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Multimodal detection of head-movement artefacts in EEG

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HIGHLIGHTS

- EEG artefacts are detected with SVM classifiers trained on EEG and gyroscope data.
- Combining EEG and gyroscope classifiers can improve artefact detection accuracy.
- An analysis of data fusion methods at feature and classifier levels is carried out.
- Feature and score level (sum rule) fusion are the best performing fusion methods.

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ABSTRACT

Artefacts arising from head movements have been a considerable obstacle in the deployment of automatic event detection systems in ambulatory EEG. Recently, gyroscopes have been identified as a useful modality for providing complementary information to the head movement artefact detection task. In this work, a comprehensive data fusion analysis is conducted to investigate how EEG and gyroscope signals can be most effectively combined to provide a more accurate detection of head-movement artefacts in the EEG. To this end, several methods of combining these physiological and physical signals at the feature, decision and score fusion levels are examined. Results show that combination at the feature, score and decision levels is successful in improving classifier performance when compared to individual EEG or gyroscope classifiers, thus confirming that EEG and gyroscope signals carry complementary information regarding the detection of head-movement artefacts in the EEG. Feature fusion and the score fusion using the sum-rule provided the greatest improvement in artefact detection. By extending multimodal head-movement artefact detection to the score and decision fusion domains, it is possible to implement multimodal artefact detection in environments where gyroscope signals are intermittently available.

1. Introduction

Ambulatory electroencelephalography (AEEG) is a valuable tool in a number of emerging medical applications. Automated seizure detection, widely accepted as useful in aiding a clinician in diagnosing patients with suspected epilepsy, can be extended to the domestic environment with the use of AEEG (Waterhouse, 2003; Casson and Rodriguez-Villegas, 2011). In brain–computer interface (BCI) applications such as cognitive state estimation, AEEG holds the potential to monitor tiredness levels in vehicle drivers and robotic surgery operators (Lan et al., 2007; Müller et al., 2008). Similarly, BCI-controlled text editors for disabled persons (Allison et al., 2007) can be extended to the mobile domain using AEEG (Lotte et al., 2009). However, contamination of the EEG signal by electrical artefacts arising from head-movements has been widely acknowledged as being problematic in ambulatory EEG (Waterhouse, 2003; O'Regan et al., 2012; Winkler et al., 2011; Gwin et al., 2010). By corrupting the EEG, head-movement artefacts can obscure the signal and interfere with its interpretation by a clinician/researcher. In automated neurological event detection systems, such as automated epileptic seizure detection or automated Alzheimer's disease recognition, head-movement artefacts may cause the classifier to falsely misinterpret a section of artefactual EEG as a neurological event (Kelleher et al., 2010; Lehmann et al., 2007).

Head movements can introduce a wide range of non-cerebral electrical activity into the EEG, typically taking the form of some combination of electrode pop, muscle (EMG), electrode movement and ocular artefacts. These component artefact signals display a wide range of characteristics. Electrode pop, which occurs when an electrode temporarily breaks contact with the surface of the scalp, is usually accompanied by fast, high amplitude spikes (Barlow, 1986). Muscle artefacts are predominantly high frequency signals, and can range from low to high amplitude (Willis et al., 1993; Brunner et al.,

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1996; Goncharova et al., 2003). Electrode movement traditionally results in slow-wave baseline drifts, but can sometimes manifest as apparent oscillation in the EEG. Ocular artefacts, introduced due to relative movement between the eye and the electrode, typically cause high amplitude deflections in the EEG (Lins et al., 1993; Berg and Scherg, 1991; Croft and Barry, 2000; Gasser et al., 1992; Picton et al., 2000). While these component artefact signals exhibit diverse temporal, frequency and structural characteristics, they are significantly different from those of background EEG. In previous work, it was shown that these component artefact signals (EMG, electrode pop, movement and ocular artefacts) could be grouped together in distinguishing them from normal EEG activity (O'Regan et al., 2010a,b, 2012).

Recent advances in the miniaturisation of gyroscopes have resulted in their inclusion in a number of commercially available EEG headsets (Emotiv EPOC, 2012). By measuring angular rotation of the headset, these gyroscopes represent a promising method of accurately detecting the occurrence of head-movements. As head movements often result in EEG artefacts (and certain head-movements may be more likely than others to introduce artefacts to the EEG), in previous work, the use of gyroscopes for artefact detection was introduced illustrating that features extracted from gyroscope signals are useful in determining if head-movement artefacts have contaminated the EEG (O'Regan et al., 2010b, 2012). The question then arose as to whether gyroscope features provide complementary information to features extracted from the EEG. By combining features extracted from the EEG and the gyroscope signals in a single classifier (feature fusion), it was found that artefact classification performance improved, suggesting that the gyroscope features contain information regarding the production of artefacts that is not provided by the EEG features alone.

