A REVIEW: HARNESSING IMMERSIVE TECHNOLOGIES PROWESS FOR AUTONOMOUS VEHICLES

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ABSTRACT: *Emerging immersive technologies comprising Virtual, Augmented and Mixed Reality (VAMR) and Electroencephalography (EEG) environments are creating a revolutionary and non-invasive Brain Robot cum Human-Computer interaction paradigms. The burgeoning rise of autonomy in the vehicles and expected introduction of self-driving vehicles will underpin the interesting use of such technologies creating a "brain to vehicle" connectivity, digitalization, efficiency, improved situational awareness, portable environment for riders and provision of safe testing grounds in real time conditions. Harnessing the collective prowess of these technologies will be at the forefront of predicting, developing and deployment of autonomous vehicles. Despite the increased industrial interest, there is very less attention being paid by the academia in the use of these immersive technologies in the testing, operation and users' perception of autonomous vehicles. This exploratory research study being part of a larger study is an attempt to venture into these emerging immersive technology applications and explore their recent role in a wider AEC industry setting with a special focus and linkages to driverless technology through optimally designed in-vehicle user's interfaces. Moreover, through an appropriate synthesis of recent and systematic literature review, an effort has been made to highlight the development of new brain-computer interaction paradigms that assist in the successful implementation of this technology and improving the users' trust, comfort, and safety.*

KEYWORDS: *Virtual, Augmented and Mixed Reality, Electroencephalography, Autonomous Vehicles, Human Computer Interaction.*

ABBREVIATIONS: *Brain Computer Interfaces (BCI), Virtual, Augmented and Mixed Reality (VAMR), Electroencephalography (EEG), Autonomous Vehicles (AV), Human Computer Interaction (HCI), Augmented Reality (AR), Virtual Reality (VR), Mixed Reality (MR), Head Up Displays (HUDs), Laser Ranger Finder (LRF), Global Position System (GPS), Information transfer rate (ITR), Building Information Modelling (BIM), Battlefield Augmented Reality System (BARS), Autonomous Intersection Management (AIM), Forward Collision Warning Alert System (FCW), Stop Distance Algorithm (SDA), Graphical User Interface (GUI), Human Machine Interface(HMI), Artificial Intelligence (AI), Machine Learning (ML)*

1. INTRODUCTION

Digitalization has a dynamic imprint on global markets paving the way towards human progress and ever-increasing appetite to control the surroundings. Rüßmann et al. (2015) identified that we are in the midst of the fourth wave of new digital industry technology referred as Industry 4.0 fueled by nine technological advances where cyber physical systems including sensors, IT systems, machines and work pieces are connected in a single enterprise with standard internet based protocols. The Augmented Reality (AR) and Autonomous Robots are among these nine pillars of this advancement and much to gain from each other. Increased focus on vehicle autonomy and advent of self-driving cars has led to explore another vista of research domain investigating the role of Human-Robot Interaction (Meschtscherjakov et al., 2018), use of immersive technologies, shared situational awareness, shared control and authority, virtual assistance and controlled transition procedures from the vehicle to the human driver and vice versa (Politis, Brewster & Pollick, 2015; Walch, Lange, Baumann & Weber, 2015). Nowadays, brain-computer interfaces detect neural activation patterns and control the devices by brain signals. Such BCIs comprise EEG headset in combination with vehicle dashboard systems and other optimally designed user interfaces can be employed to interact with vehicular systems in conjunction with VAMR platforms (Cernea, Olech, Ebert & Kerren, 2012). A systematic review of literature suggests that there is a research gap of how to make computers smart enough to assimilate non-verbal signals and natural gestures from humans in a real-time and communicate to autonomous vehicles using immersive technologies, mind controllers, sensors, wearables, photogrammetry, 3D scan capture, EEG, BCI, and HMI (Stergioulas, n.d.). Despite the increased industrial interest in these technologies, there is very less attention being paid by the academia in their use in the testing and operation of autonomous vehicles.

