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Improving the performance of GIS/spatial analysts though novel applications of the Emotiv EPOC EEG headset

Justin Carter

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IMPROVING THE PERFORMANCE OF GIS/SPATIAL ANALYSTS THROUGH
NOVEL APPLICATIONS OF THE EMOTIV EPOC EEG HEADSET

BY

Justin Carter

A REPORT

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

In Integrated Geospatial Technology

MICHIGAN TECHNOLOGICAL UNIVERSITY

2012

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This report has been approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE in Integrated Geospatial Technology.

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Abstract

Geospatial information systems are used to analyze spatial data to provide decision makers with relevant, up-to-date, information. The processing time required for this information is a critical component to response time. Despite advances in algorithms and processing power, we still have many “human-in-the-loop” factors. Given the limited number of geospatial professionals, analysts using their time effectively is very important. The automation and faster human-computer interactions of common tasks that will not disrupt their workflow or attention is something that is very desirable. The following research describes a novel approach to increase productivity with a wireless, wearable, electroencephalograph (EEG) headset within the geospatial workflow.

1. Introduction

During my undergraduate studies at Michigan Technological University as a Surveyor, I learned about Geospatial Information Systems (GIS), photogrammetry and remote sensing. Combined with a hobbyist understanding of computer science and learning of these fields, I have been greatly interested in pursuing a career in a field that combines these disciplines. My education had given me a great introduction to these fields but I knew I wanted more and I didn't know how to integrate these fields together for a career, or how interrelated they actually are! The natural choice was to obtain more education by pursuing an advanced degree in the new Integrated Geospatial Technology program at Michigan Technological University. The program offered exactly the education I was looking for in terms of coursework and research and allowed me to develop myself professionally and make contacts with those in industry.

In addition to taking advanced courses on GIS, photogrammetry and remote sensing, I was also able to take courses that assisted me in my research. This aided in the design, implementation, and integration of the Emotiv EPOC EEG headset into GIS and photogrammetric applications. This integration of technologies has given me a unique opportunity to be on the cutting edge of software development; Allowing me to develop my programming skills and a deeper understanding of computer science.

2. Papers

2.1 Cognitive Human-Computer Interactions Approach to Support Visual Analytics in Multi-Dimensional Environments

Carter, J.; Levin E.; “Cognitive Human-Computer Interactions Approach to Support Visual Analytics in Multi-Dimensional Environments” Unpublished paper presented at ASPRS 2012 Annual Conference, Sacramento, CA.

2.1.1 Introduction

Given the limited number of human GIS/image analysts at any environmental organization, the efficient use of their time is important. One of the most obvious resources to optimize image analyst’s workflow is to develop human-computer interactions method that will take less of their time to perform operations and will not interrupt their attention from primary tasks – image analysis. Usability of information systems is a subject of Human-computer interaction (HCI) – novel field in computer science which researches innovative interface devices and interaction techniques with computers and other technology. Gerson's research at Columbia University [Gerson et al. 2006] is the most interesting related to the stated problem research in human-computer symbiosis (HCS). They used an electroencephalography (EEG) system capable of detecting neural signatures for visual recognition to implement a “human visual processor” during visual searching. The system can detect the subconscious “aha” moments when the analyst finds a target, what allows accelerating image search drastically. Another potential technology that may revolutionize modern geospatial systems is eye-tracking, which is already popular in computer vision and augmented reality. Duchowski [2002, 2003] defines two eye-tracking interactions: (1) selection, where the gaze position is used to direct a cursor, and (2) gaze-contingent, where

the gaze is used to change the rendering of displays. Coltekin and Duchowski have applied displays with eyetracker interactions to geospatial imaging [Coltekin 2008, Coltekin 2009, Duchowski and Coltekin 2007], and Nikolov has implemented gaze-contingent multimodality displays for visual information fusion [Nikolov et al, 2003]. Eye tracking has also been used in 3D environments [Jones et al 2000]. Our previous research was resulted in eyegrammetry effort [Levin et al 2008a, Levin et al 2008b, Gienko and Levin 2005] which deploys eye-tracking technology as a tool for 3D photogrammetric measurements by replacing image correlation process with human-stereopsis registration. Current research belongs to the novel mainstream in spatial information sciences, defined as cognitive GIS [Montello 2009], which widely deploys human-factor [Klippel 2009] developments. This paper describes a research and cognitive architecture that will bridge state-of-the-art GIS environments with human perception analysis and cognitive action modules such as control of robotic geodetic instruments. Successful completion of this research will result in development of various Cognitive Geospatial Systems including: geodetic data acquisition systems and data collectors controlled by means of human operator decisions and smart-GIS deployed supporting environmental systems, emergency situations assessments, and response.

2.1.2 “Mind Controlled” HCI for Geospatial Applications

GIS analysts interact with GIS data by viewing, performing queries, making reports on graphical mapping and adding textual attribute to data. Typical work tasks of geospatial analysts include, but not limited to: retrieving information, image interpretation, detecting change, 3D surface reconstruction and updating geospatial metadata. A similar workflow is that of a land surveyor; one can detect analyzing actions of the surveyor in the field while he operates a data collector. In the case of field surveying, it comprises not only operations with graphical data, but also data streams from surveying instruments; such as a total station, level, GPS receiver, etc. Commands which geospatial analyst or surveyor perform

during this workflow can be categorized as: a) changing view – zoom in/out, panning; b) select elements to modify; c) editing selected elements; d) saving or sending results; e) operational commands for instrument. Typically it is done by calling respective menus, mouse clicks or stylus instrumental commands. There are a lot of research efforts in geospatial enterprise to optimize HCI and improve usability of this workflow. Specifically possible the most interesting solutions reviewed in HCI literature include: a) gesture and facial voice-command assisted interfaces [Quek 2006, Rausher et al 2002, McEarchen, 2005]; b) touch-screen and touch table control [TT]; c) enriched keyboards [Voluson]; d) on-screen menus similar to on the Ipad [URISA]. Current research represents an attempt to build HCI based on commands given by power of mind.

