasing government interest in active transportation modes and infrastructure construction as well as an increase in peoples' awareness of the disadvantages of an inactive life. The shift towards vehicle communication for safety purposes, rather than relying on mentality and driver perception, may be one of the reasons why many of the studies on HAS concerned with drivers have dropped. Moreover, the development of modern vehicular abilities in detecting road parameters and preventing road departure may be one of the reasons for the reduction of research concerned with the tiredness or sleepiness of drivers. Studies have also been classified into research papers, reports, and theses. Since the largest number of these studies are research papers with a few research reports and a scarcity of theses, research reports and these were excluded from the statistical evaluation.

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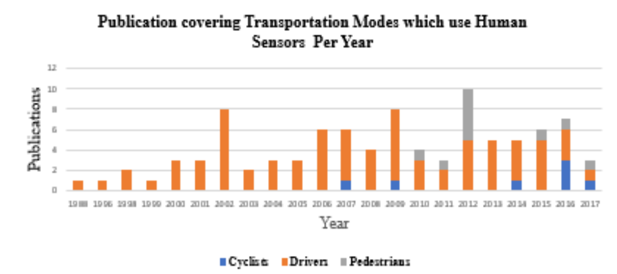
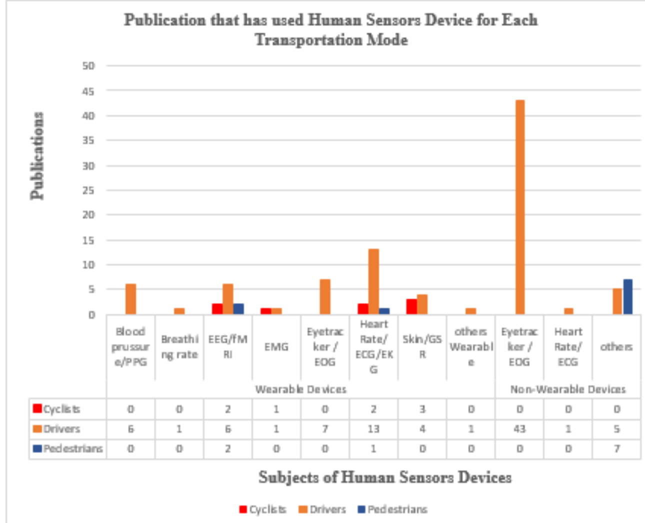


Transportation Mods	References	Count
Pedestrians	[26], [27], [28], [29], [30], [31], [32], [33], [34], [35]	10
Cyclists	[36], [37], [38], [39], [40], [41], [42], [43], [18], [19],	10
Drivers	[44], [17], [45], [46], [47], [1], [48], [49], [50], [51], [52], [53], [54], [55], [56], [57], [58], [59], [60], [61], [62], [10], [63], [64], [65], [66], [67], [68], [69], [70], [71], [72], [73], [74], [75], [76], [77], [78], [78], [79], [80], [81], [82], [83], [84], [85], [86], [87], [88], [89], [90], [91], [92], [93], [94], [95], [96], [97], [98], [99], [100], [101], [102], [103], [104], [105], [106], [107], [108], [109], [110], [111], [112], [113], [114], [115]	63

Figure 2 Publication covering Transportation Modes which use HAS per Year



	Wearable Devices								Non-Wearable Devices		
	Blood prussure/PPG	Breathing rate	EEG/fMRI	EMG	Eyetracker / EOG	Heart Rate/ ECG/EKG	Skin/GSR	others Wearable	Eyetracker / EOG	Heart Rate/ ECG	others
Cyclists	0	0	2	1	0	2	3	0	0	0	0
Drivers	6	1	6	1	7	13	4	1	43	1	5
Pedestrians	0	0	2	0	0	1	0	0	0	0	7

Figure 3 Publication that has used HASs Device for Each Transportation Mode

B. Subjects of Publication

Research specialized in the study of HAS is depicted in Figure 3. The figure illustrates the number of studies for each sensor technology with each type of transportation mode. It should be noted that this figure is fragmented into two main parts. The right part is for non-wearable devices and the left for wearable devices. It is evident that research using non-wearable eye-tracking sensors are most widely used, especially those designed to study driver behavior. The amount of wearable eye tracking devices shown in the left part of the figure is acceptable compared to the number of other wearable devices. Although the availability of wearable devices designed to monitor the eye in an easy and unrestrictive way, eye tracking devices were not used in the field of monitoring pedestrian and cyclist behavior.

Wearable EEG devices were used in most studies. The number of studies that have used EEG devices to investigate the behavior of drivers is comparable to other wearable devices. Studies that used wearable EEG devices to explore the behavior of pedestrians and cyclists are scarce. Studies within the field of transportation that use non-wearable EEG devices were not found to give adequate information.