2. RESEARCH METHODOLOGY

This exploratory research is based on conceptual literature review of quality assured peer review publications and industry reports between years 2000 to 2018 from Web of Sciences database using key words “Immersive Technologies”, “Autonomous Vehicles Interfaces”, “Augmented Reality”, “Electroencephalography “Mixed Reality” and “Virtual Reality application in Architecture Engineering Construction”, and recent industry reports regarding use of VAMR and EEG applications in a wider AEC industry settings and then to identify and explore their emerging linkages with autonomous vehicles. This study is an early stage of a larger sequential research process to address holistically the impact of immersive, non-invasive and other emerging technologies in garnering the trust, comfort and safety of the users in driverless shuttles thorough optimally designed innovative interfaces. The aim at this stage is to explore these technologies and their emerging roles in the context of human computer cum brain robotic interaction paradigms to realize their futuristic role in driverless technology through appropriate and systematic literature review and longitudinal analysis. This research study will assist in achieving a reliable platform for further investigation.

3. SIGNIFICANCE OF AUTONOMOUS VEHICLES

The advent of AVs is expected to transform the future of the world in many ways (Geng et al., 2017). This disruptive yet beneficial technology will assist in shaping the future mobility, transport infrastructure, urban landscape, ensuring vehicle safety with less congestion, improved environmental outcomes, efficiency and productivity (Fagnant & Kockelman, 2015). AVs can help to reduce the human error contributing up to 90% of vehicles collision (Bonnefon, Shariff, & Rahwan, 2015; Gao, Hensley, & Zielke, 2014). AVs technology is one of “23 technologies providing new insights into the emergence of seamless intelligence” which was identified by nine IEEE Computer Society technical leaders (Alkhatib et al., 2015). Moreover, these can prove a test bed for various advanced technologies including AI, Computer Vision and Machine Learning (Katrakazas, Quddus, Chen & Deka, 2015) and this research study’s immersive and non-invasive technologies. The term ‘autonomous vehicle’ is used here to refer to a vehicle that has the capacity to sense its environment and navigate without human input (Gehrig and Stein, 1999). The design of AVs is comprised of three layers, i.e., a perception, planning and a trajectory control layer (Geng et al., 2017). AVs combine various sensors to perceive the surroundings, including radar, laser light, GPS, odometry and other in-vehicle systems and have great potential to improve the transportation safety, mobility, customers’ satisfaction while reducing the transportation costs, energy consumptions, and crime rates (Ross and Guhathakurta, 2017). In Construction Industry, autonomous vehicles, robots and self-driving construction equipment have their applications in mining, brick laying and glazing, concrete printing, digging and grading, efficient organization of job site, safety and productivity (Alderton, 2018; Bouge, 2018;Kirkpatrick, 2018).

4. IMMERSIVE AND NON-INVASIVE TECHNOLOGIES

Immersive technologies blur the boundary between the physical and the virtual, simulated, digital or cyber world thereby creating a sense of immersion for end users (Suh & Prophet, 2018). The use of immersive technologies including AR, VR and MR foster learning experiences, collaboration and increases creativity in various fields of education, marketing, entertainment and health care. These technologies allowing users to connect real and digital world for better decision making and efficient work procedures (Altinpulluk, 2017; Rüßmann et al., 2015) have been researched in both academic and the automotive industry alike. The proliferation of advanced computer technologies comprising AI and ML in conjunction with immersive technologies of VAMR and non- invasive EEG can prove to be vital in testing and operation of the autonomous vehicles. Nowadays, considerable and fruitful discussion into the use of VAMR and EEG technologies in driverless vehicles is taking place beside testing vehicles in controlled environments. The non-invasive use of EEG technology can significantly influence the decision-making module providing safe and reasonable abstract driving actions and collision avoidance strategies. These state-of-the-art technologies can provide a forward-looking capability to decision-making system of AVs, and their interface with VAMR can be used to predict future driving behaviors (Wei, 2016).