Fusion at the feature level (sometimes referred to as early integration) is only one method of combining information from multiple signals for use in making a classification decision. Fusion at the classifier level (sometimes referred to as late integration) is a well-researched method of combining information from different modalities, with a range of options available to combine a set of classifiers into a final decision rule. Classifier output scores (score fusion) or binary output decisions (decision fusion) are two such classes of classifier fusion that allow individual classifiers to be combined to produce an overall classifier output. Classifier fusion offers a number of implementation advantages over feature fusion, such as more robustness in the absence of one of the input signals and easy incorporation of additional signals to the classification task.

There are many examples in the literature where classification using a combination of EEG and additional signals outperforms the base classifiers in the set (Peng et al., 2007; Kapoor et al., 2008; Qian et al., 2009; Polikar et al., 2010). However, the results reported in the literature do not clearly indicate whether early or late integration will offer better performance for the multimodal head-movement artefact classification task. In the seizure detection domain, Greene et al. (2007) investigated the combination of EEG and ECG signals in improving the performance of neonatal seizure detection and found feature fusion to outperform classifier fusion. Malarvili and Mesbah (2008) found the opposite, with fusion of EEG and ECG signals at the classifier level offering better detection of seizure in neonatal EEG. Bermudez et al. (2007) performed a similar analysis for detecting temporal lobe epilepsy in adults but found that classifier fusion offered better classification performance than feature fusion. In this paper, a number of methods combining EEG and gyroscope artefact detection classifiers are investigated. By taking advantage of both EEG and gyroscope signals, it is shown that the classification performance improvement introduced with feature fusion (early integration) in O'Regan et al. (2012) can be extended to classifier fusion (late integration). In doing so, the complimentary nature of EEG and gyroscope modalities regarding head-movement artefact is confirmed. Amongst the classifier fusion methods investigated, the score fusion sum-rule exhibited the best performance and offers a number of advantages to feature fusion; most notably, robustness in the face of intermittent gyroscope signals and easy integration of additional physiological signals should they become available. To the best of the authors' knowledge, this is the first time that an analysis of multimodal fusion of EEG and gyroscope signals has been conducted.

2. Materials and methods

2.1. Data collection

Subjects. 30 min of head movement data was collected from 7 healthy male adults (23–50 years, mean age 30). None of the participants had a history of neurological or psychiatric disorders and none were on chronic medication. Informed consent was obtained from all participants.

Artefact generation protocol. An artefact generation protocol was drawn up which instructed the participants to perform repetitions of each of the following movements: shake head, clench jaw, nod, roll head, raise and lower eyebrows. Between repetitions participants were asked to remain still in order to generate reference EEG. Particular focus was placed on movement artefacts that have been observed to occur more regularly in an ambulatory EEG system. The artefact generation protocol is described in detail in Table 1. Demonstrations of example movements were performed before recording took place, and the participants were instructed to perform similar movements at the designated times. Participants were instructed to perform the movements as naturally as possible and to vary the pace and direction of head movements where appropriate in order to avoid excessively repetitive, periodic artefacts that may be unlikely to occur in a natural ambulatory environment.

Experimental set-up. The 14-channel Emotiv EPOC EEG headset was used, sampled at 128 Hz (Emotiv EPOC, 2012). A referential montage was utilised, with reference electrodes taken from behind the ears. The Emotiv EPOC employs gold-plated contact-grade hardened copper electrodes with saline-moistened felt pads to record the EEG. This device has recently been used as an

Table 1
Artefact generation protocol.

Head-movements	Duration	Description
Shake head	30 s	Shake head from side to side, varying pace and direction
Remain still	20 s	Remain seated, avoiding head movements and eye blinks and movements
Clench jaw	30 s	Prolonged as well intermittent clenches (mimicking chewing)
Remain still	20 s	Remain seated, avoiding head movements and eye blinks and movements
Nod head	30 s	Nod head up and down, changing pace as doing so
Remain still	20 s	Remain seated, avoiding head movements and eye blinks and movements
Roll head	30 s	Roll head in both directions, changing pace as doing so
Remain still	20 s	Remain seated, avoiding head movements and eye blinks and movements
Raise and lower eyebrows	30 s	Changing pace and amplitude throughout
Remain still	20 s	Remain seated, avoiding head movements and eye blinks and movements