B-C-Invisibility Power: Introducing Optical Camouflage Based on Mental Activity in Augmented Reality

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ABSTRACT

In this paper we introduce a novel and interactive approach for controlling optical camouflage called "B-C-Invisibility power". We propose to combine augmented reality and Brain-Computer Interface (BCI) technologies to design a system which somehow provides the "power of becoming invisible". Our optical camouflage is obtained on a PC monitor combined with an optical tracking system. A cut out image of the user is computed from a live video stream and superimposed to the prerecorded background image using a transparency effect. The transparency level is controlled by the output of a BCI, making the user able to control her invisibility directly with mental activity. The mental task required to increase/decrease the invisibility is related to a concentration/relaxation state. Results from a preliminary study based on a simple video-game inspired by the Harry Potter universe could notably show that, compared to a standard control made with a keyboard, controlling the optical camouflage directly with the BCI could enhance the user experience and the feeling of "having a super-power".

Author Keywords

Optical camouflage; BCI; invisibility;

ACM Classification Keywords

H.5.1 Information Interfaces and Presentation: Multimedia Information Systems—*Artificial, augmented, and virtual realities*; H.5.2 Information Interfaces and Presentation: User Interfaces—*Input devices and strategies*

INTRODUCTION

Virtual Reality (VR) or Augmented Reality (AR) technologies can sometimes provide a feeling of having "superpowers" allowing users to perform actions that no human being would be able to do. One of such super-powers is the "power of invisibility", i.e., being able to be surrounded with other individuals without being seen. This old dream could have come true several years ago with the appearance of "optical camouflage" [3].

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Figure 1. The "B-C-Invisibility power" enables users to become virtually invisible by performing mental tasks. Brain signals are extracted using EEG electrodes and analyzed within the BCI.

In this paper we propose a novel and interactive approach for optical camouflage called "B-C-Invisibility power" based on Augmented Reality and Brain-Computer Interfaces (see Figure 1). An optical camouflage system is designed based on background subtraction and optical tracking. Then, a BCI allows users to control their invisibility level in function of their concentration level.

The remainder of this paper is organized as follows. First we will introduce our system and describe its main components. Then we will present a pilot study comparing two input devices used to control a level of camouflage: a BCI and a keyboard. The paper ends with a general discussion and a conclusion.

RELATED WORK

Several attempts have already been made in virtual reality to provide humans with super-powers. This has been illustrated by Ishibashi et al. [4] in virtual reality. In their experiment, participants could use a super-power (launching a virtual web) to jump from one virtual building to another. Bailenson et al. [6] provided users with a super-power of flying in a virtual environment (VE). Participants had to help a diabetic child or tour a virtual city, having either this superpower or being a passenger in a helicopter. The experimenter then provoked a non-virtual event needing help from the participant: she would let some pens fall from a table. This experiment showed that users having these virtual super-powers had an increased helping behavior.

"Optical camouflage" has been defined by Inami et al [3] as a type of active camouflage that uses optical projection. Their system worked by projecting an object's background on itself to make it almost invisible. A camera was placed behind the object that had to become camouflaged to record its background. A projector then rendered an image on the object, as viewed from a particular viewpoint. Inami et al. [2] also applied an optical camouflage on objects using AR. Their objective was to hide a haptic interface by using a head-mounted projector. Users could manipulate virtual objects and even cause occlusions.

In this paper, we introduce a variant of optical camouflage. Instead of projecting background elements on a person to make her disappear, an outlined image of her body is separated from the background and overprinted on another image. This outlined image can be overprinted with various levels of transparency, allowing the user to camouflage himself within the VE. Compared to the aforementioned works, our setup provides a new way of controlling optical camouflage by using only mental activity, in order to give a greater feeling of having a super-power.

THE "B-C-INVISIBILITY POWER"

Concept

The "B-C-Invisibility Power" aims at allowing users to control the power of becoming virtually invisible by camouflaging themselves. This "super-power" is mind-controlled, so that they can experience invisibility without having to move any muscle, only by controlling a mental activity (here concentrate or relax). Users see themselves on a screen as in a mirror, a reflection of their body following their movements and being displayed with a varying level of transparency (see Figure 2-top).

