Realities of Brain-Computer Interfaces for the Automotive Industry: Pitfalls and Opportunities

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June 25, 2018

Summary

Brain-Computer Interfaces, especially those based on EEG as the primary sensing modality, has the potential to be a useful tool in the design and testing of next-generation human-machine interfaces as well as some other aspects of (semi) autonomous vehicles. However, due to several limitations posed by the very nature of the sensing modality, in particular, the hardware involved, we believe that the large-scale consumer adoption and usage of EEG based technology solutions remain highly unlikely if not impossible, at least in the next 5-10 years. We recommend considering a long-term research and development endeavor focused on niche EEG use-cases that don't require consumer participation.

Report

Brain-computer interfaces (BCI), specifically those using electroencephalography (EEG) as their primary signal, have been under study by automobile manufacturers for over two decades. They have been investigated within the context of direct control, as well as an opportunistic assessment of driver/passenger cognitive and emotional state. Most recently, at Consumer Electronics Show (CES) 2018, Nissan demonstrated their *Brain-to-vehicle* Technology[1] that uses EEG signals derived from their custom headset to aid and personalize semi-autonomous and fully autonomous systems in their vehicles. Below, we briefly review efforts to use BCI in automobiles, discuss technical challenges, and provide what we believe are realistic expectations and opportunities. In all cases when we use the term BCI, we assume non-invasive systems, which do not require an implant in the brain or any form of neurosurgery. We note that efforts are not taking place only at academic institutions but also are actively pursued by automakers (e.g., Daimler AG has been actively involved in research efforts in this area since the early 1990s). However, some of these industry efforts are more secretive and have not been published, and therefore are difficult to assess regarding the approach and the likelihood of their commercial success.

Challenges: There are some significant technical challenges for using a BCI system in an automobile environment. The main ones include;

1. <u>Limitations of an obtrusive headset</u>: Most EEG sensing headsets currently used in research are bulky and require the use of ionic gel ("wet" sensors) to obtain a good signal. These headsets are also uncomfortable to wear for prolonged periods of time (> 1-2 hours). Although less obtrusive hardware exists (using a lower number of "dry" sensors), it invariably produces a poor signal-to-noise ratio of the recorded data that limits the efficacy of any technology that uses that data. Furthermore, the use of metallic sensors in most commonly used headsets, wet or dry, poses a significant safety challenge as those sensors can lead to head injury during a major crash. Therefore, we believe the EEG hardware itself represents the most significant obstacle to the commercial applicability of EEG.

2. <u>Environmental noise and movement artifacts</u>: Electromagnetic (EM) waves in the environment around an EEG headset– such as the 60 Hz A/C encountered near American power lines - can introduce noise in the EEG signal. Given that a car has electrical wires and devices embedded throughout the cabin, we anticipate significant EM corruption of any EEG recordings. Physical movement of the electrodes and the connecting wires due to physical actions of the person wearing the EEG headset can also introduce artifacts in the recorded data. Therefore, use-cases that depend on high signal quality would be unsuitable for EEG as a measurement modality.

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[1] https://www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/b2v.html

This limitation precludes any real-time inference and accompanying action by AI, as a high rate of false positives would provide a poor user experience.

3. Limited information transmission rate: Even if reasonably high-quality EEG can be collected, the ability to decode meaningful information from the raw data in real-time is relatively limited. For example, the information transmission rate for BCI is between one and two orders of magnitude lower than that for human speech (roughly 1 bit per second for EEG BCI versus 60 bits per second for speech). The realization of such limitations has dampened the enthusiasm for Facebook's much-vaunted effort to bypass mouse and keyboard and use a BCI as a computer interface.[2] Therefore, the specific information obtained from a BCI system, for it to have practical value, should be hard or impossible to gain otherwise.

Safety-related applications: There has been some previous EEG-based BCI research on developing new interfaces for improving driver safety. Some of this work has focused on the mental and physiological state of the driver using simulations and road tests[1]. For example, EEG measures of alpha power (power in the 8-12 Hz frequency band of the EEG) have been used to detect drowsiness during driving [2]. Neural markers of mind wandering [3] and attentional state [4] have also been tracked in driving simulations, with such markers being used to alert the driver and re-engage them during substantial lapses of attention. These approaches look to re-orient the attention and/or increase the arousal of the driver to improve safety and reduce accidents. Another avenue of R&D for BCI in automotive safety is to improve the timing of emergency braking by measuring "intent to brake." For example, EEG and electromyography (EMG, a measure of the electrical activity in muscles) has been fused to enable "braking assistance systems" that provide 100-200 ms reaction time advantage over overt action by the driver, which in theory could reduce accidents [5].

Opportunities: Though there are significant challenges that temper the potential for mass adoption of EEG-BCIs in automobiles in the foreseeable future, we do see some niche applications of EEG-BCI systems, and real-time neuro-assessment in general, as potential tools for the automotive industry. Below we describe two possible near-term opportunities.

1. Assessing human-machine interaction and non-verbal communication in autonomous vehicles. Efficient human-machine interaction is critical to the success of autonomous vehicles. Although current EEG systems are unlikely to be adopted by consumers, human factors and UX engineers at automotive companies could more effectively use EEG during the design process, where environmental conditions can be controlled. For example, facial expression, electrodermal activity (EDA), and other non-neural measures could be augmented with EEG in ways that provide better models of the human-machine interaction and the state of the human during different driving

[2] https://www.wired.com/2017/04/facebooks-race-link-brain-computer-might-unwinnable/

scenarios. The “error potential” EEG signal (ErrP) could be particularly useful in identifying moments when the AI's behavior did not match the user's expectations [6, 7]. This data could inform design choices made by engineers and AI/robotics system designers on how to best modulate human-machine interactions. Nissan's CES 2018 *Brain-to-vehicle* demonstration involved using ErrP signal [7] as well as "movement-related cortical potential" (MRCP) to induce changes in the control system so as to aid steering effort; while the science behind the technology is clear and defensible, we have doubts about the practicality of a real-time on-road system because of the challenges described above. However, Nissan could leverage this technology to study and fine-tune their onboard AD/ADAS system during design phase to possible offer better user experience[3].