Emerging gaming technologies use commercially available EEG sensors such as the Emotiv EPOC [Emotiv]. The Emotiv EPOC measures neural impulses on the head at the skin's surface. This is accomplished by measuring the voltage of the impulses at 14 locations on the scalp in relation to a standard baseline provided by the manufacture's software. This baseline can be further enhanced and tailored to specific users through training sessions that improves the precision of the supplied baseline algorithm.



Figure 1. Emotiv EEG sensor

This is a typical measurement circuit for microvolt-scale biopotentials with very high

input impedance, a fixed reference electrode and a secondary driven reference electrode which causes the detection system to ride on top of common-mode signals, rejecting about 85dB of common mode input and allowing the amplifier reference level to follow the background body potential with high accuracy. The references are commonly referred to as CMS (Common Mode Sensor) and DRL (Driven Right Leg - a reference to the attachment of this sensor to the right leg of the patient in early electrocardiogram circuits for which it was originally developed). Emotiv EPOC input signals are AC coupled (0.16Hz high-pass) and passed to a buffer amplifier with extremely high input impedance and a passband of DC-87Hz. The signals are sampled internally using a 16-bit ADC at 2048 samples/sec per channel and then refiltered in the digital domain to remove 50Hz, 60Hz and to heavily attenuate signals above 64Hz. This removes any residual harmonics of the mains signal, and other high-frequency noise components (including some EMG and very high frequency EEG data). In combination with the 50Hz notch filter the effective bandwidth of the signal is now 0.16 - 43Hz. The signals is downsampled to 128 samples/sec/channel, packaged into data packets and transmitted wirelessly to the receiver. All of this filtering and processing removes all high frequency components which would otherwise appear as alias components in the 128Hz data stream. So to summarize, the remaining signal has an effective 14 bits of skin surface voltage signals, with the LSB resolution of about 0.5uV, with undistorted output from 0.16 to 43Hz, covering the delta, theta, alpha, beta and low gamma bands. This voltage trace can then be analyzed in the PC to extract these components. Example of Emotiv EPOC EEG recording in 14 zones mentioned above is given below.

Emotiv allows controlling gaming application by means of user emotions, head and hands movements (actual and mental). Emotiv is deployable standalone and also has the application program interface (API), which is based on .NET technology. Since Emotiv has two wirelessly connected headsets (see Fig. 2), it is possible for analysts to collaborate on image interpretation. For example, an experienced

analyst could move the image to the worktable of a junior analyst without eye-image interruption for either analyst.



Figure 2. Emotiv gaming EEG system

Specifically we are investigating and integrating the Emotiv EEG Expressive and Cognitive toolsets. The Expressive toolset enables detecting the following events:

- Blink: low level indicates a non-blink state, while a high level indicates a blink.
- Right Wink / Left Wink: these two detections share a common graph line. A center level indicates no wink, low level indicates a left wink and high level indicates a right wink.
- Look Right / Left: these two detections share a common graph line and a single sensitivity slider control. A center level indicates eyes looking straight ahead, while a low level indicates eyes looking left, and a high level indicates eyes looking right.
- Raise Brow: low level indicates no expression has been detected, high level

- indicates a maximum level of expression detected. The graph level will increase or decrease depending on the level of expression detected.
- Furrow Brow: low level indicates no expression has been detected, high level indicates a maximum level of expression detected. The graph level will increase or decrease depending on the level of expression detected.
 - Smile: low level indicates no expression has been detected, high level indicates a maximum level of expression detected. The graph level will increase or decrease depending on the level of expression detected.
 - Clench: low level indicates no expression has been detected, high level indicates a maximum level of expression detected. The graph level will increase or decrease depending on the level of expression detected.
 - Right Smirk / Left Smirk: these two detections share a common graph line. A center level indicates no smirk, low level indicates a left smirk and high level indicates a right smirk.
 - Laugh: low level indicates no expression has been detected, high level indicates a maximum level of expression detected.

Sample of Expressive toolset screen is given in Fig. 3

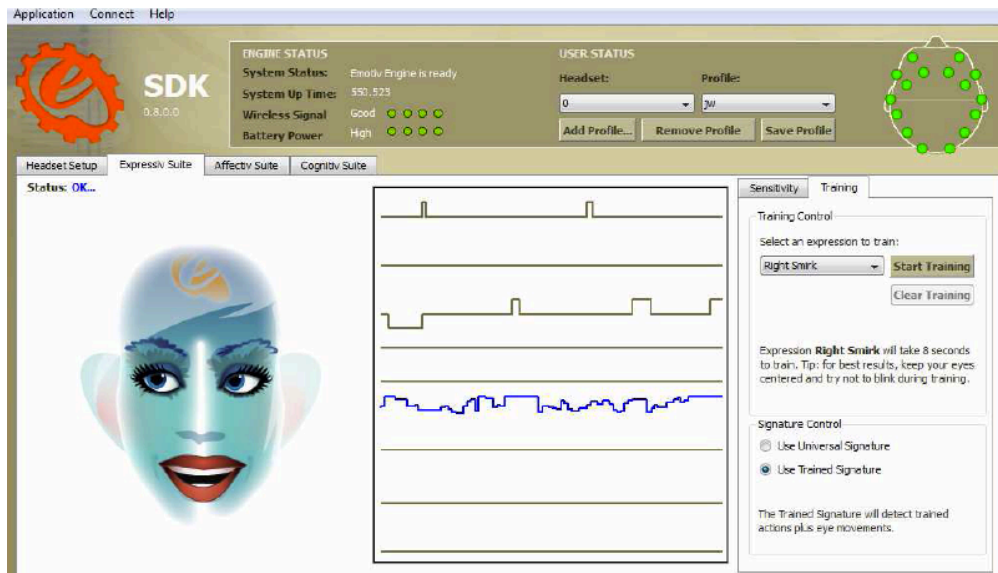


Figure 3. Facial emotion (smile) recognized by Emotiv Expressive toolset

The Cognitive detection toolset evaluates a user's real time brainwave activity to discern the user's conscious intent and perform physical actions on objects. The detection is designed to work with up to 13 different actions: 6 directional movements (push, pull, left, right, up and down) and 6 rotations (clockwise, counter-clockwise, left, right, forward and backward) and an additional action: disappear.

