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A flexible infrastructure for delivering Augmented Reality enabled Transcranial Magnetic Stimulation

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Abstract. Transcranial Magnetic Stimulation (TMS) is the process in which electrical activity in the brain is influenced by a pulsed magnetic field. Common practice is to align an electromagnetic coil with points of interest identified on the surface of the brain, from an MRI scan of the subject. The coil can be tracked using optical sensors, enabling the targeting information to be calculated and displayed on a local workstation. In this paper we explore the hypothesis that using an Augmented Reality (AR) interface for TMS will improve the efficiency of carrying out the procedure. We also aim to provide a flexible infrastructure that if required, can seamlessly deploy processing power from a remote high performance computing resource.

Keywords. Augmented Reality (AR), Transcranial Magnetic Stimulation (TMS), Tracking, Visualization, High performance computing,

1. Introduction

Augmented Reality (AR) applications superimpose computer-generated artifacts onto an existing view of the real world. These artifacts must be correctly orientated with the viewing direction of the user who typically wears a suitable Head Mounted Display (HMD). AR is a technology growing in popularity in medicine, manufacturing, architectural visualization, remote human collaboration, and the military [1,2].

The use of AR in medicine has great potential and many clinical areas are currently being addressed [3], particularly for image guided surgery and similar applications. However, no previous work has been published on applying AR to Transcranial Magnetic Stimulation (TMS), a procedure in which electrical activity in the brain is influenced by a pulsed magnetic field [4]. TMS is extremely important for researchers as it allows them to accurately stimulate different points of the cortex and by recording the responses it is possible to validate the function of different areas of the brain. TMS has also been found to be useful in therapy and has had positive results when attempting to treat severe depression, auditory hallucinations and tinnitus as well as other drug resistant mental illnesses such as epilepsy. Common practice during the TMS procedure is to place an electromagnetic coil on the subject's head so that it is aligned with a region of interest

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on the cortex of their brain. The coil and subject's head can be tracked using optical sensors, and targeting information is calculated and displayed on a local workstation. This procedure allows analysis of the visual induced perceptions related to the cortical site stimulated. The Brainsight, frameless image-guided, TMS system (Magstim, UK) used during this project, incorporates a Polaris optical tracking system for tracking.

In this paper we explore the hypothesis that using an AR interface for TMS will improve the efficiency of carrying out the procedure. A complete implementation of this application requires more computational resource than is currently available on a local workstation. We therefore also aim to provide a flexible infrastructure that if required, can seamlessly deploy processing power from a remote high performance computing resource.

2. Implementation

We have written our own software for interfacing with the Brainsight tracking system that allows us to find the quaternion and translation position of each of the tools (coil or patient marker). We then use a custom written OpenGL application to render the subject's brain according to the operator's viewpoint, allowing for a calibration of the markers being tracked and movement of the patient. In order to accurately render the subject's brain from the view point of the operator, we need to know the orientation of both the subject's head and the view point of the operator. The Polaris Optical tracking system is supplied with several tools, which include a head position tracker and a probe that is used for the accurate pinpointing of positions in the trackers view. We use the head position marker to represent the subject and the probe to identify the position of the operators viewpoint through the HMD - see figure 1.

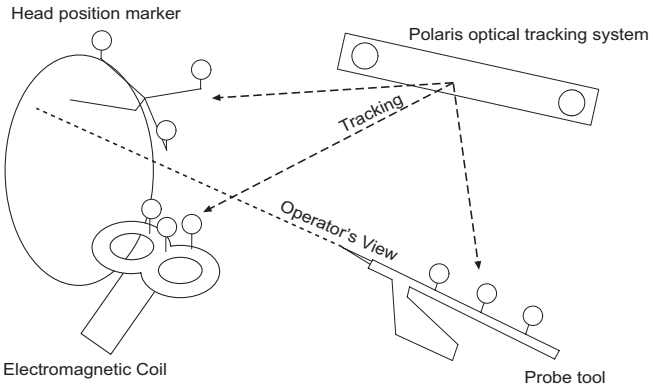

Figure 1. The tools being tracked

The operator's HMD utilizes a USB webcam to capture a video stream from their viewpoint. This video stream is then combined with the graphics rendered with our software to produce the final image that the operator will see during the procedure.

2.1. Polaris Interface

Communication between the operator's laptop and the Tracking System is achieved by sending ASCII text messages from the serial port of the laptop using the RS232 standard as shown in figure 2. All communications are initiated by the laptop which sends a message and will in response receive a reply either containing the requested information or a flag indicating whether or not the last command was successful. A 16-bit Cyclic Redundancy Check (CRC) is used to validate the integrity of each command using the polynomial $x^{16} + x^{15} + x^2 + 1$ [5].