2. <u>Assessing interior design choices using neural correlates of emotion and engagement.</u> The world of marketing and advertising has used EEG and other neural and physiological signals to augment subjective reporting by market focus groups for a decade [8]. These brain-based methods for assessment are often more objective and can yield continuous, time-resolved correlates of emotional state and preference, with small population responses used to infer large population preferences. One explanation for the improved predictability for large population preferences is that the neural correlates can be measured without the need for the subjects to overtly respond or even “think about” responding, this being less distracting compared to surveys or overt rating systems. The approach is also less susceptible to reporting bias, which can skew results for small groups, making results less relatable to large populations. Architects have also used these BCI methods to assess design preferences in real and virtual spaces[4]. The detected neural correlates of preference, engagement, and emotional valence in an environment can be used to label parts of the environment as positive or negative influences, or even to dynamically update the environment to improve the user’s state of mind. The same technology could be leveraged to optimize design choices in automotive interiors, consoles, and other aspects

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[3] The Nissan-funded paper by Zhang et al. [7] employs a paradigm that evokes error related potential (ErrP) activity in the EEG when a driver appraises the suggestions made by an automatic driver assistance system. Specifically, experiments were conducted in both a simulated vehicle and in a real vehicle where a driver assist system’s recommendation for an upcoming turn was shown to the driver on a heads-up display. Driver’s EEG signal was decoded to see if the ADAS recommendation would evoke an ErrP when the turn direction was not congruent with the direction the driver expected, given the pre-planned route they were required to take. The researchers found that they could accurately decode the ErrP 68% of the time, which was significantly better than chance. Though this ‘proof of principle' study showed that ErrPs could be detected in a moving vehicle, it did not present a compelling use-case since the accuracy was far below what would be needed to use this information to guide or change the driver assist recommendation on the fly. However, it may be possible is to use these brain signals to reinforce certain behaviors of the car that the driver agrees with.

[4] http://www.thecloudlab.org/dumbo_neural_cartography.html

of function and aesthetics of the vehicle. We believe that BCI based solutions may prove a more accurate and efficient way to assess users' design preferences than behavioral surveys alone. The resulting cost savings and the increase in speed of concept iteration by automotive design engineers could be significant.

Patient optimism is necessary to pursue B2V technologies. While we remain cautious about the applicability of EEG-BCIs for consumer-facing applications within the automotive environment, we remain hopeful that scientific breakthroughs will eventually overcome the current challenges in their use. It may take a considerable amount of time, and the resulting technology might barely resemble anything our imaginations can conjure up today, however, the idea of controlling a vehicle by mere thought is fantastic enough to compel a minority of 'dreamers' to keep pushing the boundaries of BCIs. Automakers willing to support such efforts through internal and external investment should be applauded, but also need to be cognizant of the patience required of them before they can see a significant ROI. Unwarranted hype or expectations around the capabilities and possible timelines for such technologies would be counterproductive.

Reference for BCI papers cited in this report:

1 Lin, C.-T., Chung, I.-F., Ko, L.-W., Chen, Y.-C., Liang, S.-F., and Duann, J.-R.: 'EEG-based assessment of driver cognitive responses in a dynamic virtual-reality driving environment', IEEE Transactions on Biomedical Engineering, 2007, 54, (7), pp. 1349-1352

2 Wei, C.-S., Wang, Y.-T., Lin, C.-T., and Jung, T.-P.: 'Toward Drowsiness Detection Using Non-Hair-Bearing EEG-Based Brain-Computer Interfaces', IEEE Transactions on Neural Systems and Rehabilitation Engineering, 2018

3 Lin, C.-T., Chuang, C.-H., Kerick, S., Mullen, T., Jung, T.-P., Ko, L.-W., Chen, S.-A., King, J.-T., and McDowell, K.: 'Mind-wandering tends to occur under low perceptual demands during driving', Scientific reports, 2016, 6, pp. 21353

4 Wang, Y.-K., Jung, T.-P., and Lin, C.-T.: 'EEG-based attention tracking during distracted driving', IEEE transactions on neural systems and rehabilitation engineering, 2015, 23, (6), pp. 1085-1094

5 Haufe, S., Kim, J.-W., Kim, I.-H., Sonnleitner, A., Schrauf, M., Curio, G., and Blankertz, B.: 'Electrophysiology-based detection of emergency braking

intention in real-world driving', Journal of neural engineering, 2014, 11, (5), pp. 056011

6 Escalante J, Butcher S, Costa MR, Hirshfield LM. 'Using the EEG Error Potential to Identify Interface Design Flaws.' International Conference on Augmented Cognition, 2013 Jul 21 (pp. 289-298). Springer, Berlin, Heidelberg.

7 Zhang, H., Chavarriaga, R., Khaliliardali, Z., Gheorghe, L., Iturrate, I., and Millán, J.-d.-R., Journal of Neural Engineering, 2015, 11, (6), pp. 066028

8 Lee, N., Brandes, L., Chamberlain, L., & Senior, C.: 'This is your brain on neuromarketing: reflections on a decade of research.' Journal of Marketing Management, 2017, 33(11-12), 878-892.