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Ultra low-cost 3D gaze estimation: an intuitive high information throughput complement to direct Brain-Machine-Interfaces

William Welby Abbott and Aldo Ahmed Faisal

The advancement of Brain Machine Interface (BMI) technology for controlling neuromotor prosthetic devices holds the hope to restore vital degrees of independence to patients with motor disorders, improving quality of life. Unfortunately, emerging rehabilitative methods come at considerable clinical and post-clinical operational cost, beyond the means of the majority of patients (Shih et al. 2012). We present an ultra-low cost alternative: using eye-tracking. Monitoring eye movement provides a feasible alternative to traditional BMIs because the ability to control eye-movements can be retained in cases of severe traumas or pathologies in which all other motor functions are lost (Kaminski et al. 2002; Kaminski et al. 1992). Based on disease statistics, we find that within the EU alone, there were over 16 million people in 2005 (3.2% of the population) with disabilities that would benefit from such gaze based communication and control systems (Jordansen et al. 2005). Despite this, eye tracking is not widely used as control interface for movement impaired patients due to high cost, poor signal interpretation and lack of control flexibility.

We propose that tracking the gaze position in 3D rather than 2D (as is used in most gaze interaction methods (Majaranta et al., 2011)) provides a considerably richer signal for neuroprosthetic control by allowing direct interaction with the environment rather than via computer displays. We demonstrate that by using mass-produced video-game hardware that an ultra-low cost binocular eye-tracker with comparable performance to commercial systems more than 800 times as expensive is possible (Abbott & Faisal 2012). Our head-mounted system has 30 USD material costs and operates at over 120 Hz sampling rate with a 0.5-1 degree of visual angle resolution. We perform 2D and 3D gaze estimation, controlling a real-time volumetric cursor, essential for driving complex user interfaces. Our approach yields an information throughput of 43 bits/s, more than ten times that of invasive and semi-invasive BMIs that are vastly more expensive.

William Welby Abbott
Imperial College London, Dept. Bioengineering, UK
Aldo Ahmed Faisal
Imperial College London, Dept. of Computing and Dept. Bioengineering, UK

In contrast, BMI information rates from direct recording of neuronal activity are ultimately constrained by noise in the recording systems and the nervous system itself (Faisal et al. 2008). In particular physical noise sources inside central neurons (Faisal et al. 2002; Faisal 2009) and peripheral axons (Faisal et al. 2005) will limit decoding performance from limited numbers of independent neuronal sources. Thus, to compensate for noise, BMI signal decoders have to observe signals for longer periods of time, thereby increasing response latencies for direct BMIs. While these issues will be ameliorated by the steady progress of sensor quality and density, eye movements already offer a highly accurate, low-latency (and low cost) read out. This is because the brain has already evolved to minimise the role of noise and delays in eye movements, which form an aggregated output of the nervous system. The leap in readout performance (in terms of readout performance and latency) enables closed-loop real-time control of rehabilitative and domotic devices beyond what is achievable by current BMIs: e.g. it was estimated that powered wheelchair control requires, on average, 15.3 bits/second and full-finger hand prosthetics require 54.2 bits/second (Tonet et al. 2008). We have demonstrated how an ultra-low cost, non-invasive eye-tracking approach can form the basis of a real-time control interface for rehabilitative devices – making it a low-cost complement or alternative to existing BMI technologies.

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