COGNITIVE HUMAN-COMPUTER INTERACTIONS APPROACH TO SUPPORT VISUAL ANALYTICS IN MULTI-DIMENSIONAL ENVIRONMENTS

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ABSTRACT

The main goal of geospatial technologies in various multi-dimensional environments is to provide decision makers with relevant information at optimal time intervals. Some of the most challenging application scenarios, where visual analytics is important, are associated with efficient decision support during anthropogenic and natural environmental accidents, such as floods, hurricanes, earthquakes, oil spills, terrorist attacks, and others. The time required for processing information is critical in each scenario. 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 can only be provided by skilled geospatial professionals. Given the limited number of human GIS/image analysts at any organization deploying multi-dimensional environments, the rational and efficient use of their time is important. One of the most obvious ways 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. Specifically, potentially innovative and promising solutions for the problem can be 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. The ultimate goal of cognitive geospatial technology research and development is establishing an interactive geospatial environment optimizing decision support workflow, making it more efficient and accelerating productivity by producing automatic reactions to an analyst’s attention, emotions, and minds. This paper describes innovative approach and research experiments on integrating wireless wearable electroencephalography (EEG) device within geospatial technology workflow. Preliminary results indicate opportunities of design geospatial systems controlled by “power of the human mind”.

KEYWORDS: Cognitive GIS, EEG, HCI. Human-computer symbiosis

INTRODUCTION

Given the limited number of human GIS/image analysts at any environmental organization, the rational and 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.

**“MIND-CONTROLLED” HCI FOR GEOSPATIAL APPLICATION SCENARIOS**

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, http://ow.ly/i/bqZh/original]; 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 manufacturer’s software. This baseline can be further enhanced and tailored to specific users though training sessions that improves the precision of the supplied baseline algorithm.

![Figure 1. Emotiv EEG sensor.](image)

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](image)

**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.

**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.

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

Geospatial researchers and developers worldwide are preparing to interoperate within cyberinfrastructures. In fact, such preparations can be exampled 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 5. Simulated example of smart GIS visualization (aerial imagery fused with satellite at the area of user attention concentration by mind driven command).

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 Emotive 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.

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.

REFERENCES


[TT] www.touchable.com