4.1 Mixed Reality (MR) Applications in Engineering and Construction.

Mixed Reality (MR) is one of the advanced computer technologies integrating physical and virtual spaces (Yoo & Bruns, 2006). Mixed Reality (MR) technologies are becoming increasingly relevant for human interaction in various fields of construction (Milgram & Kishino,1994; Riexinger, Kluth, Olbrich & Bauernhasl,2018) by connecting the on-site real work environment with digital information or virtual objects. MR instruments connect the virtual environment for self-inspection and self-instructions to check working processes and get interactive onsite guidance for preventing incorrect actions. Moreover, the thermal and acoustic evaluation of buildings and equipment can be enabled using MR through BIM based process simulation for self – instruction. Also onsite workers can visualize how to fix, install remove elements for refurbishment works. Lee, Soonhung and Jeongsam (2011) developed the idea of virtual factory layout planning system using mixed reality based digital manufacturing equipment integrating real images with virtual objects. Dunston (2008) described a vision for using MR systems in the AEC industry. This largely increases the efficiency for scheme explanation.

4.2 Virtual Reality, Augmented Reality and Mixed Reality (VAMR)

VR is a powerful method to immerse the end users into simulated situations and tasks where accurate control of the state is provided (Innocenti, 2017). VR has the potential to enhance the effectiveness and efficiency during the project lifecycle, from initial conceptual design through planning, preparation, and detailed design, to completion (Thabet, Shiratuddin, & Bowman, 2002). Shi, Du, Lavy, and Zhao (2016) indicated that VR enables real-time interactions of remote stakeholders in the same environment, with a shared immersive walkthrough experience, which can largely increase the design intent's understanding, improve the project's constructability, and minimize changes. VR can be applied to the majority of the economic sectors where 3D explanation or training is engaged, such as construction (Thabet et al., 2002), education (Sampaio et al., 2010), healthcare (Ford et al., 2018), etc. With the help of Building Information Modelling (BIM), the creation of a VR environment could be easier as the 3D model will be available as soon as the BIM-based design is completed. In the education sector, VR emerges as an effective tool for motivating students (Sampaio, Ferreira, Rosário, & Martins, 2010), thus making the learning process into an interactive game. It brings a change from passive learner attitudes into action. AR refers to the real-time perception of an environmental setting that has been enhanced by means of computer-generated virtual components (Raja and Calvo, 2017). It is a real time live view of the world environment whose elements are "augmented" by computer-generated visual information (Ruggiero, 2018). It has a specific place in the reality-virtuality spectrum as shown in Figure 1, in which AR position itself in the left hand side as main component of reality and computer generated visual information is a secondary component augmenting the reality.

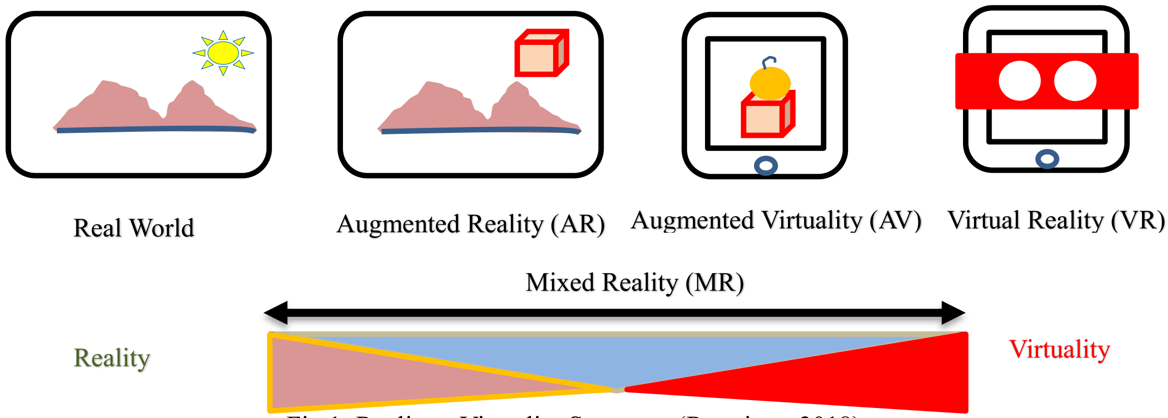

Fig 1: Reality – Virtuality Spectrum (Ruggiero, 2018)