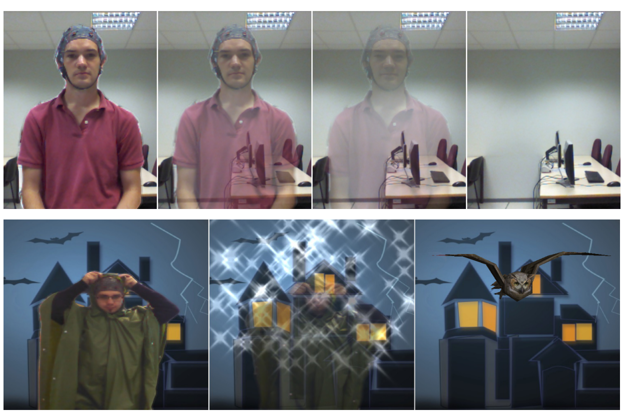

Figure 2. Top: Users can see themselves with various levels of transparency. Bottom: An "Invisibility Cloak" illustrates an entertaining concept freely inspired by the Harry Potter universe. In this case, the player puts a cloak's hood and concentrates to become invisible. Removing it prevents any level of invisibility. A particle effect appears each time the user puts the hood on her head.

System Description

Our system comprises various components which are displayed in Figure 3-left:

- **EEG acquisition/processing:** Brain activity recording is performed using an ElectroEncephaloGraphy (EEG) cap (1) fitted with electrodes. An EEG amplifier (2) pre-processes the data recorded by the electrodes. Further processing is done by the OpenViBE software platform [5], running on a computer (3). A signal processing pipeline uses a linear regression (whose coefficients have been calculated per-user during a calibration phase) to provide a numerical estimation of the user's concentration level (See sections *EEG Data Processing* and *Experiment Description*).

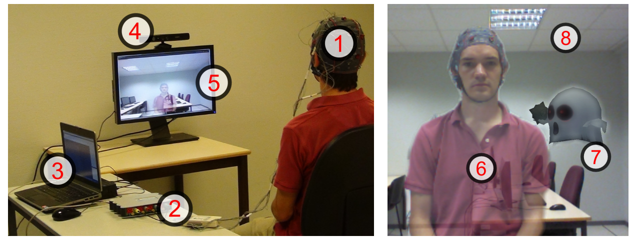

Figure 3. Left: System overview; (1) EEG cap, (2) EEG amplifier (g.USBamp, g.tec), (3) computer, (4) optical tracking system (Kinect camera), (5) computer screen. Right: Experimental environment overview; (6) participant's cut out image, (7) virtual entity: a ghost, (8) pre-captured background image of the real background scene in which the participant is standing.

- **Image processing and tracking:** An optical tracking system (4) records 640x480 pixels color images and 320x240 pixels depth images at a frequency of 30 Hz. The tracking of the user is achieved using the color and depth recordings with the help of the Kinect development kit. An application running the Unity3D engine processes the final rendered image containing a static background, an image of the user and virtual 3D elements. Rendering is achieved at a frequency of approximately 25 Hz.

- **Display:** A computer screen (5) displays the real scene in which the user is standing.

A middleware application receives the BCI information and the video feed from the 3D camera and sends it to the Unity3D engine that performs the rendering of the static background overlayed by an image of the user.

EEG Data Processing

EEG data was acquired at a frequency of 512Hz using a cap fitted with 16 electrodes and transmitted to a computer through a g.USBAmp acquisition system. EEG electrodes were placed at positions T7, T8, F7, F8, Fp1, Fp2, C3, Cz, C4, O1, O2, F3, F4, P3, Pz and P4 according to the international 10-20 system. A subject-specific model obtained using machine learning similar to [1] was used to estimate the concentration level of each participant at any moment. This processing pipeline uses training data to compute a linear regression's coefficients that outputs a single value which represents the participant's concentration level. Expected values ranged from -1 to 1, a lower value (respectively higher) means that the participant is in a relaxed (respectively concentrated) mental state.

Illustrative Use Case

We have developed an entertaining application inspired by the Harry Potter universe: an "Invisibility Cloak" (see Figure 2-bottom). In a video-game, a player must escape from foes and be visible by friends. In our application, the player has to put the hood of the "Invisibility Cloak" on her head and concentrate to become invisible from a ghost. Removing the hood makes the user visible again regardless of her concentration state, in order to be visible by a friendly owl.

