The Future of Brain-Computer Interaction

How Future Cars Will Interact With Their Passengers

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***Abstract*—Traditional automotive industry has reached advanced levels of car mechanics, performance, efficiency, and safety. A differentiating factor in future cars would be the embedded and interactive digital technology in the cockpit and under the hood, requiring high levels of interactivity with the occupants. While automotive industry has –in the last few years-rapidly, and successfully assimilated several decades of computing, Artificial Intelligence, and Human Computer Interaction (HCI) principles in autonomous and driver vehicles, they are still limited to traditional interaction paradigms like GUI, touch screens, and speech recognition. In this paper, we look ahead into emerging interaction paradigms, and assess their potential application in future cars. We summarize our findings of critical research regarding promising technologies, namely brain-computer interaction (BCI) as a viable alternative. A literature review was performed for the purposes of understanding the past and present of BCI. This information is used in formulating predictions regarding the nature of future interaction between human brains and the vehicles that transport them.**

Keywords—brains; computers; brain-computer interaction (BCI); Human-computer interaction (HCI), future cars; driverless cars.

I. Introduction

Brains and computers have been interacting since the invention of the computer. These two entities have accomplished a long list of momentus tasks together, including landing man on the moon and coming close to understanding how the physical universe operates on the most fundamental levels using quantum physics. As the years have gone on, the interaction between the two has increased in breadth and depth, and will continue to do so at an increasing rate in the years to follow.

One area in which brain-computer interaction (BCI) has noticably strong potential in the next years is in the context of individuals interacting with the digital infotainment systems that their personal vehicles are equipped with [1]. With the rapid adoption of advanced and sophisticated technology extensively used in modern cars, interaction and HCI has occupied the technology forefront for both driver cars and autonomous ones. "Driver cars" are currently passing through a bottle neck [2]. The rate of adding digital technologies surpassed our ability to provide the same level of advanced interaction without taking away from the driver attention [3]. The result was an exponential rate of death due to driver distraction. Besides traditional methods commonly used in computer domain research [4, 5, 6], design [7, 8], and dissemination [9], new methods are emerging to help understand the emerging problem. In the case of autonomous vehicles, new needs arise to look for highly intelligent interaction between all passengers and the car they are using. In the near future, the interior of an autonomous vehicle will provide "continuous access" to users' music, movies, preferences, contacts, business, social- and other cyber media. With the growing advances and richness of cockpit media, BCI could allow for a seemless transition between home, car, and office, as well as smoother personalized interaction with each passenger without the need to log on or select specific apps from their rich cyberspace. The purpose of this research project is to make predictions regarding how the interfaces between humans and their cars will continue to evolve over the coming years.

To accomplish this goal, first a brief history of BCI was developed to understand how brains and computers have come closer and closer together over the last half of a century. Next, an in-depth literature review was performed to understand the cutting-edge advancements that are being made every day in BCI applications. Finally, results were extrapolated into predictions regarding how BCI will continue to evolve in the context of personal transporation. To compliment these predictions, trends in the cost of computational power over time are briefly examined before a conclusion.

II. A Brief History of BCI

A. The 1960s

The 1960s was characterized by a large amount of university and government funded research in the domain of computation, leading to a foundation on which modern computers are based.

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In 1962, Doug Engelbert proposed and subsequently implemented a word processor with the capabilities that are now taken for granted on virtually all personal computers. While working at the Stanford Research Lab, he created a program that boasted several new functions: automatic word wrapping, search and replace, user-definable macros, commands to edit or delete characters or blocks of text, and more [10].

In 1963, several first-generation computer aided design (CAD) programs were designed and rolled out. A notable example is Timothy Johnson's MS thesis at MIT, which was funded by the Air Force. The main deliverable of this project was Sketchpad 3, which was an interactive three-dimensional design program. These systems came into industry at a remarkably fast rate, considering how incredibly useful they were in certain manufacturing atmospheres. The first CAD system in industry was most likely DAC-1, which was designed and implemented at General Motors in 1963, the very same ear in which CAD programs were first introduced by university research teams [10].