In terms of heart rate/ECG monitoring devices, especially those that are wearable, the number of such studies is comparable to other wearable devices, while the observed number of studies on non-wearable devices were fewer than the wearable device.

The approach to the use of in-vehicle devices that do not contact the driver and monitor heart activity is a brilliant and promising innovation. These devices are able to oversee and monitor driver health as well as give drivers the freedom of movement.

The number of commercial products used to monitor physical activities (including the cardiac activities of pedestrians and cyclists) is not consistent with the number of heart activity monitoring studies for both pedestrians and cyclists. The amount of research with heart activity monitors is comparable to the amount of research that involves the monitoring of changes in the skin response to road users (GSR). GSR has begun to spread in many commercial products designed to monitor physical activity. It works on the principle of galvanic skin response, as it measures changes in the electrical properties of the skin. The resulting signals can be used as a parameter for the sweat glands. This tool is useful for examining the function of the automatic nervous system. This technique was not used as a non-wearable, so no studies were found on this subject.

C. Research Themes of Human Activities sensors:

Four of the most important topics covered by human Activity sensors research are:

C.I. Road Users' Psychological Activity Recognition

The behavior of road users is the leading cause of collisions. The estimated number of deaths is 1.25 million per year worldwide according to World Health Organization (WHO) [14]. In urban and rural communities, safe mobility is crucial and is a right [15]. Aggressive driving and driving errors are dangerous behaviors that may threaten road safety [16].

Literature shows that there is a correlation between road conditions and user assessment. Poor infrastructure design or traffic operation increases user pressure and also affects the user's psychological state. Many studies diagnose changes in drivers' psychology by measuring the heart rate or brain-planning signals [17].

C.II. Road Users' Physical Activity Recognition

There is an increase in the usage of HAS for wearable health fitness and the identification of road users' physical activity. The reasons for the popularity of these devices are: improving physical fitness and ease of use [18]. Another application of these devices is observed within road infrastructure for non-motorized road users, such as pedestrian and cyclist detection technologies. The advantages offered by these techniques are numerous. For example, it can provide information about the presence of a pedestrian or the speed of a cyclist. Some of the detection techniques are microwave, infrared, video, and inductive circuits [19].

C.III. Training and Rehabilitation of Road Users

Training and rehabilitation are necessary to enhance human life as well as for assessing skills, psychological, and health situations of people. Therefore, HAS is often used with simulation techniques. Simulation techniques have significant benefits associated with cost reduction, time reduction, real risk reduction, and repetition of the same requirements [20], [21], and [22]. Moreover, organizations benefit from human sensors to move to e-learning by providing consistent worldwide training, reducing delivery cycle time, increasing learner convenience, reducing information overload, improving tracking, and lowering expenses [23].

Bicycles are used for rehabilitation of individuals suffering from chronic and post-surgical conditions. They are provided with HAS to assess their reactions, in particular when the patient is weak or less coordinated [24].

Eye-tracking techniques are used to measure the cognitive load of participating drivers for real-time training purposes. Significant progress in these systems and great accuracy in data analysis programs have been achieved. Nevertheless, the high costs of these systems is still a major obstacle for the deployment and commercialization process [23].

C.IV. Remote Monitoring for the Health of Road Users

Certain societies are experiencing aging populations as well as various physical and mental illnesses resulting from environmental changes and the accelerating pace and pressures of life. Therefore, HAS is necessary. Monitoring those individuals with health issues using HAS has substantially decreased in cost [25].

Road users may be vulnerable to health challenges. Literature suggests that there is enormous potential for HAS techniques to monitor muscle activity, blood sugar levels, and oxygen content in the blood, brain activity, and motion.

CONCLUSIONS

This study aims to provide a comprehensive review on HAS and associated applications, particularly related to transportation. Many past studies were reviewed, and detailed references were presented to help researchers. Various techniques and functions have been used to monitor the physical and psychological activities of road users by detecting their presence and movements. None of these techniques are restricted to a particular area. In transportation applications, HAS research specialized for drivers was declining while studies for investigating the behavior of pedestrians and cyclists were increasing. It was also observed that HAS research in transportation heavily used eye-tracking devices, ECG devices, and EEG devices.

This study has reviewed studies using HAS for various road users. We found that human sensing applications used for pedestrians and cyclists were much greater than those used for drivers. Applications of HAS is continuously increasing in practice as well as scientific research thanks to the easiness of applications and compatibility with mobile technology. There is still large room for further enhancement on those devices and further research potentials. This study intended to shed lights on the application of human sensors in transportation applications.

Previous studies performed in terms of driver's behaviors. Therefore, the application of HAS related to pedestrians and cyclist should be steadily analyzing in the future for encouraging non-motorized transportation. In addition, it need to develop methodology to analyze transportation mode user's status by integrating various device. The studies using HAS would be contribute that the policy makers establish transportation strategies more user-friendly than existing policy by reflecting user behavior.

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