

Evaluating the Performance of a Face Movement based Wheelchair Control Interface in an Indoor Environment

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Abstract: This paper presents a novel facial movement based human machine interface for an intelligent wheelchair to operate in an indoor environment. Five random selected intact subjects are designated to control a wheelchair by using the proposed control interface. The testing is carried out in a designed indoor environment. The system performance is evaluated by implementing same tasks ten times, with the criteria of control easiness and the time spent on each task. The experimental result shows that this new control strategy can assist disabled and elderly users for hands-free control of an electric powered wheelchair.

Keywords: *Intelligent wheelchairs, eye detection, hands-free control, face detection, HMI, HCI.*

I. INTRODUCTION

Recognizing human facial activities are an important way to understand human intentions. These facial activities include head gestures, eye blinking, facial expressions and speech, which can be detected by sensors and then interpreted by a computer so that people can interact with a machine or a robot. This kind of human machine interface is extremely useful for people with physical disabilities such as spinal cord injury, quadriplegia, hemiplegic or amputation, and for elderly people with weakening hand control ability. Up to now, some advanced human machine interfaces have been developed, including voice controller [1] and eye-gaze controller [2]. It remains a great challenge to develop advanced hands-free human machine interfaces for these people to access assistive devices and robots so that their quality of life can be much improved.

Currently, fitting an electrical wheelchair with hands-free control interface has been a popular research subject. Bio-signals such as Electro-myography (EMG), Electro-oculography (EOG) and Electro-encephalography (EEG) are used for hands-free control of electric-powered wheelchairs [3][4][5][6][7]. Apart from using these single-modality human bio-signals, computer vision information, speech information and multi-modality signals have been studied and applied as wheelchair control interface. Ju and Shin et al. introduced a vision based intelligent wheelchair system developed for people with quadriplegic in [9]. Li

and Tan [10] proposed a bimodal wheelchair control approach by integrating vision and speech signals. Matsumoto and Ino et al. [11] applied the recognition of head motion and eye gaze onto a locomotive wheelchair system. Ferreira and Silva et al. [12] proposed an HMI structure to control a robotic wheelchair by scalp EMG and EEG signals. Both eye blinking and eye close movements are used as control commands to control a mobile wheelchair through an onboard PDA.

This paper presents a new hybrid control method that is able to recognize five facial movements from both forehead EMG signals and facial image information. In order to test the designed control strategy, an indoor environment is setup and five subjects are tested with an electric powered wheelchair equipped with a joystick and the designed control strategy. A task is designed for the subjects to follow a specified route for ten times with joystick control and face movement control in turn and the result is given in terms of time duration in the task.

The rest of the paper is organized as follows. Section II describes overall system hardware & software architecture. How to select facial movements for control and an effective pattern recognition method are discussed in Section III. Section IV presents some experimental results to show the feasibility and performance of the proposed human machine interface in the real-world setting. Finally, a brief discussion and potential future extension of the system are given in Section V.

II. SYSTEM ARCHITECTURE

As shown in Fig. 1, the system architecture of the proposed system mainly consists of three parts. The first part is the intelligent wheelchair system which has an onboard computer and motor control unit. The second part is EMG and visual sensors that used for detecting human facial movements. The third part is the human computer interface which is responsible for recognizing human facial movements and converts these movement patterns into wheelchair control commands. The details of the system architecture and respective functions of these three parts are described in the following paragraphs.