Use of Emotiv controlled processes can be efficient for processing 2D and 3D datasets. It may accelerate search and selection type of operations due to the fact that many manipulations are possible by "power of the brain" instead of mouse clicking. Combination of eye-tracker with EEG is also a viable research effort.

2.1.3 Experimental Results

Our first experiences with Emotiv EEG indicate that non-trained undergraduate students are able to work with Emotiv EPOC EEG in less than 15 minutes. The "pull" command was used to move selected image, and the "disappear" command can be used to cancel the operation without interrupting of visual attention. To detect visual attention FaceLab [SM] eye-tracking system was deployed. Fig. 4 outlines preliminary results of the experimental research

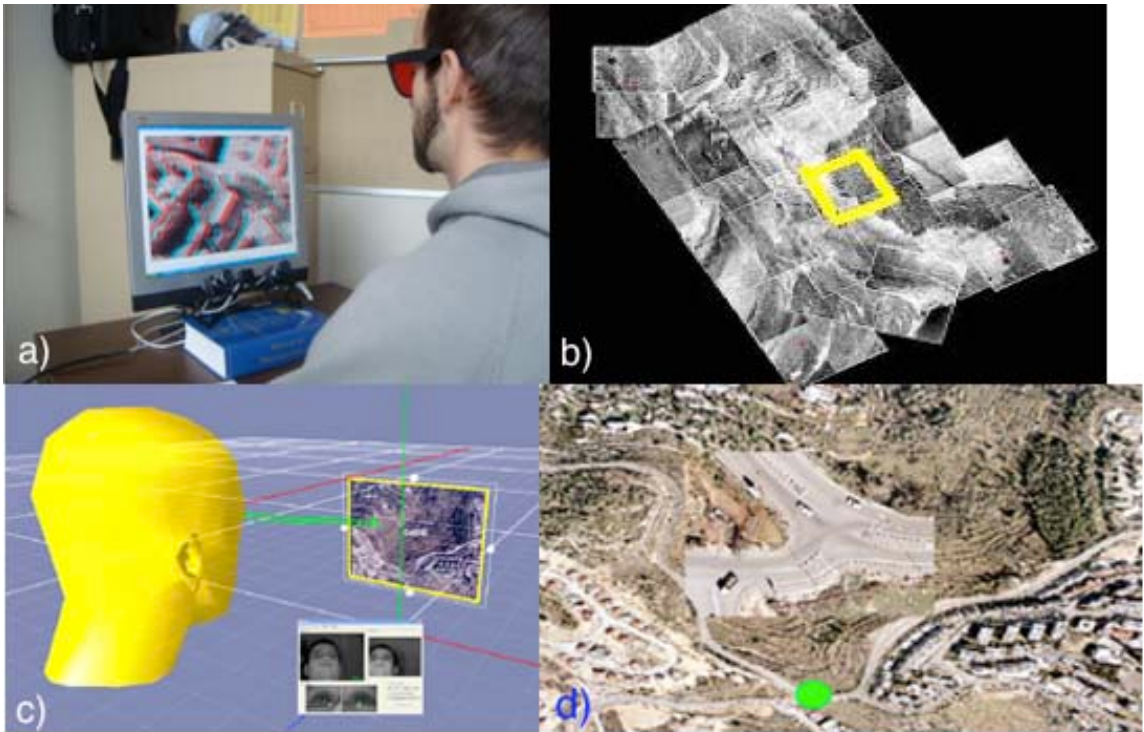


Figure 4. a) work with facelab eye-tracker b) selection of the image by facelab c) visual attention eye-tracking assisted overhead imagery broad area visual search(green circle is automatically detected in real-time gaze-point) d) sample result from when image zoom is applied to the area around gaze when EEG command performed(cognitive loupe working without break of eye-image contact).

Method developed in experiment described may also serve as a key module of the novel human-in-the-loop system in “smart” GIS that could adjust content of the visual information displayed on the screen depending on the frequency and duration of attention in particular zones, images, or groups of objects. A simulated example of the “smart” GIS controlled multi-sensor visualization of aerial and satellite geospatial imagery is depicted in Fig. 5.

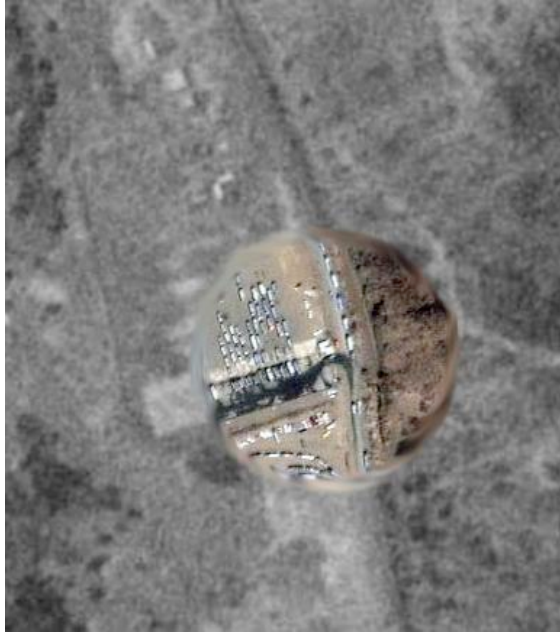


Figure 5. Simulated example of smart GIS visualization (aerial imagery fused with satellite at the area of user attention concentration by mind driven command)

Automatically managing appearance of visual geographic information, smart GIS will establish an instant intelligent interaction between the user and the system.

2.1.4 Cognitive HCI and OpenGIS

Geospatial researchers and developers worldwide are preparing to interoperate within cyber-infrastructures. In fact, such preparations can be exemplified by formation of the Open Geospatial Consortium [OGC], a public-private partnership dedicated to the development of consensus interoperability standards. For the preparation of smart-GIS integration/interoperability within web-GIS domain was developed C# application combining EEG with Google Earth system[GE]. Our efforts were concentrated on connection of pan and move functions of Google Earth with head movements sensed by the Emotiv gyroscope along with controlling Zoom-in and Zoom-out commands by “Pull” and “Push” Emotiv Cognitive suite. Man-machine interface of the developed application is shown on

Figure 6.