The modern computer mouse was developed at Stanford in 1965 as a less expensive and more reliable alternative to light pens. Doug Engelbert was a main contributor to this development, which was part of an NLS project. A large amount of the funding for this project came from NASA. The mouse was popularized as an extremely practical device with which to interact with computers in the 1970s by Xerox [10].

Doug Engelbert first demonstrated tiled windows in his 1968 NLS, which allowed users to navigate between multiple different programs while remaining attached to the same overall computer display. Alan Kay proposed overlapping windows in his 1969 PhD thesis, and later implemented them while working at Xerox. Eventually, the X Window System international standard was developed at MIT.

B. The 1970s

The 1970s were a time of making BCI more efficient and rewarding, building on the base discussed previously and branching out to many new applications for BCI.

Conway's Game of LIFE was impelemented on computers at MIT and Stanford in 1970. The first commercially popular video came was Pong, which was released in 1976 [10]. Since then, video gaming has become an incredibly large and complex industry.

A huge development for the internet and information systems in general was the invention and implementation of hypertext. The idea was first introduced by Vannevar Bush in 1945, however at the time his idea was ahead of the technology available. The same 1965 NLS project that produced the mouse (led by Doug Engelbert at Stanford) made heavy use of hyperlinking concepts. The NLS journal, which was one of the first fully online jourals in existence, included fully linking articles by 1970. The first hypertext system released to the user community was PROMIS, which was developed by the University of Vermont and released in 1976, being used for the purposes of medical information handling at the university's medical center. Eventually, in 1988, Apple's HyperCard helped to bring the concept of hypertext to a wider audience, and it was finally used in 1990 by Tim Berners-Lee in his invention of the World Wide Web [10].

The first spreadsheet program to be developed was VisiCalc, created by Franklin and Bricklin in 1977 while they were students at MIT and the Harvard Business School. The program was implemented with the Apple II computer upon its release. The solver capabilities in VisiCalc were based on algorithms that were developed by Sussman and Stallman at MIT. Since VisiCalc, Microsoft Excel has become the dominant spreadsheet program and is used on an incredibly wide scale in modern industry [10].

C. The 1990s and Beyond

By the time the 1990s came about, computers were becoming more affordable and more applicable to a wider range of activities. With the invention of the world wide web in 1990, the growth of computing power and the use of computing power took off at an explosive rate.

Although gesture recognition has been under development and use in industrial environments since the 1960s, it was not until 1992 when it became a more standardized and universal aspect of BCI with the release of the Apple Newton. The first trainable gesture recognizer was developed in 1964 by Tietelman, after which they were implemented into many commercial CAD systems throughout the 1970s. After popularization by the Apple Newton, gesture recognition has become a fundamental part of most personal computers used by individuals today [10].

Early theoretical work for virtual and augmented reality was completed by several important researchers including Ivan Sutherland, Tom Furness, Myron Kruegers, Fred Brooks, Henry Fuch, and others through the last 50 years. Much of this research was concerned with head-mounted displays and other ways in which a user could interact with a virtual or augmented feature of reality. NASA was a major contributor to funding in these research areas [10]. However, much of this work was hindered by the fact that technology had yet to catch up to the ideas. Since the early 2000's, however, virtual and augmented reality have become much more of a tangible technology. One shining example of this is Google Cardboard, which was introduced in 2014 and serves as an affordable way for individuals to interact with virtual reality applications.

Natural speech recognition is another example of a computational capability which has existed in theory for a long time, but not in practice for a long time due to technological catch-up. Most of the foundational research for natural speech recognition has been performed by leading research universities and industry leaders like CMU, MIT, IBM, and AT&T Bell Labs [10]. Apple's speech recognition software, Siri, was first released in 2010 and was a major catalyst in popularizing speech recognition software as a more fundamental part of using computers. Since Siri, there have been many other competing voice recognition software programs that attempt to integrate speech recognition into many of the tasks that can be accomplished on computers. Some dominant examples are Windows' Cortana, Amazon's Alexa, and Google's Google Home.

