DESIGN AND DEVELOPMENT OF AUTOMATED SYSTEM FOR LOCALISED ELF MAGNETIC FIELD STIMULATION OF THE HUMAN BRAIN

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Abstract: The automated system was designed and developed for accurate and fast localisation of extremely low frequency (ELF) electromagnetic field (EMF) exposure to any particular brain region and therefore record for any changes in the EEG activity before and after stimulation. The automated system consisted of a general user interface (GUI) where the users had the ability to precisely control and move an EMF source (coil) via robotic arm to any EEG electrode position or region. The 3-D movements of the robotic arm were controlled via a serial linked motor driver board that controlled two motors. The software was able to initially store the estimated 3-D EEG electrode positions and therefore identify the areas where ELF EMF exposure from the coil could be applied. The testing and final measurements of this system revealed the robotic arm precision of 0.1mm and maximum speed of 0.211 cm/sec (x-axis) and 0.827 cm/sec (y-axis).

1 INTRODUCTION

A particular system needed to be designed with the purpose to modernise bioelectromagnetic apparatus and aid researchers in unravelling many of the unknown changes in EEG activity due to ELF/RF EMF exposures. Accurate and fast automated system needed to be designed and developed to provide an Extremely Low Frequency (ELF) Electromagnetic Field (EMF) exposure at any specific 3-D positions or region around the human head. Once the EMF source (coil) could be positioned and exposure applied to subject's head, the resultant electrical brain activity (EEG) could be recorded. The EEG recording and ELF EMF exposure were not to be applied simultaneously due to EMF interference and induction of electrical fields within the EEG leads and electrodes, resulting in inaccurate recorded EEG signals.

1.1 Background

It has been known that the brain cells send electrical signals along the fibres that make up their communication networks. Considering that changing (sinusoidal) magnetic fields can induce current in electrical conductors, researchers thought that a magnetic pulse might stimulate currents in the brain and therefore alter the brain's electrical activity (EEG) (Nature, 2002). Researchers have used a Transcranial Magnetic Stimulation (TMS) technique in the past and have reported that depending on the intensity, frequency and localisation of the magnetic field applied to brain, the simple cognitive tasks could be explained (Walsh V., 1999)(Ueno S., 1999).

One study investigated whether an alternating 3Hz magnetic field of 0.1mT applied to the head over a period of 20 minutes caused any changes in EEG parameters. This study was able to justify that alternating weak magnetic fields do affect the specific EEG activity (Hausser K, 1997). It has also been reported that magnetic field stimulation localised in the region of the "Hess" area of cat's brain can cause an impulse and a proliferation of reactions from neural cells, which as a result triggers the sleep centre and causes it to resonate in

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synchronisation (Hu Y., 1998). A simulated brain wave pattern of slow wave sleep was coupled from the coil to cat's brain, in order to induce the encephalic electrical activity to synchronise gradually with the external low-frequency magnetic fields and thus induce sleep in the cat.

An interesting study, led by Cook and Persinger, conducted an investigation to find any interaction with and to control the EM correlates of consciousness generated by the brain through applied complex magnetic fields whose characteristics simulated natural, transcerebral EMFs (Cook C. 1999). They designed a device to produce rotational, circumcerebral transient magnetic fields between 5 and 10μT, using 8 solenoids, which were arranged circumcerebrally (every 45°) at the level of the temporal-orbital plane. There were two conditions utilised for this experiment: clockwise or counter-clockwise arrangement of the 8 solenoids. For the clockwise condition, solenoid 1 was placed over the right prefrontal region such that solenoids 1-4 were equally spaced (45°) over the right hemisphere and solenoids 5-8 were equally spaced over the left hemisphere, along the orbito-temporal plane. For the counter-clockwise condition, solenoid 1 was placed over the left prefrontal region such that solenoids 1-4 were placed over the left hemisphere and solenoids 5-8 were placed over the right hemisphere. The counter-clockwise arrangement generated a field sequence that moved in a rostral to caudal direction along the left hemisphere but in a caudal to rostral direction along the right hemisphere. The frequency characteristics employed burst-firing and frequency modulated "Thomas pattern" (Thomas A.W, 1997).