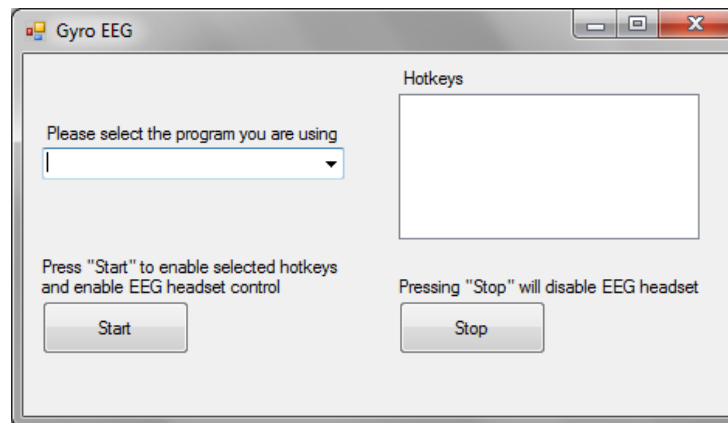


Figure 6. Preliminary design of the Man Machine interface of Cognitive control for Google Earth

The design of the main window is simple so this way any user should know what to do. All options have explanations of what each button and drop down box is used for. When starting the application, the user is first prompted to select the program that they wish to use the the Emotiv device with, e.g., Google Earth. When the user selects Google Earth from the drop down menu, associated cognitive and expressive functions, with respect to the Emotiv EEG, for a few of commonly used hotkeys will be shown in the “Hotkeys” text box. Pressing the “Start” button will enable the EEG device with respective hotkeys for the selected program and will enable control of the mouse cursor with the device’s gyroscope. Pressing the “Stop” button will disable the hotkeys and control of the mouse cursor.

2.1.5 Conclusion and Future Research

Geospatial science and technology may gain the following benefits of integrating described HCI approach:

- No distribution of analyst's visual attention;
- Increased analyst productivity by using combined EEG and eye-tracking interaction techniques; subconscious eye-brain processes are analyzed before upper levels of the brain can generate gestures or other commands (our previous research indicates it may save 15% of time [Levin et al 2008a]);
- Applicable for both single display and multi-display systems because method can be applied to either worktable displays or windows;
- Collaborative work because the Emotiv EEG allows to controlling two EEG devices;
- Ease of learning and use;
- Interoperability and compatibility with currently deployed by industry systems and software.

Design and development of the future HCI will be informed by Hierarchical Task Analysis (HTA), heuristic analysis and usability studies. Efficient task sequences will be delineated that modulate analyst's cognitive workload with automation. Tasks appropriate for human supervision will be matched with physical and cognitive interactions that compose a metaphor analogous to the interactions with analog photogrammetric and geodetic devices. Video recordings and post test interviews can qualitatively illuminate usability and training program. The conjugation of quantitative and qualitative usability measures will delineate usability problems that will be addressed by redesigning the apparatus or interaction scheme. In addition, the usability results will be used to document appropriate training.

Future research will be devoted to the evaluation of possibility of development transformation from C# to free open-source environments.

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[SM]http://www.seeingmachines.com/product/facelab/?_kk=facelab&_kt=34fb64c9-3200-47ff-9c6d-da095ddbe9a5&gclid=CJjX56DaoqkCFape7AodU0zCtg

[TT] www.touchtable.com

[URISA] http://urisa.org/files/publications/mobile_gis/mobile_gis.pdf

[Voluson] Voluson 730 Expert GE ultrasound system,
http://www.kpiultrasound.com/Cardiac-ultrasound-machines/Voluson730-Expert/flypage_images.tpl.html?pi_ad_id=9959529593&gclid=CPOr5d-3rKkCFWUbQgodX252LA

2.2 Human-Computer Symbiosis in Cyberspace Environments

Levin, E.; Carter, J.; Sergeyev, A. V.; “Human-Computer Symbiosis in Cyberspace Environments” SPIE Defense and Security Symposium 2012. April (2nd Quarter) 2012. (not-peer reviewed/referred). Invited Paper. Presented.

2.2.1 Introduction

The main goal of a cyberspace environment is to support decision makers with relevant information on time for operational use. One of the most challenging issues associated with efficient decision making support in cyberspace environments deployed for communication networks, transportation, finances, and standard utilities of a nation's critical infrastructure is associated with timely processing and analysis of remotely sensed geospatial data. This data includes terrestrial, aerial/UAV, satellite and other multi-sensor data obtained in electro-optical and other imaging domains. Despite advances in automated geospatial image processing, the “human in the loop” is still necessary because current applications depend upon complex algorithms and adequate classification rules that can only be provided by skilled geospatial professionals. One innovative and promising solution is associated with applying human-centric geospatial technologies as a way to utilize human-computer symbiosis for accelerated control of the vast amounts of geospatial data processing in cyberspace systems. The ultimate goal of cognitive geospatial science and technology research and development is establishing an interactive geospatial environment optimizing decision to support workflow, making it more efficient, and accelerating productivity by producing automatic reactions to an analyst’s attention, emotions, and minds. Thus signals extracted from humans become an element of a cyberspace system. This paper describes an innovative approach and research experiments on integrating wireless wearable electroencephalography (EEG)

device within geospatial technology workflow. Preliminary results indicate opportunities for the design of geospatial systems controlled by "power of the human mind."

