Quadcopter Navigation Using Google Glass and Brain-Computer Interface

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ABSTRACT
With the development of wearable computing, Brain-Computer Interface, and affordable drones, we can now explorer the idea of an "extended-self" that can be remote controlled even with our mind. In this paper, we developed a wearable system for drone navigation using Google Glass and Emotiv Headset, allowing touchpad gesture control, head posture control, and hands-free mind control through motor imagery. The drone will also display first-person view as visual feedbacks to the user. This research can be applied to many circumstances such as enabling locked-in patients to explore surroundings at will, developing mind-controlled UAV can be used in military tasks, and becoming affordable toys that can promote entertainment and socialization.

Author Keywords
Wearable; drone navigation; Google Glass; Brain-Computer Interface

INTRODUCTION

With the development of Brain-Computer Interfaces(BCIs) in assistive technology, people with severe motor disabilities can drive their wheelchairs, browse webpages, and play computer games with their minds. They can now even control a quadcopter to fly by using electroencephalography (EEG) devices. Meanwhile, wearable computers with head-mounted displays (HMDs) such as Google Glass are becoming more accessible to every one of us than ever. Their advantages over personal computers, tablets, and even smart phones are that they greatly reduce the time between intention and action or feedback, as their displays can be always within our field of view. Thus, integrating drone control with HMDs and BCIs will take one step further toward the ultimate goal of immersive flying within an "extended self", combining both the hands-free nature of BCIs and the mobility of HMDs, which will have various applications apart from assistive technology.

In this paper, we will investigate the feasibility and the usability of controlling a quadcopter through BCIs, with Google Glass displaying first-person view as visual feedbacks. The quadcopter we use is called AR-Drone, is one of the affordable quadcopters [1]. It is equipped with a front high-definition camera and Wifi to stream video and can be controlled remotely by PC, iOS, and Android devices, based on which several augmented reality applications have been developed [2]. Google Glass is a wearable computer with an optical head-mounted display (OHMD) that is being developed by Google in the Project Glass research and development project, with a mission of producing a mass-market ubiquitous computer [3]. And the BCI we use is called Emotiv EPOC Headset, a low-cost non-invasive EEG recording device which is said to be the best consumer-level EEG device. The hardware of this project is shown in Figure 1.

Figure 1. Hardware we use in this paper.

RELATED WORK

Brain-computer Interfaces (BCIs) have been studied for a long time, with the primary motivation of providing assistive technologies for people with very severe motor disabilities. BCIs have been applied to many domains such as communication, computer usage, environmental control, mobility, robotics, recreation, virtual reality, creative expression, etc. For instance, BCI has been used in wheelchair control in the Aware 'Chair project. P300-based BCI has been used for robot control. SSVEP-based BCI has been used in virtual reality computer games [4]. BCI has also been used in AR-Drone flight control [5].

Quadcopters such as AR-Drones have been used in several research projects, including the autonomous suveillance tasks, human-machine interaction, and augmented reality. For instance, at Cornell university, the AR-Drone has been used for experiments in UAV visual autonomous navigation in structured environments [1]. W. Shan used gestures to interact with the AR-Drone while the user is within the field of view of the flying robot [6]. In the AR.Race game the players race against the opposing drone using its mobile apps. AR.Rescue is a first-person view piloting game where players help the aliens to return to their planet [7].

Google Glass displays information in a smartphone-like hands-free format that can communicate with the Internet via natural language voice commands [8]. It is expected to have multiple paradigm-shifting applications, including augmented reality as in OpenGlass [9].

METHODS

Figure 2 shows the framework of our approach. The 3 components of hardware are wireless connected. User interact with Google Glass by touchpad gestures, head posture, and voice commands. User also use certain brain activities to interact with Emotiv Headset. Google Glass and Emotiv Headset will send signals to AR Drone. AR Drone will perceive the signals with its artificial intelligence. Then it will make reactions based on the user's command and its current context, and streams live visual feedback in a first-person view to display on Google Glass.

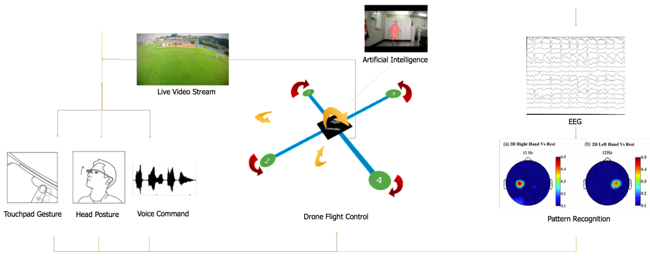

Figure 2. Framework of our method.