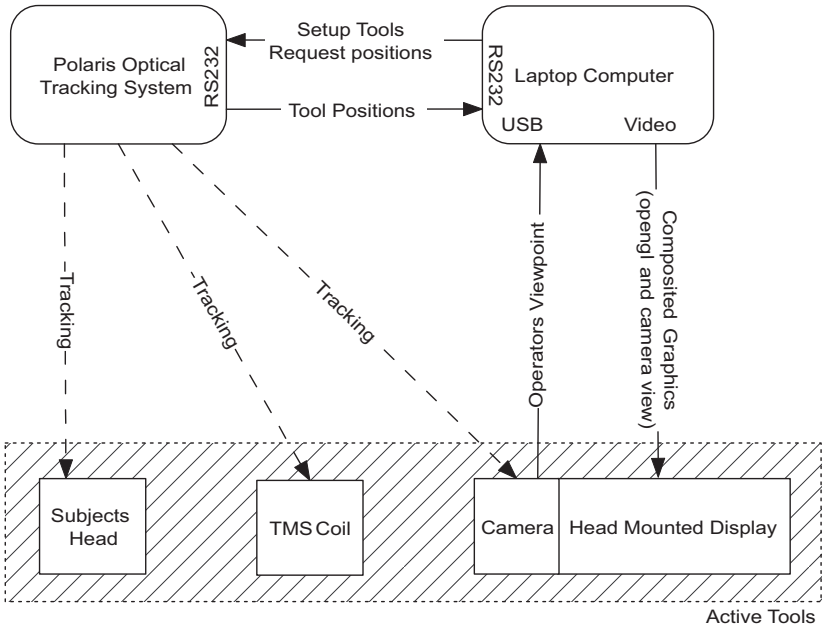

Figure 2. System Diagram showing the flow of data and the tools which are being tracked.

The description of the marker configuration for each tool is specified in a ROM file, which is provided by the manufacturer, and each tool is "plugged" into the tracker by passing the contents of these ROM files in messages. It is then possible to simply query the tracker as to the position of each tool, which it returns as a quaternion and translation pair.

2.2. Drawing the graphics

In order to correctly align the subject's brain the position of each tool is requested from the tracker and returned in quaternion and transformation form. $Q0, Qx, Qy, Qz$ represent the quaternion rotation of the tool and Tx, Ty, Tz represent the translational components of the transformation. To enable the rotation to be used in our OpenGL application, the quaternion representation is converted into a rotation matrix [6]:

$$RotationMatrix = \begin{bmatrix} a\ b\ c \\ d\ e\ f \\ g\ h\ i \end{bmatrix}$$

$$\begin{aligned}
a &= (Q0 \times Q0) + (Qx \times Qx) - (Qy \times Qy) - (Qz \times Qz) \\
b &= 2 \times ((Qx \times Qy) - (Q0 \times Qz)) \\
c &= 2 \times ((Qx \times Qz) + (Q0 \times Qy)) \\
d &= 2 \times ((Qx \times Qy) + (Q0 \times Qz)) \\
e &= (Q0 \times Q0) - (Qx \times Qx) + (Qy \times Qy) - (Qz \times Qz) \\
f &= 2 \times ((Qy \times Qz) - (Q0 \times Qx)) \\
g &= 2 \times ((Qx \times Qz) - (Q0 \times Qy)) \\
h &= 2 \times ((Qy \times Qz) + (Q0 \times Qx)) \\
i &= (Q0 \times Q0) - (Qx \times Qx) - (Qy \times Qy) + (Qz \times Qz)
\end{aligned}$$

Using OpenGL we can then simply transform to the position of the subject's head and draw the brain, then transform to the operator's viewpoint using an offset established during calibration to produce the final viewpoint. This view is then composited onto the video stream from the camera and presented back to the operator via the HMD.

3. Utilizing High Performance Computing Resources

The prototype developed is indicating that our initial hypothesis is correct. Although a full validation study is outside the scope of this project, favourable comments about the ease of use of the AR interface have been obtained from the Brainsight operator's in the School of Psychology. As shown in figure 3 the alignment is accurate, and the AR interface for positioning the coil is more natural than having to look between the subject and the results displayed on the workstation monitor (even if the workstation display is also projected onto the wall). However there are some limitations as to how well the software can perform. The laptop computer only has basic graphics capabilities and as such can only render the graphics at a low screen resolution, whilst maintaining real time performance.