2.2.2 Ubiquitous EEG to Integrate with Geospatial Cyber-Infrastructures

Human analysts interact with geospatial data by viewing, performing queries, making reports on graphical mapping and adding textual attribute to data. Typical work tasks of geospatial analysts include, but not limited to: retrieving information, image interpretation, detecting change, 3D surface reconstruction and updating geospatial metadata. A similar workflow is that of a land surveyor; one can detect analyzing actions of the surveyor in the field while he operates a data collector. In the case of field surveying, it comprises not only operations with graphical data, but also data streams from surveying instruments; such as a total station, level, GPS receiver, etc. Commands which geospatial analyst or surveyor perform during this workflow can be categorized as: a) changing view – zoom in/out, panning; b) selecting elements to modify; c) editing selected elements; d) saving or sending results; e) operational commands for an instrument. Typically it is done by calling respective menus, mouse clicks or stylus instrument commands. There are a lot of research efforts in geospatial enterprises to optimize these interactions and improve usability of this workflow. Specifically, the most intriguing solutions seen in Human-Computer Interactions (HCI) literature include: a) gesture and facial voice-command assisted interfaces [Quek 2006, Rausher et al 2002, McEarchen, 2005]; b) touch-screen and touch table control [TT]; c) enriched keyboards [Voluson]; d) on-screen menus similar to the iPad [URISA]. Current research represents an attempt to build HCI based on commands given by power of mind.

The Emotiv EPOC measures neural impulses on the head at the skin's surface.

This is accomplished by measuring the voltage of the impulses at 14 locations on the scalp in relation to a standard baseline provided by the manufacturer's software. This baseline can be further enhanced and tailored to specific users through training sessions that improves the precision of the supplied baseline algorithm.

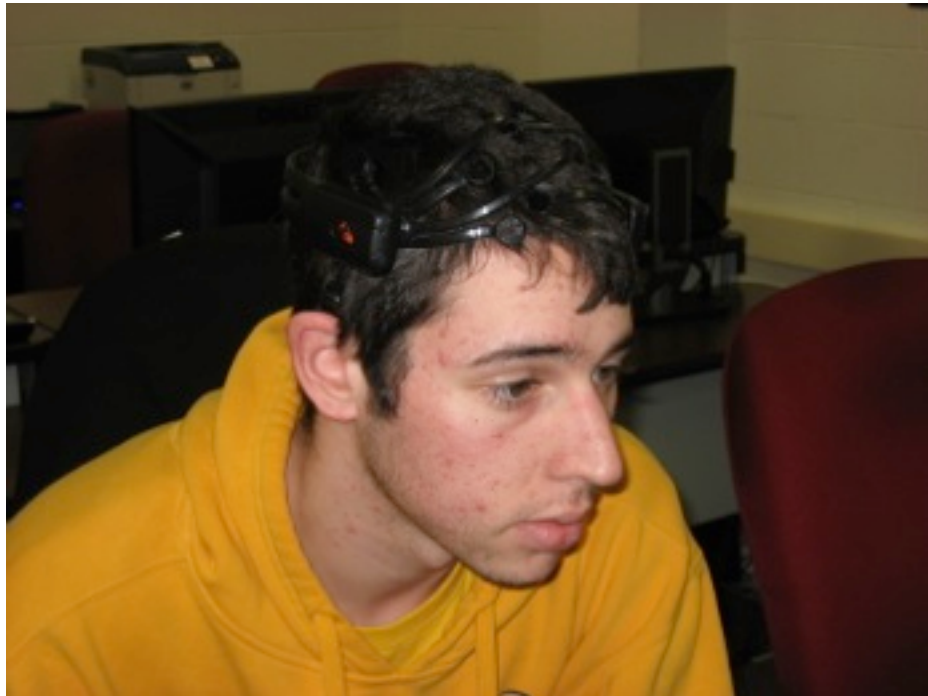


Figure 1. Emotiv EEG sensor (Depicts a newer model)

This is a typical measurement circuit for microvolt-scale biopotentials with very high input impedance, a fixed reference electrode and a secondary driven reference electrode which causes the detection system to ride on top of common-mode signals, rejecting about 85dB of common mode input and allowing the amplifier reference level to follow the background body potential with high accuracy. The references are commonly referred to as CMS (Common Mode Sensor) and DRL (Driven Right Leg - a reference to the attachment of this sensor to the right leg of the patient in early electrocardiogram circuits for which it was originally developed). Emotiv EPOC input signals are AC coupled (0.16Hz high-pass) and passed to a

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Emotiv allows controlling gaming application by means of user emotions, head and hand movements (actual and mental). Emotiv is deployable standalone and also has a Software Development Kit (SDK), which is based on the C++/C#/VB.NET programming languages, to assist with integration into other applications. Since Emotiv has two wirelessly connected headsets (see Fig. 2), it is possible for analysts to collaborate on image interpretation. For example, an experienced analyst could move the image to the worktable of a junior analyst without eye-image interruption for either analyst.



Figure 2. Emotiv gaming EEG system

Specifically we are investigating and integrating the Emotiv EEG Expressive and Cognitive toolsets. The Expressive toolset enables detecting the following events:

- Right Wink / Left Wink: these two detections share a common graph line. A center level indicates no wink, low level indicates a left wink and high level indicates a right wink.
- Look Right / Left: these two detections share a common graph line and a single sensitivity slider control. A center level indicates eyes looking straight ahead, while a low level indicates eyes looking left, and a high level indicates eyes looking right.
- Raise Brow: low level indicates no expression has been detected, high level indicates a maximum level of expression detected. The graph level will

increase or decrease depending on the level of expression detected.

- Furrow Brow: low level indicates no expression has been detected, high level indicates a maximum level of expression detected. The graph level will increase or decrease depending on the level of expression detected.
- Smile: low level indicates no expression has been detected, high level indicates a maximum level of expression detected. The graph level will increase or decrease depending on the level of expression detected.
- Clench: low level indicates no expression has been detected, high level indicates a maximum level of expression detected. The graph level will increase or decrease depending on the level of expression detected.
- Right Smirk / Left Smirk: these two detections share a common graph line. A center level indicates no smirk, low level indicates a left smirk and high level indicates a right smirk.
- Laugh: low level indicates no expression has been detected, high level indicates a maximum level of expression detected.



Figure 3. Facial emotion (smile) recognized by Emotiv Expressive toolset

The Cognitive detection toolset evaluates a user's real time brainwave activity to discern the user's conscious intent and perform physical actions on objects. The detection is designed to work with up to 13 different actions: 6 directional movements (push, pull, left, right, up and down) and 6 rotations (clockwise, counter-clockwise, left, right, forward and backward) and an additional action: disappear.