Network

The quadcopter, AR.Drone, is equipped with Wifi 802.11b/g/n, and can be controlled by any client device supporting Wifi. Its Wifi range is claimed to be up to 100m. Specifically, it creates a WIFI network with an ESSID and self allocates a free, odd IP address (typically 192.168.1.1) which allows client to connect and requests an IP address from the drone DHCP server. The AR.Drone DHCP server grants the client with an IP address which is the drone own IP address plus a number between 1 and 4. Then the client device can start sending requests to the AR.Drone IP address and its services ports.

Controlling and configuring the drone is done by sending AT commands on UDP port 5556 on a regular basis (usually 30 times per second). Information about the drone (like its status, its position, speed, engine rotation speed, etc.) are sent by the drone to its client on UDP port 5554 at a rate from 15 to 200 times per second. A video stream is sent by the AR.Drone to the client device on TCP port 5555 [11].

Google Glass has Wifi 802.11b/g and Bluetooth connection [12]. Emotiv Headset sends data to a USB dongle through its own proprietary wireless protocol. AR Drone has a USB port. We connect Google Glass to AR Drone by Wifi. Technically we can mount the USB dongle of Emotiv to AR Drone's USB port and let AR Drone read the data from Emotiv Headset. Currently we simply use a Mac Pro to connect the Emotiv.

Video Stream

One of the most important aspects of this project is that the drone can stream live visual feedback taken by its frontal camera. The frontal camera is a CMOS sensor with a 90 degrees angle lens.

The AR Drone automatically encodes and streams the incoming images to the host device. AR.Drone 2.0 use H264 (MPEG4.10 AVC) baseline profile for high quality video streaming and video recording, with a frame-per-second (FPS) between 15 and 30, resolution of 360p (640x360) or 720p (1280*720) [11].

Google Glass connects to the AR Drone, decodes the video packet and then presents the video on its prism display. the prism display is said to be high resolution equivalent of a 25 inch high definition screen from eight feet away [12]. The video decoder we use is from Parrot, and can display first-person view like in Figure 3.

Figure 3. Live video stream displayed on Google Glass.

Gesture Control

Google Glass allows touch gestures by tapping and sliding your finger on the touchpad located on the right side of the device near the user's temple. It can detect up to three-finger multitouch. Therefore we mapped gestures to drone flight control as is shown in Table 1.

Gesture	Command
Three-Finger Tap	Take Off/Land
Two-Finger Tap	Go Forward
Swipe Left	Turn Left
Swipe Right	Turn Right
Two-Finger Swipe Left	Lift Down
Two-Finger Swipe Right	Lift Up
Long Press	Enter Posture Control Mode
Tap	Quit Posture Control Mode

Table 1. Touchpad gestures mapped to drone control commands.

In this mode, we make use of the drone's assisted control of basic manoeuvres. This mode feature levers and trims for controlling UAV pitch, roll, yaw and throttle. Basic manoeuvres include take-off, trimming, hovering with constant altitude, and landing. It generally takes hours to a beginner and many UAV crashes before executing safely these basic manoeuvres. The AR Drone's sensor onboard sensors make take-off, hovering, trimming and landing completely automatic and all manoeuvres are completely assisted. For instance, "take off" command willautomatically start engines, take-off and hover at a pre-determined altitude, and "turn left" command will turn the AR Drone automatically to the left at a predetermined speed. Otherwise the AR Drone automatically keeps the same orientation.

We can also modify the speed and duration of the movements. Here we set the speed to 0.5, which is relatively half of the full speed. The duration of movement is set to be 600 milliseconds.

Head Posture Control

Google Glass has accelerometer, gyroscope, and magnetometer located on the optics pod, which users rotate to align the device with their sight. They can be used to detect the tilt and posture of the user's head. AR Drone can also be controlled by a combination of pitch, yaw, and roll. Therefore we map the head movement to the drone's orientation, as is shown in Figure 4.

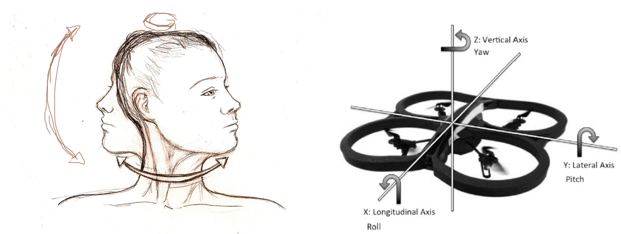

Figure 4. Mapping head position to drone orientation.

Varying left and right rotors speeds the opposite way yields roll movement. This allows to go forth and back. Varying front and rear rotors speeds the opposite way yields pitch movement. Varying each rotor pair speed the opposite way yields yaw movement. This allows turning left and right.