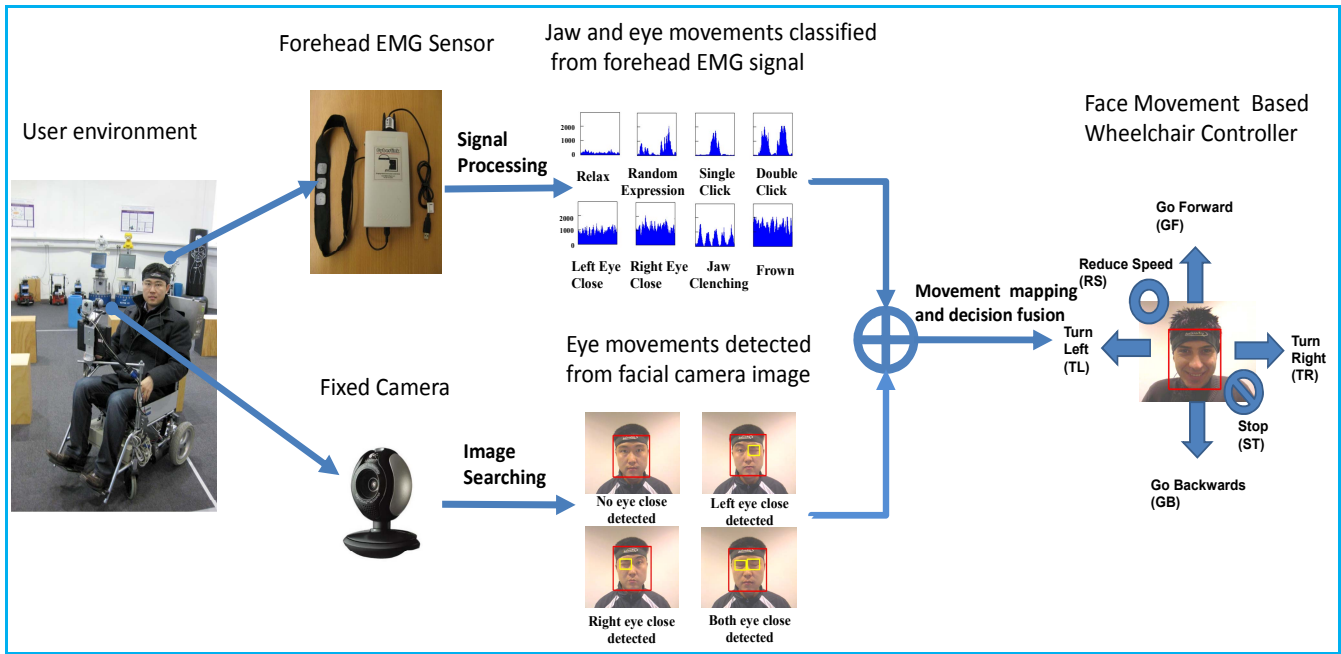


Fig. 1 Sketch of system architecture with data processing procedure and control strategy details

A. EMG and Image Data Acquisition

Fig. 2(Left) shows the wheelchair system, in which an EMG signal acquisition device CyberlinkTM [8] and a Logitech S5500 web camera are mounted at its front and pointing to wheelchair user's face. The EMG device has a data processing box and a wearable headband with three flat attachable electrodes used for detecting facial movements of a user. The electrodes are attached to human forehead by fastening the headband.

From three electrodes, one channel EMG signal can be obtained with one positive electrode, one negative electrode and a reference electrode. The raw EMG amplified from the electrodes are then processed in data acquisition box and turned into digital averaged EMG data sequence with a sampling frequency of 100Hz;



Fig. 2 Intelligent wheelchair setup for subject and indoor experiment environment (Left) and the CyberlinkTM headband and data acquisition device (Right).

B. The Intelligent Wheelchair

The intelligent wheelchair system deployed in this experiment is an electric-powered wheelchair equipped with an industrial computer and a built-in motor control board. The motor control board is embedded with a digital signal processing (DSP) unit which can implement open-loop liner motor control or closed-loop PID motor control for controlling differentially-driven wheelchair wheels; the wheelchair is mounted with a laser range finder and sonar sensor array, from which the onboard computer can calculate real-time range information to avoidance obstacles such as boxes, people, walls etc. In this experiment, the obstacle avoidance function is disabled.

C. Human-machine Interface (HMI)

The human machine interface is responsible for extracting features and classifying selected face movements and mapping the classified movement patterns into wheelchair control commands. The detailed procedure of this process is graphically depicted in Fig. 1. As can be seen, along the EMG sensor, five designed jaw and eye movements are classified into different patterns and with the eye close information detected from the camera, five face movements are identified. These movement patterns are mapped into six wheelchair control commands i.e. "GO Forward", "Go Backwards", "Turn Left", "Turn Right", "Reduce Speed" and "Stop", which imitates direction and speed control of a joystick. The detailed pattern recognition process and control strategy mapping procedure including data segmentation, feature extraction, classification and logic control will be discussed further in the next section.

III. CONTROL MOVEMENT CLASSIFICATION AND CONTROL STRATEGY DESIGN

A. Control Movement Selection

Five designated face movements employed in this experiment are namely single jaw clenching (SJC), forehead double jaw clenching (DJC), left eye close (LEC), right eye close (REC) and continuous jaw clenching (CJC) movement. Detailed motion of the five selected control movements are described as follows: SJC is a heavy jaw clenching movement which can be produced by the subject holding up their teeth and pushing the jaw against upper teeth and making a strong contraction of masseter and buccinators muscles with a fast jaw clenching movement. Similar to teeth holding up motion in SJC movement; CJC can be produced by a subject making gentle and repetitive clenching, compared with SJC clenching, CJC is gentle and persistent jaw clenching movement.