In 2017, scientists at BrainGate published findings on a research project they had been conducting over the course of more than two years regarding advanced BCI. Although the project took place in a medical context, the findings are extremely relevant to BCI in general because they show so much about how the brain functions and how electrical stimulation can be used to take advantage of the brain's natural and preexisting hierarchical analytical structures. These scientists were able to restore reaching and grasping motions in a patient who suffered from paralysis due to a spinal cord injury. The patient was able to "[perform] self-paced reaches to drink a mug of coffee… and feed himself" [11]. This was accomplished using two implanted systems: a functional electrical stimulation (FES) system and an intracortical brain-computer interface (iBCI) system. Using the iBCI system, which consisted of microelectrode arrays implanted directly into the motor cortex, scientists were able to monitor and decode the patient's neural activity for the purposes of inferring his movement intentions. Next, the intentions were fed to the FES system, which was implanted throughout the right arm of the patient and directly electrically stimulated the muscles to carry out the intentions received from the iBCI.

All of these feats of BCI were and are historic developments for the field. The groundwork for the future of interaction between brains and computers is continuing to be laid, the best example discussed here being the advances made in 2017 at BrainGate. After developing and reviewing this history of BCI, it is clear to see that the two entities are coming closer and closer to seamless interaction, and at a faster and faster rate. This seamless interaction will bleed into every facet of human life, which obviously includes the facet of personal transporation using cars. To get a better idea about how brains will interact with car computers specifically, an in depth literature review of how modern BCI works was performed.

III. TODAY'S ADVANCED BCI TECHNOLOGY

After developing a timeline regarding BCI over the last 50 years, the next task was to conduct an in-depth literature review regarding today's most cutting-edge BCI technology. This was to allow for a clearer vision of the direction that BCI is heading for the purposes of making predictions regarding how BCI in cars will contnue to evolve.

There were three major areas that research was conducted in: 1) neural signal mapping, decoding, and decoder recalibration, 2) audial prosthesis, and 3) visual prosthesis.

A. Neural Mapping, Decoding and Recalibration

Neural mapping is the process of monitoring electrical brain signals that are given off by the brain's tissue. Neural mapping has progressed significantly in the last century, first being accomplished using electroencephalography (EEG) on human beings in 1924 by Hans Berger [12]. Neural mapping using EEG is usually accomplished by employing a net-like set of scalp electrodes resting on the head, which serve the purpose of monitoring for electrical signals given off by the brain, which are detectable through the scalp.

There are, however, significant limitations that come along with using the traditional set of scalp electrodes. The distance that exists between the actual source of electrical signals and the electrode which receives them limits the accuracy of the EEG readings. Additionally, more secluded areas that lie deeper within the overall structure of the brain's tissue are hard to get any readings from at all. For these reasons, scientsts have turned to a more advanced, granted more invasive, solution for monitoring brain activity: microelectrode arrays. A microelectrode array is a set of many small, metal electrodes which are designed to penetrate the peripheral tissue of the brain, allowing for longer term and more reliable measurements of electric signals given off. Additionally, these devices allow for installation in harder-to-reach areas of the brain. Not only do microelectrode arrays have the ability to monitor electric signals, but they can also stimulate the brain tissue with electric signals of their own. This opens an entire new door of applications, which will be discussed in more detail later. An example of an industry leading microeletrode array is BlackRock Microsystems' Utah Array [13]. This microelectrode array contains up to 128 microelectrodes that allow for immediate high quality neural recordings immediately after installation. It was this microelectrode array that researchers at BrainGate used when they made an incredible stride in neural decoding and recalibration.

Neural decoding is simpler than it might sound: all it takes is recording the output of the brain in certain predetermined areas while asking the subject or patient to think about executing a certain action. Then, the neural recording data can be mapped to the intention that the subject was asked to think about carrying out. The scientists at BrainGate used exactly this method when initially calibrating their neural decoding algorithms for a virtual typing application for paralyzed medical patients: "ask[ing] the user to imagine that she or he is controlling the movement of an effector (for instance a computer cursor or a robotic arm) that is moved automatically to a series of presented visual targets" [14] allowed the initial calibrations of their intent-decoding algorithms to be established.