EEG Control

Ideally we will use Google Glass and Emotiv controlling AR Drone at the same time. So far we have experimented flight control one at a time. We connect Emotiv Headset's dongle to a Mac Pro, and connect the Mac Pro to the AR Drone.

The Emotiv EPOC Headset is a non-invasive EEG headset with a set of 14 sensors plus 2 references to collect electric signals produced by the brain. The placement of sensors on user's head is shown in Figure 5. The sampling method is sequential sampling with single analog-to-digital converter (ADC). The sampling rate is 128 samples-per-second (SPS) with 2048 Hz internal. Its spacial resolution is 14 bits 1 LSB = 0.51μV (16 bit ADC, 2 bits instrumental noise floor discarded). There is also a built-in digital 5th order Sinc filter [13].

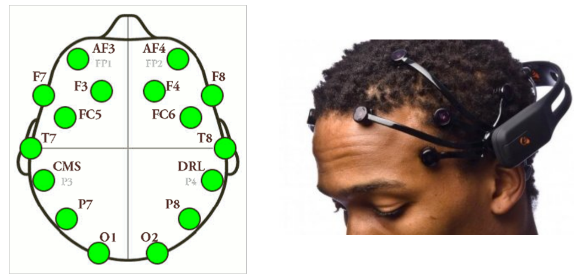

Figure 5. Emotiv sensors placement.

There are two popular methods for EEG remote control: Steady-State Visual-Evoked Potentials (SSVEP) and motor imagery.

SSVEP

SSVEP is a frequency-coded brain response modulated by the frequency of periodic visual stimuli higher than 6 Hz. SSVEP is known to be most prominent at the parieto-occipital scalp locations over the visual cortex. SSVEP provides high signal-to-noise ratio (SNR), high information transfer rate (ITR) and minimal user training, and thus has been widely adopted in a brain-computer interface (BCI). By means of determining the frequencies of stimuli from a user's non-invasively recorded electroencephalogram (EEG), SSVEP becomes a promising medium signal in current BCI applications [14].

It is unknown that Emotiv Headset can be used to detect SSVEP. So we did a user test to let the user gaze at a black/white flickering stimulus from 8 Hz to 16 Hz for 60 seconds. We collected data from O1 and O2 which is placed over the parieto-occipital region, which has been reported most sensitive to SSVEP detection [14] and used Fourier Transform to get the spectral plot of the data. If Emotiv can detect SSVEP we will expect to see a spike similar to the stimulus' frequency, like in Figure 6.

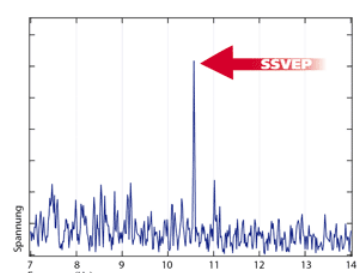

Figure 6. Typical representation of SSVEP signal.

However we didn't see a significant spike throughout the experiment, which shows that the Emotiv Headset might not be an adequate tool for SSVEP detection.

Motor Imagery

Motor imagery is a mental process by which an individual rehearses or simulates a given action. Motor imagery can modify the neuronal activity in the primary sensorimotor areas in a very similar way as observable with a real executed movement. One part of EEG-based BCI is based on the recording and classification of circumscribed and transient EEG changes during different types of motor imagery such as, e.g., imagination of left-hand, right-hand, or foot movement [15]. Most of the work in this area place electrodes over the person's sensorimotor cortex to detect imagination of physical movement, as in Figure 7.

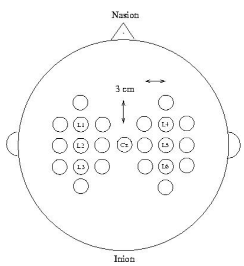

Figure 7. Electrodes placement for motor imagery.

The Emotiv Headset does not have electrodes placed directly above the sensorimotor cortex, therefore we need to bend it backward to place F3/F4 electrodes over that area. Since all the other electrodes are too far way and there is no way we can use electrodes other that F3/F4.

The flow of apply pattern recognition on data from F3/F4 is shown in Figure 8. To collect data, users are asked to relax, then imagine left-hand, right-hand, both-hand, and both-foot movement.

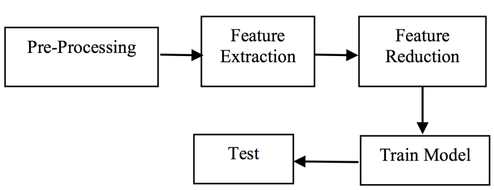

Figure 8. Flowchart of EEG data pattern recognition.