As shown in Fig. 1 and 3, CJC movement can cause a series of short and regular EMG waveforms while SJC arouse a sharp and high waveform, DJC is made of two consecutive SJC movements. LEC and REC movements are one eye open and one eye close movements start from eye closing movement of both left and right eyes and the movement state can last by keeping the eye closed. Unlike gentle eye closing movement during blinking or sleeping, LEC and REC are heavier muscle movements and can be described as eye squeezing movement. The finishing state of the movement is marked by opening the closed eye.

B. Control Movement Recognition

In order to recognize five face control movements described above, features from EMG signal and face image information are jointly extracted and classified. Fig. 3 shows EMG waveform patterns obtained during corresponding control movements. These EMG patterns are classified with two separate procedures i.e. SJC, DJC procedure and CJC, EC procedure.

SJC and DJC are recognized by a threshold based strategy. SJC is detected by calculating uninterrupted EMG overshoot amplitudes when EMG amplitude is continuously above a preset threshold, if the length of time falls within a preset range, then SJC patterns is detected. This strategy is also implemented by Torsten and Bernd in [7] which uses SJC movement to control a powered wheelchair.

In the second procedure, an support vector machine (SVMs) classifier are trained by using training data collected from a standard subject performing various face movements including CJC, LEC, REC, SJC, DJC, relaxing, talking, smiling etc. These movement patterns are assembled into three classes which are class EC, class CJC and class Others (OT); as shown in Fig.3, class EC contains two patterns which are EMG patterns produced during LEC and REC movements. Class CJC contains a single pattern which from CJC movement. And class OT contains all the other patterns other than the patterns in EC and CJC classes. Class OT contains a range of EMG patterns such as SJC and DJC movement patterns, patterns from facial movements when subject is relaxing, talking, smiling etc.

Training data are sampled according to the movement patterns described in these three classes, and the recorded movements' data are therefore segmented into 200ms sections for feature extraction purpose. Eight waveform features, including five from the time domain: mean absolute value (MAV), root mean square (RMS), waveform length (WL), zero crossing (ZC) and slope sign changes (SSC) and three from the frequency domain: frequency mean (FMN), frequency median (FMD) and frequency ratio (FR), are extracted from each data segment. With extracted features from three classes, a RBF kernel SVM classifier gives a best classification accuracy of 93.5% on a threefold cross validation procedure.

Alongside with classified EMG patterns, two face image patterns denoting LEC and REC movements are also classified with an adaptive Boosting learning approach on Haar-like features. As shown in Fig. 1, two classifiers for detecting left-closed eye and right-closed eye are trained. The training is based on sampling closed-eye images from 5 different subjects under various illumination conditions, changing subject face orientation and distance relative to the sampling camera.

As a result, a number of 1475 closed-eye images are collected for left eye training, and for the right eye, the positive image set have 1318 closed eye images. Based on these images, a left-closed eye classifier with 20 cascades is trained, and the classification accuracy validated among sample training images is 91.75%. For the right-closed eye, the training process stops at 19 cascades with a classification validation accuracy of 92.2%.

Facial Movements	EMG Patterns	Image Patterns	Control Commands
	Continuous Jaw Clench (CJC)	Any	↑ Go Forward (GF)
	Eye Close (EC)	Left Eye Close (LEC)	→ Turn Right (TR)
	Eye Close (EC)	Right Eye Close (REC)	← Turn Left (TL)
	Single Jaw Clench (SJC)	Any	⊙ Reduce Speed (RS)
	Double Jaw Clench (DJC)	Any	⊘ Stop (ST)
	Double Jaw Clench (DJC)	Any	↓ Go Backwards (GB)

Fig. 3 Control strategy among face movements, classified movement patterns and wheelchair control commands

C. Decision Fusion and Control Strategy

Fig. 3 describes the decision fusion process for classified EMG and visual patterns and wheelchair control commands. Six control commands namely “Go Forward” (GF), “Turn Left” (TL), “Turn Right” (TR), “Reduce