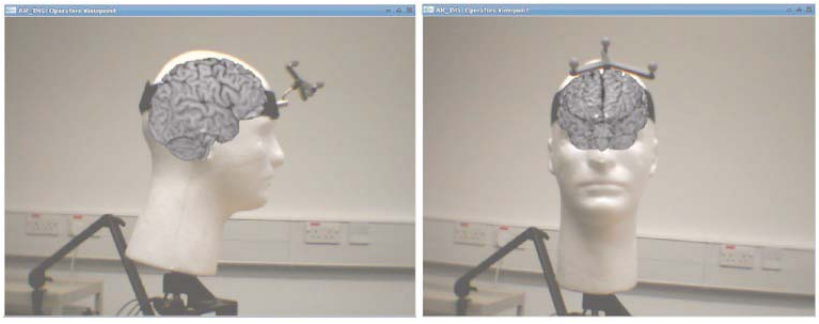

Figure 3. The operator's view showing accurate alignment of the real world and the computer graphics

One solution to this is to utilize high performance graphics resources on a remote server either across a local network or using the computational Grid [7]. This raises

many issues such as providing redundancy in mission critical situations, avoiding latency problems, and maintaining real time performance. It is essential that the rendering is produced in real time to ensure that the illusion of AR is not lost and also inaccurate alignment can occur should the operator be working with graphics that are a few seconds late.

The e-Viz project [9] is currently under development and aims to provide a generic flexible infrastructure for remote visualization using the Grid [8]. e-Viz intends to address many of the issues using a combination of intelligent scheduling for new rendering pipelines and the monitoring and optimisation of running pipelines, all based on information held in a knowledge base. Our application has been developed specifically to allow easy integration with the e-Viz framework by implementing our software as an e-Viz client, as shown in figure 4. This means that once we receive the orientation of each tool we can render the desired representation of the subject's brain using any appropriate high performance visualization resources rather than drawing it locally using the often limited graphics resources available on the workstation. The operator, however, is unaware that the system is utilising remote resources.

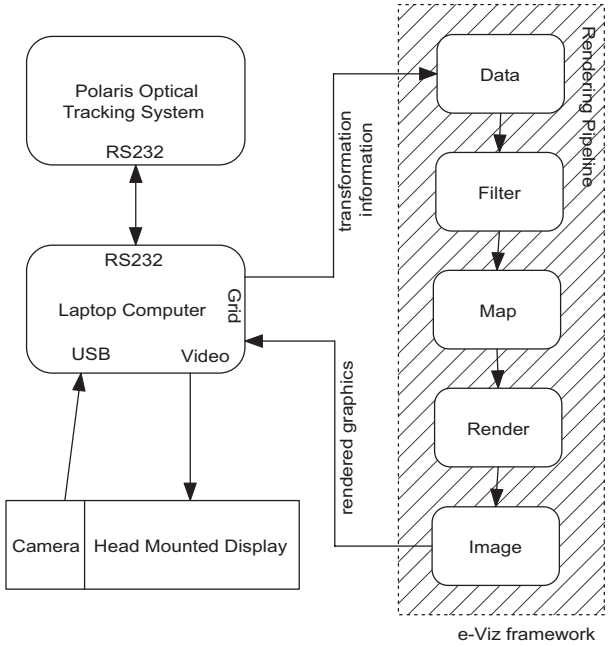

Figure 4. System Diagram extended to use e-Viz.

4. Discussion and Conclusions

We are working to improve the accuracy and quality of the computer generated results, whilst maintaining real time performance. We also need to extend the functionality of the system, for example, to allow the operator to look inside the brain during the targeting process. This involves using volume rendering as well as surface rendering, and using

clip planes within the AR environment. A future aim is also to provide a version of the TMS procedure that is not reliant on optical tracking equipment. There has recently been new research into performing tracking by extracting feature points from the camera view generated using simple edge and corner detection ideas [10]. Over a series of frames these feature points can then be used to estimate the pose of an object in view and with basic calibration this can provide an effective tracking mechanism for our AR application. This novel method of tracking has to be integrated directly into the e-Viz framework as a user defined control, and would use the data gathered from the camera directly to steer the viewpoint rendering of the brain rather than just a set of transformations.

All of the above improvements to the system will mean that the processing requirement is too large for the local workstation alone to be able to achieve. Our solution is therefore to integrate our system with the e-Viz framework and so enable access to remote high performance computing resources.

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