AR can provide direct as well as indirect real-time view of the augmented environment. AR is referred as an integrated technique of image processing and display system of complex information which generates virtual objects over real objects to produce a mixed world (Jiao et al., 2013, Yang et al., 2013, Irizarry et al., 2013). According to Azuma et al. (2001), it could combine real and virtual objects in a real environment, run interactively in real time, and align with each other. Using the AR technique, integration between 2D and 3D can be achieved. With the 2D drawings, QR codes or even real-world views, virtual objects could be shown from 3D model using the mobile device. AR has been adopted in many fields of science and engineering. In game entertainment, Thomas et al. (2000) researched outdoor/indoor AR first-person application ARQuake, an extension of the desktop game Quake. In the military, Livingston et al. (2002) developed the Battlefield Augmented Reality System (BARS) for military operations. In medicine, Birkfellner et al. (2002) presented a simple design of the modified head-mounted display for AR visualization. In addition, AR is also considered as one of the advanced computer technologies which has potential to provide significant advantages through visualization to the AEC industry (Dunston, 2008). Kuo, Jeng, and Yang (2013) stated that AR has been gaining extensive applications in the construction field, such as real-time 3D display of on-site construction progress (Woodward et al., 2010), introduction of objects assembling procedures (Behzadan, Khoury, & Kamat, 2006), design and revitalization in existing built environments (Donath, Beetz, Grether, Petzold, & Seichter, 2001). Ruggiero et al. (2018) recently explored AR applications in building evacuations regarding training purposes, navigating and visualizing building evacuation simulations. Compared to AR, MR performs more interactivity. The end users can directly make interactive operations by using their body languages. MR mixes everything more seamlessly and offers a greater amount of user interaction. This is widely used in video games, and entertainment, but also present in education, healthcare, and engineering (Juraschek et al., 2018). For educational use, Ke et al. (2016) developed an MR platform for training teaching assistant in universities. Ford et al. (2018) utilize MR in burn care therapy as he found that merging in MR can reduce the pain for the patients.

4.3 Non-Invasive Electroencephalography (EEG)

A trend is emerging to use EEG in smart controls in buildings or transportation sector. Luo, Han & Duan (2015) explored EEG applications in smart home systems by designing a BCI control based on EEG for elderly and disabled people self-care. It included six functions of light on, light off, withdraw curtain, draw curtain and turn off and on the air conditioning system integrating android software. EEG is the measurement of brain electrical fields via electrodes (which act as small antennas) placed on the head (Cohen, 2017). EEG is widely used in neurophysiology research. It has proven effective in providing a more comprehensive understanding of the neural mechanisms underlying human cognition. Besides, EEG is an emerging biomarker of pathophysiology. Traditionally, the use of Graphical User Interface for smart control aims to enhance environmental accessibility yet it is challenging for many disabled users (Sirvent Blasco, Iáñez, Úbeda, & Azorín, 2012). Additionally, Conventional VR interfaces need more complex manipulation in Human-Computer Interaction (HCI) and physical features to assist disable people. EEG technology depends on a BCI, which processes the data received from an enhanced or wired brain and sends signals to external devices. Such a friendly interface eliminates the dependence on finger operations. Therefore, a sync of VAMR and EEG might prove to be a way forward, where a disabled person's mind can control the physical cum virtual world. It has other wide-ranging application in medical, education, self-regulations, production, marketing, security, gaming and entertainment (Abdulkader, Atia& Mostafa, 2015).

5. EXPLORING VAMR AND EEG LINKAGES WITH AUTONOMOUS VEHICLES

With regard to human-robot interaction, instance-based learning approach has been successfully employed in dynamic decision making and transfer of job knowledge from a human to a robot (Gonzalez, Lerch & Lebiere, 2003; Park, & Howard, 2015). AR can be a significant tool in enforcing conviction in autonomous driving by allowing the vehicle to perceive objects, generating a rationale for decisions and conveying its intent to the driver for manual intervention (Ng-Thow-Hing et al., 2013). It can also show a planned lane change to the driver to augment its situational awareness. Additionally, AR Head Up Displays are likely to be the future of car navigation and enhanced control mechanisms to improve traffic safety (Palladino, 2018) through 3D navigation overlay on road geometry and outside objects including pedestrians, bikers, and wheelchair users. Figure 2 below depicts how AR heads-up displays navigational images directly over what the driver observes from the windshield, thus reducing the mental energy of applying the information, avoiding distraction and reducing driver error.