Use of Emotiv controlled processes can be efficient for processing 2D and 3D datasets. It may accelerate search and selection type of operations due to the fact that many manipulations are possible with the "power of the brain" instead of mouse clicking. Combining this technology with eye-tracking [Duchowski and Coltekin 2007] is also a viable research effort.

2.2.3 Experiments in Geospatial – EEG System Integration

In the discussed above concept we integrated an Emotiv EEG with Google Earth (GE) geospatial interface by means of the Emotiv SDK. Specifically it was implemented cognitive deployment of "zoom-in", "zoom-out", "move-left", "move-right", "move-up" and "move-down" commands. Experiments were culminated in development and testing of Windows-based C# software application. Man-machine interface and experiment deployment sample are depicted on Fig 4 bellow.

(clicking, zoom in/out, etc), this is located under the “Hotkeys” box on the right side of the window. Once the user is ready to begin using Google Earth, clicking the “Start” button will initialize the functions under “Hotkeys” and the user can begin to interact with the Google Earth using the Emotiv EPOC headset. The Gyro EEG application will also enable control of the mouse using the gyroscope built in to the headset. Moving the mouse across the screen is as simple as turning one’s head. Looking from side to side, up and down will cause the mouse pointer to move across the screen just the same as a mouse would. Clicking “Stop” with either the mouse or the headset will disable headset control of the mouse and the various “Hotkey” actions.

2.2.4 Analysis of Potential Cyber-Infrastructure Centered Application Scenarios

Geospatially driven man-machine interfaces will be massively deployed in forthcoming cyberinfrastructure environments. This is due to fact that linkage information to location is a natural way of many human-in-the-loop perceptual activities. Visualization and spatio-temporal thinking will be helpful in many defense and security application scenarios. Given that fact, EEG-Geospatial integrative approach was expanded into tactical 3D visualization system. Specifically it was performed experimentation on cognitive control of Skyline [SL] 3D visualization system within tactical situation application scenario.

During tactical cyberinfrastructure prototyping we implemented the same functionalities as were previously modeled in Google Earth. The significant difference we observed during tactical experiments compared to Google Earth was associated with a large amount of dynamic objects in tactical application scenarios. The Google Earth experiment was just a static environment. When given multiple moving ground (tanks, cars) and aerial (jets, UAVs) vehicles involved in a tactical case, the quick changing of the users focus becomes an issue. This complicated

situation required the user to divert more attention, concentration, and work to multiple tasking. Rapidly changing situations required faster reactions on the simulation events. Thus, eye-tracking integration would be useful and then analysis of user visual attention concentration area will make the proposed approach more stable and reliable.

2.2.5 Conclusion and Future Work

Geospatially integrated cyberinfrastructure will gain the following benefits of integrating described approach:

- No distribution of human (in the loop) visual attention;
- Increased analyst productivity by using combined EEG and eye-tracking interaction techniques; subconscious eye-brain processes are analyzed before upper levels of the brain can generate gestures or other commands (our previous research indicates it may save 15% of time [Levin et al 2008])
- Applicable for both single display and multi-display systems because method can be applied to either worktable displays or windows;
- Collaborative work because the Emotiv EEG allows to controlling two EEG devices;
- Ease of learning and use

Design and development of the future man-machine interactions methods will be informed by Hierarchical Task Analysis (HTA), heuristic analysis and usability studies. Efficient task sequences will be delineated that modulate analyst's cognitive workload with automation. Tasks appropriate for human supervision will be matched with physical and cognitive interactions that compose a metaphor analogous to the interactions with analog photogrammetric and geodetic devices.

Video recordings and post test interviews can qualitatively illuminate usability and training program. The conjugation of quantitative and qualitative usability measures will delineate usability problems that will be addressed by redesigning the apparatus or interaction scheme. In addition, the usability results will be used to document appropriate training.

Future research will be devoted to the evaluation of possibility of development transformation from C# to free open-source environments.

2.2.6 References

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3. Conclusions and Future Works

Reflecting upon the body of work presented by these papers it is easy to see that the research is moving in an interesting direction. Developing a new hardware interface is never an easy process, much less integrating it with current technologies to produce new ways of interacting with technology. There is a lot of usability testing needed to determine if the Emotiv EEG headset will be an efficient way to interact with computers in this way. At this time there are efforts to begin this testing and I have been working extensively with Dr. Chunming Gao to realize this by developing applications to test the accuracy of the mouse functions (i.e right click, left click, and translation of head movements of the integrated gyroscope to mouse pointer movements) of the Gyro EEG application. This analysis, however, will most likely be performed after my studies here and I am only minimally involved. The further development of the Gyro EEG application will also be handed off to other graduate students to improve upon and create their own derivations.

4. Appendices

Appendix A. Gyro EEG Code

Program.cs

```
/*
Author: Justin Carter

This part of the program generated by Visual Studio 2010
*/

using System;
using System.Collections.Generic;
using System.Linq;
using System.Windows.Forms;

namespace Gyro_EEG
{
    static class Program
    {
        /// <summary>
        /// The main entry point for the application.
        /// </summary>
        [STAThread]
        static void Main()
        {
            Application.EnableVisualStyles();
            Application.SetCompatibleTextRenderingDefault(false);
            Application.Run(new Form1());
        }
    }
}
```