The more challenging aspect of the scientists' work at BrainGate was keeping their decoder calibrated throughout sessions of use. Neural patterns in the human brain are dynamic, meaning that a pattern that maps to a certain intention can change over time, making an initial calibration reading less and less accurate as use goes on. To tackle this issue, they came up with a retrospetive target inference (RTI) algorithm: "To calibrate the RTI decoder, the person's intended movement direction was retrospecitvely assumed to have been directly toward his or her next selected target; then, similar to standard closed-loop calibration with presented targets [as used for initial calibration], these retrospecitvely inferred intended directions were mapped to the corresponding neural data" [14]. This RTI calibration method, combined with adaptive feature mean tracking and velocity bias correction to account for changing baseline channel rates, allowed for users to virtually type using their minds for long periods of time without degradation in the system's ability to accurately interpret the user's intentions, and also without obtrusive re-calibration tasks. This represents a major breakthrough for neural mapping and decoding, as these methods "can be extended to a variety of neurally controlled applications" [14] for the purposes of maintaining long-term performance without recalibration tasks.

B. Audial Prosthesis

Cochlear implants, which allow hard-of-hearing or deaf patients to increase ability to hear sounds in their environment, have been under development since the 1970s. A basic cochlear implants consist of a microphone, a speech processor, a transmitter, and a receiver. The microphone collects sound waves from the environment, which are then translated into electrical impulses by the speech processor. Next, the electric impulses are transmitted to the receiver, which directly electrically stimulates auditory nerve fibers in the cochlea. Then, the electric signals are sent through the brain's natural hierarchical structures for interpretation by the user. These devices have helped thousands and thousands of patients around the world with results "nothing short of miraculous" [15].

Auditory brainstem implants (ABIs) expand upon the concept of cochlear implants, going past the cochlea and interacting directly with the auditory brainstem, also known as the cochlear nucleus. In 2008, Steven Otto and his team published their findings regarding the use of penetrating ABIs (PABIs). While conventional ABI systems use surface electrodes that simply rest on the brain tissue, a PABI uses both penetrating and surface electrodes in an attempt to "use microstimulation to reduce threshold current levels, increase the range of pitch percepts, and improve electrode sensitivity and speech recognition" [16]. Although the team was able to meet these goals successfully relative to non-penetrating ABI results, there were still some challenges. Choosing which patients will be the best candidates for the best results remains an issue, as there was a significant amount of variability in results. Additionally, there is still some confusion about which type of electrodes should be used (penetrating or surface), and in which relative combinations. Overall, however, ABI research is expanding upon already established research regarding the cochlea, and might one day make audial prosthesis even more directly possible.

C. Visual Prosthesis

Visual prosthesis is another field that is already established nicely and moving forward at a quick rate. Two promising methods are retinal stimulation and stimulation of the visual cortex. A retinal stimluation system for visual prosthesis consists of three main componenets. First, there is a camera, which collects visual information from the environment and translates it into an electrical signal output. Next, there is a transmitter, which wirelessly feeds the electrical signal from the camera to the third component, which is retinal stimulation circuitry. The retinal stimulation cirtuitry then feeds the electrical signal directly to the retina, where the brain's natural analytical structures take over [17].

Another promising method for visual prosthesis is the use of direct electrical stimulation within the visual cortex. This is where microelectrode arrays come back into play. Researchers at Monash University have made remarkable progress as of late with their Gennaris project. Gennaris is what one might call a bionic eye, allowing for direct electrical stimulation of the visual cortex using microelectrode arrays for the purposes of restoring some sense of sight in blind individuals [18]. Using coordinated series' of electrical stimulations, scientists are able to evoke brief flashes of light in the user's field of vision, which can be used almost as pixels to build a picture for the user to see. Although at this point the technology is still somewhat young and has some hurdles to get past (such as finding the best electrode installation methods), it is a promising path that shows 3 main advantages when compared to retinal stimulation: 1) the visual cortex boasts a large surface area in which to install electrodes, 2) electrodes are easier to plant in peripheral brain tissue than the retinal tissue, and 3) the utility of cortical stimulation is applicable to virtually all causes of visual impairment [19]. For these reasons, it seems likely that direct cortical stimulation will take the lead in the field of visual prosthesis over the coming years as scientists perfect installation and stimulation methods.