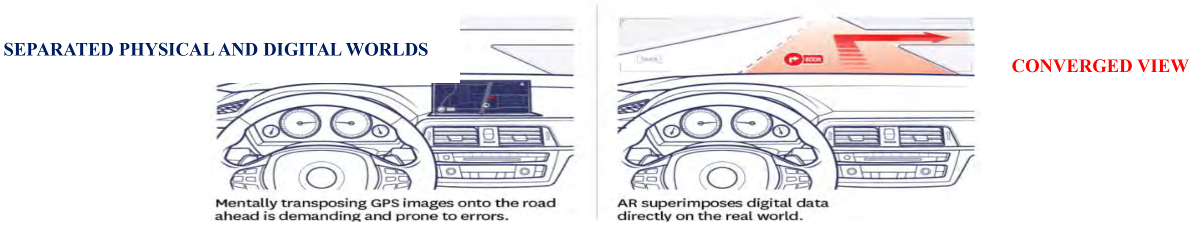

Fig 2: Augmented Reality in Autonomous Vehicles (Porter & Heppelmann, 2017)

VR windshields application will remove the requirements of road signs, traffic lights, road paintings and reconfigure multi-lane road based on demand. In the industry context for introducing innovative technologies, there is always a need to address cost reduction, speeding up of processes and quality improvement. AR fulfils all these requirements by reducing production times and costs, less training efforts and reduction of errors. This research identifies that AR and VR technology will assist in transition towards autonomous reality. AR world market could reach $90 billion by 2020 (Medal, 2018). AR promises enhanced navigation, safety, adaptive cruise control and lane keeping. An AR display system was developed in a vehicle to provide all the necessary information for the drivers during the travelling (Kim, 2015). Besides, MR was also applied to develop an immersive remote driving interface (Tarault, Bourdot, & Vézien, 2005). Ng-Thow-Hing et al. (2013) stated that AR has the potential benefits towards driver enhancement by “providing better situational awareness towards driving hazards” whereas AR can also enhance the communication between the driver and AVs. As mentioned before, VR can provide an immersive scene for the drivers in the call centers. First of all, the drivers can be immersed in a VR navigational environment. However, they might not be able to perceive the outside world. The VR system only keeps on receiving the end user’s position and orientation data through its embedded accelerometer. Upon this, AR adds another input from the camera, which is capable of recognizing the outside world. AR performs better in overlaying 3D navigation instructions onto road geometry. This is more convenient for the drivers who makes remote control for the autonomous vehicles. By using AR, global awareness and local guidance by conveying the right information at the right moment can be enhanced (Pokam et al., 2015). Besides, the safety of both autonomous driving and human driving can be facilitated. In a typical MR system, more interactivity can be accrued though interactive tools, including motion controllers, leap motion. The drivers are able to make a remote connection with the vehicles efficiently in a physical-virtual-mixed world and carry on the pre-defined tasks by using a steering wheel and pedal combo. MR is adopted for Autonomous Intersection Management. According to Quinlan et al. (2010), it is possible to make intersection control for autonomous vehicles much more efficient than the traditional control mechanisms such as traffic signals and stop signs. It is highly likely that AR integration with driverless technology will inculcate a level of trust among consumers from navigation to increased awareness and translating into acceptance of autonomous future (Medal et al., 2018).