In the Pre-Processing phase, we apply a Gaussian filter with $\sigma = 5$, length = 100 on the data to reduce the noises. Then we normalize the data by dividing the maximum magnitude. After that, we apply a sliding window with a length of 128, overlapping of 64 to cut the data into frames, and label them. Note that we discard the transition between two consecutive movements to reduce ambiguity.

In the Feature Extraction phase, we extract spectral feature on the data, which is all the 64 coefficients of Fourier Transform performed on each frame. We combine coefficients of F3/F4 to form a feature vector of 128.

In the Feature Reduction phase, we use Principal Components Analysis in Weka software (version 3.7.10), with R=0.95, A=5, M=-1to reduce the dimension of features from 128 to 20.

In the model training phase, we pass these features to a use Support Vector Machine library LibSVM in Weka, with C=1, E=0.001, P=0.1. The kernel of SVM we choose is radial basis function (RBF). The design parameters of SVM are selected using training data via a grid search on a base-2 logarithmic scale. In general, the RBF kernel is suitable because its ability to model the non-linear relation between attributes and target and less numerical difficulties compared to polynomial and sigmoid kernels.

In the testing phase, we use 10-cross validation for all the frames. The data partitioning is based on random sampling of files from a pool wherein all data are mixed.

We can see the recognition result of hand-only and hand-foot in Table 2.

Motor Imagery	Total Frames	Accuracy
None, Left-Hand, Right-Hand	7035	97.7%
None, Left-Hand, Right-Hand, Both-Hand	9330	91.5%
None, Left-Hand, Right-Hand, Both-Hand, Both-Foot	11750	71.1%

Table 2. Offline pattern recognition results.

From the Table we can see that accuracy drops dramatically after adding in imagination of foot movement. This is probably because only one electrode is placed over either side of sensorimotor cortex. While adding in Both-Hand reduces accuracy, but the overall accuracy is still very high therefore we can use four classes of None, Left-Hand, Right-Hand, Both-Hand for drone control.

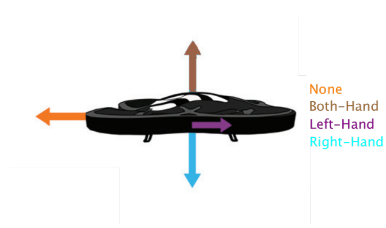

Figure 9. Mapping motor imagery to drone flight.

As is shown in Figure 9, we map None to flying forward, Both-Hand to lifting up, Left-Hand to turning left, and Right-Hand to lifting down. In testing to reduce lag due to computation, every 10th frame will go through the same process as depicted in Figure 7, and each recognized result will lead to corresponding drone movement with relative speed of 0.5, lasting 100 milliseconds.

In our test, the drone fly as we programmed. We also discovered 2 problems: First, the drone is in a constant changing state, which means there is no hovering time, which will make it harder to control. Second, in online testing the accuracy is not as good as offline pattern recognition. We believe it is because EEG is very susceptible to noises and small environmental changes. The scene of operating the drone is shown in Figure 9.

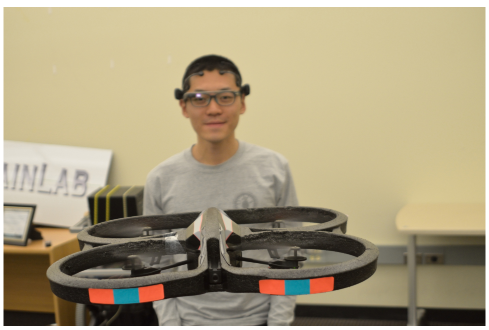

Figure 10. Controlling the drone using Google Glass and Emotiv.

CONCLUSION

In this paper, we developed a wearable system for drone navigation using Google Glass and Emotiv Headset, allowing touchpad gesture control, head posture control, and hands-free mind control. The drone will also display first-person view as visual feedbacks to the user. We have proved the feasibility of our intention, and this research can be applied to many circumstances such as enabling locked-in patients to explore surroundings at will, developing mind-controlled UAV can be used in military tasks, and becoming affordable toys that can promote entertainment and socialization.

FUTURE WORK

With the current hardware we will explore using voice control of drone flight, integrating three pieces of hardware, and improving recognition accuracy of BCI with improved features.

Since Emotiv Headset has limited performance for EEG, we will explore EEG cap with active electrodes, and novel in-ear EEG device which can be easily paired with Google Glass.

We will also research into drone autopilot which can help reduce human labour. Also we will conduct more user study to evaluate our system.

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