IV. Predictions Regarding Future Cars

Now that we have developed a timeline of BCI and gained a solid understanding of the cutting-edge aspects of BCI, we are now able to make interesting estimiations regarding how the standardization of advanced BCI will bleed out into everyday aspects of life, namely human interaction with their cars. We will be making predictions in two main areas: future design of cars and future interfaces that people will use to interact with their cars.

A. Future Design of Cars

If BCI continues to advance in the direction and at the rate that it is currently advancing, it is not hard to imagine cars that have no physical interface system built into the design. If all the information that cars currently convey to people (like geographical information, music, hardware information, etc.) could be fed directly and wirelessly into a person's visual or auditory conciousness, there would be no need for screens or heads up displays. Similarly, intention translation based on neural activity would eliminate the need for physical input devices that humans currently use to instruct the computers aboard their cars. The main components of car design would focus less on interfacial functionality and more on comfort and safety. As driverless cars become more and more of reality on a daily basis, elimination of a driver's seat is creeping closer. Without the need for interfaces other than those made possible by invasive BCI, the entire space of a car will be free for whatever design an individual feels is necessary. Family cars will have large lounge areas where families will relax and enjoy their ride, maybe even enjoying their own individual entertainment in the form of music or video through their BCI interfaces. Business vehicles will have more space for storage and general functionality. When you really stop and think what would be possible in an average sized car without a steering wheel, heads up display, dashboard, driver's seat, and any physical screens, the possibilities are staggering.

B. Future Human-Car Interfaces

After conducting our literature review regarding the most cutting-edge technology in the field of BCI, it is safe to say that human-car interfaces will take place mostly in the mind of the user. Using neural decoding and recalibration techniques like those developed at BrainGate, cars will be able to wirelessly monitor neural patterns and map intentions to neural data. This will allow users to instruct their cars to take them to certain places, to go certain speeds, or to play certain music on the speakers (if there are any, considering you would also be able to play music in your head through network enabled audial prosthesis), all from their minds. Additionally, users will be able to mentally access any of the information traditionally available on a heads-up-display such as current speed, engine heat levels, rotations per minute of the wheels, any outstanding mechanical issues, etc.. All of this information will be fed to the user through visual and auditory augmentation devices that will undoubtedly follow today's medical prosthesis devices. Our personal prediction is that cochlear implants will be the main technology used for audial augmentation, while direct visual cortical stimulation will be the method used for visual augmentation. Overall, interfacing with cars will become much more seamless, natural, and individualized, while also allowing a more productive use of the space inside of the cars themselves.

V. Conclusion

The first task this project accomplished was to build an understanding of the history of BCI. This was accomplished by looking at major breakthroughs in computational technology that increased the ability of humans to interact with computers, such as the invention of the mouse and the World Wide Web. Next, we conducted an in-depth literature review to gain fundamental understanding of how the most modern BCI technologies work including 1) neural mapping, decoding, and calibration, 2) audial prosthesis, and 3) visual prosthesis. This in-depth understanding of these technologies and their paths forward allowed us to make educated guesses regarding the future design and interfaces of cars. Highlights of these predictions were that 1) car design will shift focus away from interfacial functionality and more towards individualized comfort and safety and that 2) interfacing between cars and humans will take place virtually entirely within the mind of the user and the computer of the car, with no bulky interface systems in between.

After completing this project, one becomes excited about the future of personal transporation. It will be so very interesting to watch as cars evolve with technology. The BCI technology discussed in this report will change all aspects of human life and communication, and personal transporation is just one of the incredibly interesting areas that will be fundamentally changed forever.

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