Autonomous Vehicles technology is likely to change significantly in the backdrop of “brain to vehicle technology” utilising VAMR and EEG technologies, thus controlling the vehicles with human mind. In the application of EEG based BCI architecture to control robotic devices, a non-invasive Brain Robotic Interface technology is becoming popular to control robot systems through brain waves while considering the dynamics and kinematics of robots (Mao et al., 2017). The Dynamics explores the motion characters involving speed, acceleration, and stability thus, finding the time cost of each motion of robot, resultantly giving guidance for choosing the corresponding ITR. The Kinematics study involves path planning, path optimization and global path planning. Similarly, autonomous vehicle has a sophisticated control architecture comprising sensor fusion, path planning, motion control, GPS and different sensors such as sonars, cameras and bumpers. Modelling an autonomous vehicle architecture with appropriate mechanical kinematics and dynamics embedded with VAMR and EEG technology can greatly enhance its performance. It is to be noted that brain signals can only be used in supervising the process and giving guidance in case of emergency and rarely in path planning which is realised by camera and GPS. In an emergency, the brain signals can overrule the path planning instructions to the autonomous vehicle. Zhao, Zhang, & Cichocki (2009) used motor imagery to control EEG as well as a car in VR environment. Cernea et al. (2012) used a BCI to control an unmanned vehicle. In an another project developed by F U Berlin, Germany, an EEG headset in combination with LRF and GPS data is used to control the car (Waibel, 2011) Furthermore, in – vehicle secondary control tasks with BCI can be performed through EEG based portable headsets. Measuring the driver state during various stages of cognitive workload under influence of affective sensing (emotions) with facial analysis and EEG can assist to envisage the break reaction time of a driver which is a fundamental input in designing of collision warning systems for autonomous vehicles (Govindarajan, & Bajcsy, 2017). The underlying theory is that during time constrained and real time conditions, human mind shift from a heuristic approach to lessons learnt from past experiences. The time of alert is crucial to the driver’s recognition of Forward Collision Warning Alert System and same is applicable for autonomous vehicles under similar set of conditions. Therefore, VAMR and EEG technologies can be used for performance monitoring of autonomous vehicle and to improve upon vehicle reaction time to tune the distance of threshold used in Stop Distance Algorithm for collision warnings. Thus, an instance based learning approach can be used to mimic and model human behaviour. MR Prototyping can provide a safe testing ground for autonomous vehicles.

MR Lab at the University of Southern California has been successful in exploring human-machine teaming (USC, 2017). Most of the design algorithms in VAMR space used for human-drone pairing can be used for testing of autonomous vehicles where engineers can test, educate and carry out risk analysis in a virtual space besides allowing collaboration with other virtual systems since the virtual and physical space can be tied together in real time. This research study concentrated on the use of VR on autonomous vehicles. As a result, there are three points identified: 1) *Training*. With a pre-configured VR environment, both of the vehicle driver and the autonomous algorithms can be trained. When the automated vehicles conditionally reach its functional boundaries, the drivers are required to respond. However, such training largely depends on practice. Written knowledge can hardly get driving skills across to the learners and similarly, a real-world practice can hardly give all the circumstances to the learners. With this in mind, researchers attempted to simulate all the training scenarios in VR environment and emerge the learners within (Sportillo et al., 2018), thus it can efficiently establish environments that safely allow drivers to relearn their driving habits to towards a future operation of AVs. The research points out that AVs need to be capable of making informed, rational decisions on reacting the changing environments. With this in mind, the autonomous algorithms need to be trained on the input of video records from driving in real roads, with real driver behavior and real weather conditions. That is to say, the algorithms can also be trained in a VR environment, which provide a training environment close to reality. Such training system provide a scalable input for the autonomous algorithms; 2) *Testing*. Before real-world road testing, the prototype system can be tested in the VR environment. In a VR environment, dangerous scenarios can be simulated. This largely reduces the risks while avoids the impact from real-world weather condition. Likewise, the proposed system is potential to reduce the time consuming and costs for the testing processes; 3) *Interacting*. When the phase of autonomous driving begins, a driver-vehicle (or a human-machine) interface is needed. When the CAVs encounter with the edge cases, VR is a good tool for engaging the drivers with remote control. To make this work, a call center with a number of drivers will be established. These drivers keep on watching the whole vehicles' state. Once any vehicle is in trouble, the drivers can take control of it. In the call center, a VR environment is used for representing the scenes recorded in the cameras; and a steering wheel and pedal combo are deployed to allow the driver control the vehicle in trouble remotely. Once the vehicle back to normal, the autonomous driving system will resume control. Hence, VR tools are potential to reduce the training and testing cost and time consumption for the autonomous system development while promote the driver-vehicle interaction in the autonomous driving phase. In order to improve driver situational awareness and safety, innovative forms of visual displays based on computer vision such as lane departure and auto breaking combined with aural and haptic feedback can lead towards lesser accidents and fatalities. Additionally, VAMR applications could assist in responding to traditional phone calls thus significantly reducing the accident rates besides ending up as a "portable environment for passengers" in conjunction with AI. AI takes into account highly optimized computer vision algorithms, next-generation path planning, and traffic flow metering (Williams, 2018).