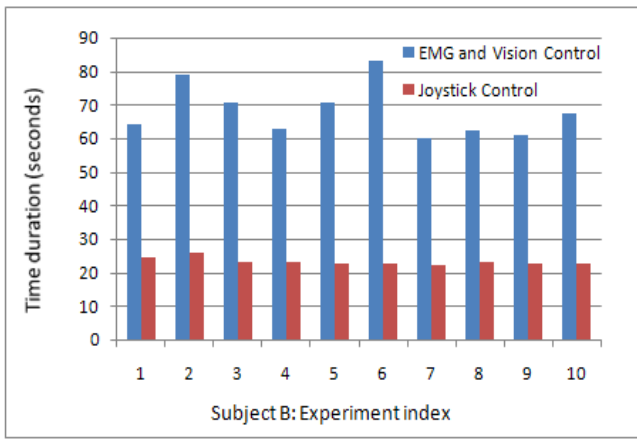


Fig. 6 Time recorded of subject B repeating designed route for ten times with EMG-vision control and joystick control

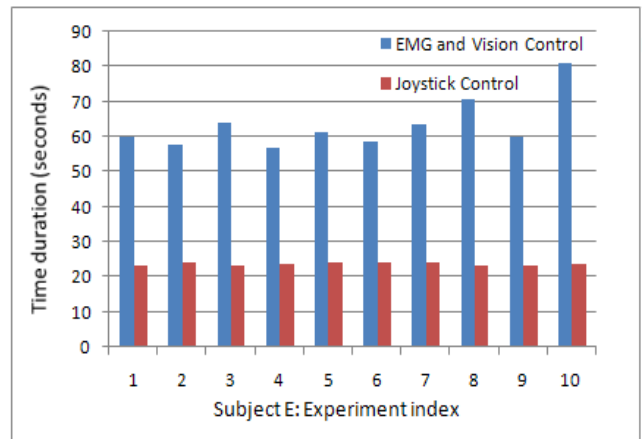


Fig. 9 Time recorded of subject E repeating designed route for ten times with EMG-vision control and joystick control

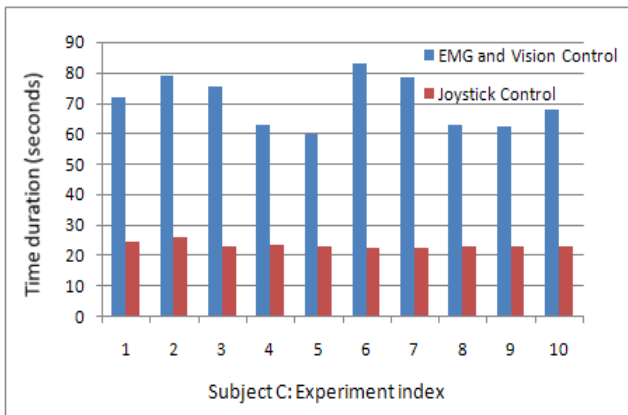


Fig. 7 Time recorded of subject C repeating designed route for ten times with EMG-vision control and joystick control

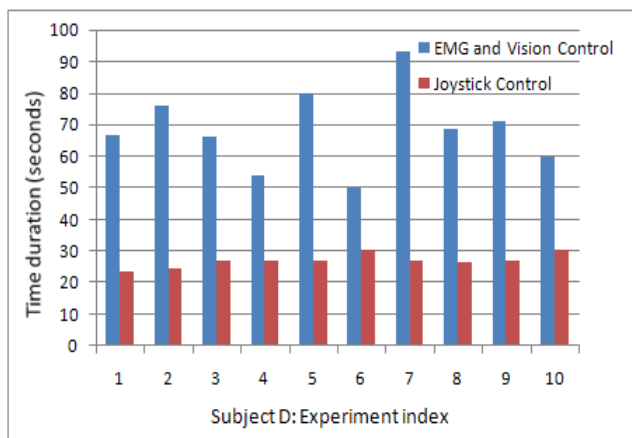


Fig. 8 Time recorded of subject D repeating designed route for ten times with EMG-vision control and joystick control

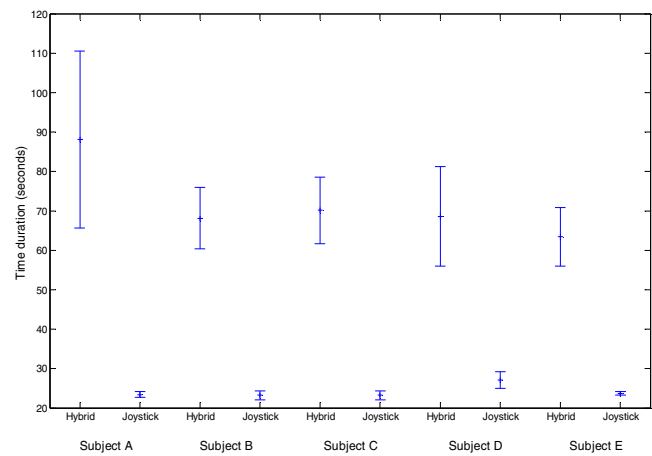


Fig.10 Mean and variance comparison of experiment result between hybrid (EMG and vision) control and joystick control in terms of time duration for five subjects