Form1.Designer.cs

```
/*
```

```
Author: Justin Carter
```

```
This part of the program generated by Visual Studio 2010  
and modified by myself
```

```
*/
```

```
namespace Gyro_EEG
```

```
{
```

```
    partial class Form1
```

```
    {
```

```
        /// <summary>
```

```
        /// Required designer variable.
```

```
        /// </summary>
```

```
        private System.ComponentModel.IContainer components = null;
```

```
        /// <summary>
```

```
        /// Clean up any resources being used.
```

```
        /// </summary>
```

```
        /// <param name="disposing">true if managed resources should be  
disposed; otherwise, false.</param>
```

```
        protected override void Dispose(bool disposing)
```

```
        {
```

```
            if (disposing && (components != null))
```

```
            {
```

```
                components.Dispose();
```

```
            }
```

```
            base.Dispose(disposing);
```

```
        }
```

```
#region Windows Form Designer generated code
```

```
    /// <summary>
```

```
    /// Required method for Designer support - do not modify
```

```
    /// the contents of this method with the code editor.
```

```
    /// </summary>
```

```
    private void InitializeComponent()
```

```
    {
```

```
        this.appSelect = new System.Windows.Forms.ComboBox();
```

```
        this.startButton = new System.Windows.Forms.Button();
```

```
        this.stopButton = new System.Windows.Forms.Button();
```

```
        this.HotkeyBox = new System.Windows.Forms.TextBox();
```

```

this.BGEmoLoop = new System.ComponentModel.BackgroundWorker();
this.label1 = new System.Windows.Forms.Label();
this.label2 = new System.Windows.Forms.Label();
this.SuspendLayout();
//
// appSelect
//
this.appSelect.FormattingEnabled = true;
this.appSelect.Items.AddRange(new object[] {
"Google Earth",
"PhotoMod"});
this.appSelect.Location = new System.Drawing.Point(12, 22);
this.appSelect.Name = "appSelect";
this.appSelect.Size = new System.Drawing.Size(176, 21);
this.appSelect.TabIndex = 0;
this.appSelect.SelectedIndexChanged += new
System.EventHandler(this.appSelect_SelectedIndexChanged_1);
//
// startButton
//
this.startButton.Location = new System.Drawing.Point(14, 65);
this.startButton.Name = "startButton";
this.startButton.Size = new System.Drawing.Size(75, 23);
this.startButton.TabIndex = 1;
this.startButton.Text = "Start";
this.startButton.UseVisualStyleBackColor = true;
this.startButton.Click += new
System.EventHandler(this.startButton_Click);
//
// stopButton
//
this.stopButton.Enabled = false;
this.stopButton.Location = new System.Drawing.Point(95, 65);
this.stopButton.Name = "stopButton";
this.stopButton.Size = new System.Drawing.Size(73, 23);
this.stopButton.TabIndex = 2;
this.stopButton.Text = "Stop";
this.stopButton.UseVisualStyleBackColor = true;
this.stopButton.Click += new
System.EventHandler(this.stopButton_Click);
//
// HotkeyBox
//
this.HotkeyBox.Location = new System.Drawing.Point(194, 22);

```

```

this.HotkeyBox.Multiline = true;
this.HotkeyBox.Name = "HotkeyBox";
this.HotkeyBox.ReadOnly = true;
this.HotkeyBox.Size = new System.Drawing.Size(181, 127);
this.HotkeyBox.TabIndex = 3;
this.HotkeyBox.TextChanged += new
System.EventHandler(this.HotkeyBox_TextChanged);
//
// label1
//
this.label1.AutoSize = true;
this.label1.Location = new System.Drawing.Point(12, 6);
this.label1.Name = "label1";
this.label1.Size = new System.Drawing.Size(59, 13);
this.label1.TabIndex = 4;
this.label1.Text = "Application";
//
// label2
//
this.label2.AutoSize = true;
this.label2.Location = new System.Drawing.Point(194, 5);
this.label2.Name = "label2";
this.label2.Size = new System.Drawing.Size(46, 13);
this.label2.TabIndex = 5;
this.label2.Text = "Hotkeys";
//
// Form1
//
this.AutoScaleDimensions = new System.Drawing.SizeF(6F, 13F);
this.AutoScaleMode = System.Windows.Forms.AutoScaleMode.Font;
this.ClientSize = new System.Drawing.Size(381, 152);
this.Controls.Add(this.label2);
this.Controls.Add(this.label1);
this.Controls.Add(this.HotkeyBox);
this.Controls.Add(this.stopButton);
this.Controls.Add(this.startButton);
this.Controls.Add(this.appSelect);
this.Name = "Form1";
this.Text = "Gyro EEG";
this.TopMost = true;
this.Load += new System.EventHandler(this.Form1_Load);
this.ResumeLayout(false);
this.PerformLayout();

```

```
}  
  
#endregion  
  
private System.Windows.Forms.ComboBox appSelect;  
private System.Windows.Forms.Button startButton;  
private System.Windows.Forms.Button stopButton;  
private System.Windows.Forms.TextBox HotkeyBox;  
private System.ComponentModel.BackgroundWorker BGemoLoop;  
private System.Windows.Forms.Label label1;  
private System.Windows.Forms.Label label2;  
  
public System.EventHandler label1_Click { get; set; }  
}  
}
```

Form1.cs

```
/*
```

```
Author: Justin Carter
```

```
This part of the program written by me with sections of code  
derived from Emotiv SDK example applications.
```

```
*/
```

```
using System;  
using System.Collections.Generic;  
using System.ComponentModel;  
using System.Data;  
using System.Drawing;  
using System.Linq;  
using System.Text;  
using System.Windows.Forms;  
using System.Diagnostics;  
using System.Threading;  
using Emotiv;  
using MouseKeyboardLibrary;  
  
namespace Gyro_EEG  
{  
    public partial class Form1 : Form  
    {  
        // Access to the EDK is via the EmoEngine  
        EmoEngine engine;  
  
        // userID is used to uniquely identify a user's headset  
        int userID = -1;  
  
        // Booleans for right/left clicks  
        Boolean LeftWink = false;  
        Boolean RightWink = false;  
        Boolean LeftWinkUsed = true;  
        Boolean RightWinkUsed = true;  
  
        // Event Handler for keyboard commands  
        EmoEngine.EmoStateUpdatedEventHandler KeyEvent;  
  
        // Used to find the user application selection  
        int SelectedIndex;
```



```

public Form1()
{
    // Create EmoEngine
    engine = EmoEngine.Instance;
    engine.UserAdded += new
EmoEngine.UserAddedEventHandler(engine_UserAdded_Event);

    // Create windows form
    InitializeComponent();

    // Allows cancelation of backgroundWorker BGEmoLoop
    BGEmoLoop.WorkerSupportsCancellation = true;

    // Event Handler for Background Worker
    BGEmoLoop.DoWork += new
DoWorkEventHandler(BGEmoLoop_DoWork);

    // Sets initialization text for Hoy Key Infor Box
    HotkeyBox.Clear();
    HotkeyBox.AppendText("Please Select Application");
}

#region Functions

private void ReadEmo_GE(object sender, EmoStateUpdatedEventArgs e)
{
    // Access to user's Emo State
    EmoState state= e.emoState;

    // Gets state of left/right eye wink for clicking
    LeftWink = state.ExpressivIsLeftWink();
    RightWink = state.ExpressivIsRightWink();

    // Gets Eyebrow Raised/Furrowed
    string LowAction = state.ExpressivGetLowerFaceAction().ToString();

    // Left Click Logic
    if (LeftWink = true)
    {
        MouseSimulator.MouseDown(MouseButton.Left);
    }
    else
    {
        // Do nothing
    }
}