Car makers including Ford, Hyundai, BMI, Mercedes-Benz, and Audi have already started using AR in HUD systems, navigation, maintenance, and servicing, virtual test drive to purchase a vehicle (Jarvis, 2017), "Civil Maps" are crowdsourcing maps to let people into the brain of autonomous vehicles through visual representation of vehicle sensor date and Lincoln and Kia have tested their self-driving vehicles on 32 acres of simulated roads in the University of Michigan (Eisenberg, n.d.). Similarly, "WayRay" technology can convert car's windshield into a giant screen for movies, and "Navdy" equipped car connects the driver with the road. PSA Peugeot Citroen's is working towards built-in augmented reality in the cockpit where the driver can view data while looking at the road with a built-in transparent display projected on the windscreen (Eiges, 2017). Nissan Car manufacturers are ready to arrange a showcase in a driving simulator in 2018 (Alphr, 2018). The brainwave technology comprising EEG not only detects the level of comfort in the passenger and displays calming visuals using augmented reality to enhance the journey experience but also assists the vehicle to respond to dangerous situations much faster than humans. However, it would be interesting to note how these technologies unfold and interpret between instinctive reactions and sensible reasoning since human mind approach a problem in a more sensible way while giving a second thought. Chinese researchers have also developed a first mind-controlled car, where a driver can control the car's various movement wearing brain signal reading equipment comprising 16 sensors from the driver's brain (Crabbe & Wang, 2018). It was first conceived for the disabled people, and now this technology is being explored for driverless cars.

In this research, we propose to use AR tools for promoting the driver-vehicle interaction. Besides, Immersive technologies of V and MR can be used for performance analysis of autonomous vehicles including simulated testing and perfection, visual displays to improve situational awareness and as a portable environment for passengers. Head-mounted VR/AR in combination with EEG based neuro-monitoring and neuro-feedback is expected to unravel an innovative dimension of human interaction with virtual, digital and cyber world creating a way forward for driverless technology (Jung, Zao & Chang, 2016).

Conclusion

Use of immersive and non-invasive technologies including VAMR and EEG facilitates HCI paradigms in the context of autonomous vehicles and provide a right platform to realize the futuristic role of driverless technology in terms of its operation, testing, safety and users' acceptance. This research study finds out that users' level of comfort and trust, confidence in service, traffic safety, ease of use and in-vehicle security can be improved through innovative interfaces. In this research paper, the performance of EEG and VMR based systems have been explored to understand the impact of these immersive technologies to facilitate human computer cum brain robot interaction with autonomous vehicles. This study is a first step towards a larger study to deliberate upon formation of a framework for realizing trust dynamics in human-autonomous vehicles interaction through optimally deigned user interfaces thus essentially exploring how to humanize driverless technology for autonomous shuttles in a smart city context and to make it more attractive for prospective users relative to current means of transportation. The aim at this stage is to venture into the prospective applications of above mentioned technologies in driverless vehicles seeing their significance in wider AEC industry and find out their further merger in shape of suitably design user interfaces. Future merger of VAMR technologies with Neuroscience cum EEG functionality can unleash infinite possibilities of human machine interaction where vehicles functionalities and the automotive value chain will change significantly in the backdrop of mega-trends of autonomous driving, connectivity, digitalization and efficiency. However, this merger of VAMR and EEG interfaces once moved from controllers, swiping and voice activation to brain activity, it might invade personal space leading to tech-social, ethical and privacy challenges which also need to be revisited.

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