A pilot study inspired by the "Invisibility Cloak" application has been set up to evaluate the "B-C-Invisibility Power" in terms of performance and user experience.

PILOT STUDY

The objective of our pilot study was to compare the BCI to a more conventional interface i.e., a keyboard, for controlling an optical camouflage. The participant's task was to control the "B-C-Invisibility Power" with the two interfaces. We focused on both task performance and user experience.

A video-game inspired prototype was presented to the participants. They had to be visible when seeing a friendly owl and invisible when seeing an evil ghost. Using the keyboard, participants had to press two different keys to increase or decrease their invisibility level. Using the BCI, participants had to be concentrated or relaxed to achieve total visibility or total invisibility. These mental states were identified in real-time by the signal processing pipeline. Both the task performance and the preference of the participants have been evaluated, using the detected concentration level and a subjective questionnaire.

Our hypotheses were that the BCI would be more motivating for participants while the keyboard would perform better (e.g. participants would have a higher success rate in controlling their camouflage).

Experiment Description

Participants were seated in front of a computer screen. Two different input devices (keyboard or BCI) were available to the participants. Twelve participants (3 females and 9 males, aged from 20 to 36, average=28.42, SD=4.5) took part in the experiment.

The signal processing pipeline for the BCI used in this study requires a calibration phase so that the system is able to recognize the two mental states. During this calibration phase, participants were asked to concentrate and afterwards relax during 2 minutes while having no visual feedback. Participants were free to choose any cognitive activity for both mental states (concentration and relaxation), but suggestions were made such as "performing a mathematical computation" (concentration) versus "thinking about nothing" (relaxation).

The experiment comprised 4 blocks composed by a device (keyboard or BCI) and one of two tasks. Participants were split equally into 4 groups corresponding to the different blocks orders. Each task ("become invisible" or "become visible") was dependent on the device. For the keyboard it would be "press the Up key" or "press the Down key". For the BCI it would be "concentrate" or "relax". Each block comprised 20 trials of 12 seconds. Only the last 8 seconds were used to compute the trial's result. At the beginning of each trial an animated 3D model appeared in one corner of the screen and moved progressively towards the image of the participant following a spiral shaped path. The 3D model could be either a ghost, in which case participants had to become invisible, or an owl, in which case they had to become visible (see Figure 3-right). The presentation order of the 10 ghosts and 10 owls within each block was randomized. The level of transparency of the participant's image depended on the current task's success rate.

At the end of the experiment, participants had to fill a questionnaire and grade the 2 input devices (Keyboard/BCI) according to the following criteria: (a) Controllability, (b) Innovation, (c) Motivation, (d) Time to become invisible, (e) Stress level, (f) Fatigue level, (g) Feeling of having a super-power. They were also asked to provide open comments about the keyboard and the BCI usages.

Results

A statistical analysis has been conducted on the BCI classification results for each trial, in order to evaluate the amount of control that participants had on the "B-C-Invisibility Power". A mixed model analysis was performed to evaluate the effects of the task ("concentrate" versus "relax"), the objective ("become invisible" versus "become visible"), and the individuals (considered as random). A significant difference between the two tasks has been found ($F(1.11)=14.37$, $p=0.003$). However, no significant difference has been found between the two objectives ($F(1.11)=0.365$, $p=0.56$). Finally, a significant difference has been found on the effect of the interaction between the task and the objective ($F(1.443)=5.62$, $p=0.02$). The average output for the concentration task was 0.49 (SD=0.34) for the "become invisible" objective and 0.54 (SD=0.29) for the "become visible" objective. For the relaxation task, the average output was 0.26 (SD=0.23) for the "become invisible" objective and 0.24 (SD=0.24) for the "become visible" objective. Comparing the average value of successful trials (out of 20) shows that the keyboard has a higher rate (99.15%, SD: 1.9%) than the BCI (66.9%, SD: 17.6%).

A paired-wise t-test has been performed on the results of the subjective questionnaire. The "controllable" ($p<0.001$) and "time to become invisible" ($p=0.001$) criteria have been found to be significantly better for the keyboard. The "innovative" ($p<0.001$) and "feeling of having a super-power" ($p=0.009$) criteria, on the other hand, have been found to be significantly better for the BCI. The "motivating" ($p=0.073$), "stress level" ($p=0.19$) and "fatigue level" ($p=0.772$) criteria have not been found as being significant.