```

```

}

// Left Click Logic
if (RightWink = true)
{
    MouseSimulator.MouseDown(MouseButton.Right);
}
else
{
    // Do nothing
}

if (SelectedIndex == 0)
{

    // Logic for Zoom In, Eyebrows Furrowed
    if (LowAction == "EXP_SMILE")
    {
        KeyboardSimulator.KeyDown(Keys.Oemplus);
        Thread.Sleep(500);
        KeyboardSimulator.KeyUp(Keys.Oemplus);
        LowAction = null;
    }

    // Logic for Zoom Out, Eyebrows Raised
    else if (LowAction == "EXP_CLENCH")
    {
        KeyboardSimulator.KeyDown(Keys.OemMinus);
        Thread.Sleep(500);
        KeyboardSimulator.KeyUp(Keys.OemMinus);
        LowAction = null;
    }

    else
    {
        // Do Nothing
    }
}

if (SelectedIndex == 1)
{
    // Logic for Parallax Change, Positive
    if (LowAction == "EXP_SMILE")

```

```

    {
        MouseSimulator.MouseWheel(5);
        LowAction = null;
    }
    // Logic for Parallax Change, Negative
    else if (LowAction == "EXP_CLENCH")
    {
        MouseSimulator.MouseWheel(-5);
        LowAction = null;
    }
    else
    {
        // Do Nothing
    }
}

// Mouse movement by gyroscope
public void TransitionMouseTo(double x, double y, double elapsed)
{
    double seconds = elapsed;
    double frames = seconds * 1000000;

    PointF vector = new PointF();
    PointF mousePos = Cursor.Position;

    vector.X = (float)(x / frames);
    vector.Y = (float)(y / frames);

    if (Math.Abs(vector.X) < 4 && Math.Abs(vector.Y) < 4)
    {
        // Do nothing, vectors smaller than logic are noise
    }
    else
    {
        for (int i = 0; i < frames; i++)
        {
            MouseSimulator.X += (int)vector.X;
            MouseSimulator.Y -= (int)vector.Y;
            Thread.Sleep((int)((seconds / frames) * 100000.0));
        }
    }
}

```

```

    }

}

#endregion

#region Events

void engine_UserAdded_Event(object sender, EmoEngineEventArgs e)
{
    // record the user
    userID = (int)e.userId;

    // enable data acquisition for this user.
    engine.DataAcquisitionEnable((uint)userID, true);

    // ask for up to 1 second of buffered data
    engine.EE_DataSetBufferSizeInSec(1);
}

private void appSelect_SelectedIndexChanged_1(object sender, EventArgs
e)
{
    SelectedIndex = appSelect.SelectedIndex;
    Object SelectedItem = appSelect.SelectedItem;

    if (SelectedIndex == 0)
    {
        HotkeyBox.Clear();
        HotkeyBox.AppendText("Right Wink = Right Click\r\nLeft Wink = Left
Click\r\nSmile = Zoom In\r\nFrown = Zoom Out");
    }

    if (SelectedIndex == 1)
    {
        HotkeyBox.Clear();
        HotkeyBox.AppendText("Parallax Change\r\nSmile = Positive Change\r
\nFrown = Negative Change");
    }
}

```

```

    }

#endregion

#region Background Thread

private void startButton_Click(object sender, EventArgs e)
{
    if (BGEmoLoop.IsBusy != true)
    {
        KeyEvent = new
EmoEngine.EmoStateUpdatedEventHandler(ReadEmo_GE);
        engine.EmoStateUpdated += KeyEvent;

        BGEmoLoop.RunWorkerAsync();
        stopButton.Enabled = true;
        startButton.Enabled = false;
    }
}

private void stopButton_Click(object sender, EventArgs e)
{
    engine.EmoStateUpdated -= KeyEvent;
    BGEmoLoop.CancelAsync();
    stopButton.Enabled = false;
    startButton.Enabled = true;
}

private void BGEmoLoop_DoWork(object sender, DoWorkEventArgs e)
{
    // connect to EmoEngine
    //engine.RemoteConnect("127.0.0.1", 1726);
    engine.Connect();
    Stopwatch sw = new Stopwatch();
    int gyroX;
    int gyroY;

    engine.ProcessEvents();
    Thread.Sleep(1000);

    BackgroundWorker worker = sender as BackgroundWorker;
    while (true)

```

```

{
    if (worker.CancellationPending == true)
    {
        e.Cancel = true;
        break;
    }
    else
    {
        try
        {
            sw.Reset();
            sw.Start();
            engine.ProcessEvents(1000);
            sw.Stop();

            // Get gyro data and put in assigned variable
            engine.HeadsetGetGyroDelta(0, out gyroX, out gyroY);

            TransitionMouseTo(gyroX, gyroY, sw.Elapsed.TotalSeconds);
        }

        catch (EmoEngineException EmoE)
        {
            MessageBox.Show(EmoE.ToString());
        }

        catch (Exception EmoE)
        {
            MessageBox.Show(EmoE.ToString());
        }
    }
}

```

#endregion

#region Unused

```

private void HotkeyBox_TextChanged(object sender, EventArgs e)
{
}

```

```
private void Form1_Load(object sender, EventArgs e)
{
}
#endregion
}
}
```