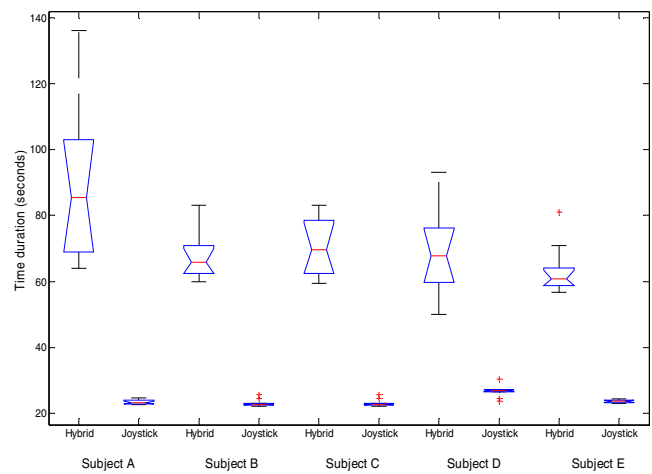


Fig. 11 One way analysis of variance (ANOVA) of experiment results between hybrid (EMG and vision) control and joystick control in terms of time duration for five subjects

V. CONCLUSION AND FUTURE WORK

This paper introduces a face movement based wheelchair control interface based on features extracted from both forehead EMG signals and facial image information. Five subjects participated in the test experiments to evaluate the performance of the new interface. The experimental results show that: visual and facial EMG based control of an electric-powered wheelchair has fast respond speed; but cannot achieve accurate motion trajectories, compared with the traditional joystick control.

To improve the system performance, we are currently working on a novel hierarchical human machine interface for the electric powered wheelchair, shown in Fig. 12. In this hierarchical structure, human intentions are divided into three layers, namely high level (thinking level), middle level (planning level) and low level (action level). The purpose is to divide and clarify human physiological phenomenon between “thinking” and “action”, from which various sensors are deployed to monitor respective physiological phenomena. All inspection information is combined to interpret human intentions.

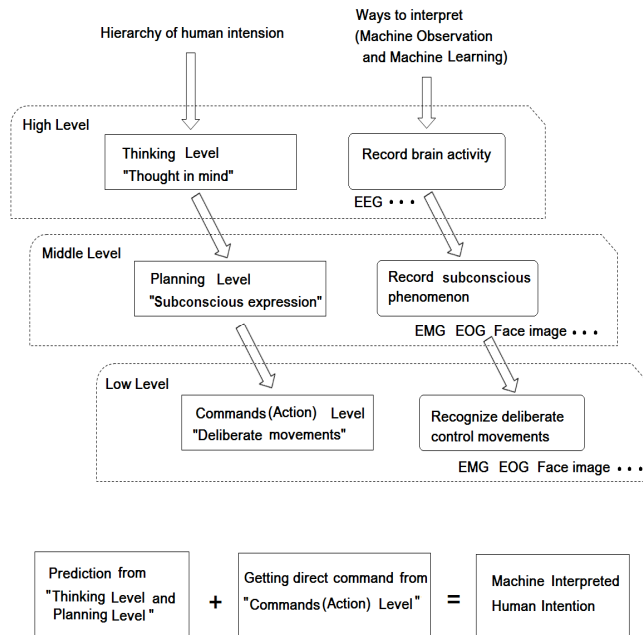


Fig. 12 Hierarchical multi-modality human-machine interface

The high level activity is brain activity which can be recorded from EEG signals. The middle level is the planning stage of a human action, i.e. the subconscious activities such as facial expressions, eye movements or eye gaze, head gestures, muscle activities, blood pressure, heart rate, skin conductance etc. The low level is the command level which contains human control commands and actions that is in forms of voice, face movement, hand movement and head movement etc. In the future work, human activities at high level and middle level will be integrated into a prediction layer so that human intentions are interpreted more precisely with a prediction process.

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