DISCUSSION

Our user study enables us to compare the use of the BCI and the keyboard to control the "B-C-Invisibility Power". As expected, performance results confirmed that participants using the keyboard almost never failed at any trial, whereas participants were more challenged when using the BCI. The lower performance obtained with the BCI could be explained by the fact that the VE was not visible during the calibration phase

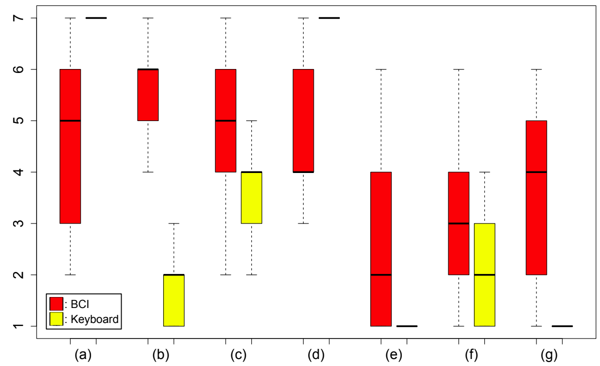

Figure 4. Subjective questionnaire results for the different criteria; (a) Controllability, (b) Innovation, (c) Motivation, (d) Time to become invisible, (e) Stress level, (f) Fatigue level, (g) Feeling of having a super-power.

(See section *Experiment Description*) compared to the rest of the experiment.

A statistical analysis of the questionnaire results shows that the BCI was perceived to be more innovative than the keyboard, and to give a better feeling of having a super-power. On the other side, the keyboard has been perceived as being more controllable and allowed participants to have more time to become visible or invisible. Having super-powers, being "augmented", often means being able to control these extraordinary elements by intuitive means. Having the ability to become invisible without having to manipulate any physical object seems to be more intuitive than using a keyboard. Additionally, the statistical analysis shows that the system was always able to distinguish between the "concentrate" versus "relax" tasks, regardless of the objective, and that it was also able to better distinguish between the two tasks when the user was asked to become visible rather than invisible.

At the end of the experiment participants could write down comments about their user experience regarding the BCI and the keyboard. Participants were also asked what strategy they have used to reach the concentrated and relaxed mental states. Eight participants indicated that they have "used a mathematical computation" task during the concentration phases. Two participants have used other tasks such as "trying to be afraid of the ghost" or "reciting passages from a book". As for the relaxation phases, some participants have indicated "thinking about nothing", "breathing slowly", or "imagining being in another place". Participants have tried other tasks than the suggested one, with various success. It could be interesting to let the participants try these tasks during a post-calibration phase, so that they can select the one that is the most efficient for them.

While our study provided valuable results, it also showed some limitations. First of all, the rich content of the VE seemed to have an impact on the BCI performance because of its distractive nature. Performing the calibration while the user can see this VE could help improving the BCI performance. Our setup also had a limited mobility since participants had to wear a BCI cap connected to a computer using wires. Using a wireless cap could allow users to move more during the experiment.

CONCLUSION

In this paper we introduced the "B-C-Invisibility Power", combining Augmented Reality and Brain-Computer Interfaces to create an optical camouflage system controlled with mental activity. Users are facing a computer screen and are able to view themselves as in a mirror. Their virtual reflection can become transparent or even completely invisible, depending on their level of concentration/relaxation as measured with the BCI. 3D objects can be integrated into the scene so to propose interactive scenarios and entertaining applications such as an "invisibility cloak" application inspired by the Harry Potter universe.

Results from a pilot study comparing BCI/keyboard to control an optical camouflage suggested that while the BCI was more challenging to control than the keyboard, participants have found the BCI to be more innovative. Compared to the keyboard, the BCI has provided participants with a stronger feeling of having a super-power. These results, therefore, indicate that the BCI can be fruitfully used as an alternative to a keyboard for controlling an "Invisibility Power".

Future work could concern further user studies and multi-user scenarios involving multiple BCI and camouflages. Our setup could be used for rehabilitation or entertainment applications.

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