They concluded that during the counter-clockwise rotations, the conscious awareness, as inferred by perception of time intervals, involved a process that may be recreated approximately every 20-25ms and may be affected by the right hemispheric activity.

The design of the rotational eight solenoid system with pulsed magnetic fields has led to undertake design and develop an automated system that would localise a single solenoid to any head region (EEG electrode position) and apply a sinusoidal magnetic field to it in order to investigate any changes in EEG activity.

2 DESIGN PROCESS

In the project, there has been several functional system attributes mentioned that the system should and may include:

- Self calibration and alignment properties.
- Scan the X and Y coordinates of the robotic arm and record these points as origin reference.
- Ability to keep a record of all coordinates and 10-20 International EEG Electrode Placement Scheme points for each test subject.
- Capability to analyse the information in conjunction with measured EEG readings at specific testing intervals.
- Utilise Bluetooth module to send and receive data to and from PC's microcontroller board.

There have been many different processes used in order to complete the design and development of this system. The design processes have therefore been divided into three major parts: Mechanical, Software, and Hardware processes.

2.1 Mechanical Design Process

For the mechanical design process of the robotic arm, important structure design factors needed to be taken into account, such as precise component dimensions; minimisation of friction due to movable plate movements; light-weightiness; durability; and material of non-electromagnetic properties. In order to minimise any induced currents onto EMF exposure system, and maintain stable EMF level during the experiment, a non-electromagnetic material such as acrylic was selected.

2.2 Software Design Process

The Control Software design process was undertaken throughout 9 versions to test and improve acceptable software modules and reject unsatisfactory modules. There have been six software modules developed: Table, Move, Head, Web, Auto-calibrate, Settings and Communication Module.

At the initial stage of software design process, only Table, Move and Head modules were undertaken. The other modules were completed in the final design process stage. The main goal of the 'Table Module' (TM) was to display reference positions for sets of points located on the head that the arm must move to. The main function of this module was to save a current reference position of the arm to one set of points in the table and also to update the selected point in the 'Move Module' (MM) to provide quick access to saved points. The initial version of the TM only contained the data table. At this stage only the main modules had been created to visualise the software design. The second version of the TM has been linked with the other modules so that points could be saved in the table. There was little more development to the TM until version 6 where a large number of modules had been altered. As a result the TM inherited a button from a now obsolete module. This button allowed the TM to record the current arm reference for the selected point or to clear the selected point. The final version of the TM has not visually changed much since version 6. There has been a global option implemented to change the display of the reference points from Stepper motor positions to Degree positions, which changed the way the module displayed the saved points. There was also a function implemented to save the points to an output file, which can then be reloaded.

2D 'Head Module' (HM) has been provided as a visual reference to select a set of points. A point could be selected by clicking on any of the red dots displayed in the image, which will update the current selected point in the TM, as shown in Figure 1. The first version of the HM was simply a plain 2D head with marked X's in the estimated point positions. The final 3D HM has a three-dimensional view of the head from multiple angles, which could allow the user to focus on any required area of the head. 3D HM in version 6 was created from an AutoCAD program of a head geometry that had been scanned and measured to produce an accurate representation. From this program, multiple jpeg images were created of the head at different angles. The 3 buttons at the bottom controlled the rotation of the head and each labelled point was selectable.

'Move Module' (MM) was responsible for sending the control signals, which moved the arm. The final version of the MM provided 3 different methods for scrolling to a point. The first method was the fastest by a point and click on the head diagram. The next method was to move the slider bars on the left and the right of the head diagram. These were useful if only movement in one axis was required. The final method was the most accurate and was useful for fine-tuning the arm position. It was performed by pressing the arrow keys, the left and right arrow keys move along the 'Theta' axis and the up and down arrow keys move along the 'Phi' axis. The MM has been the most complex to design, since it was the module responsible for sending the control signals. The first version of the move module contained only basic commands. There was a select point option to select a previously referenced point and a move button to go to the selected point and some labels to indicate the current position of the arm while it's moving. Since the control signal framework has not been established at this point, it was difficult to determine the module requirements.

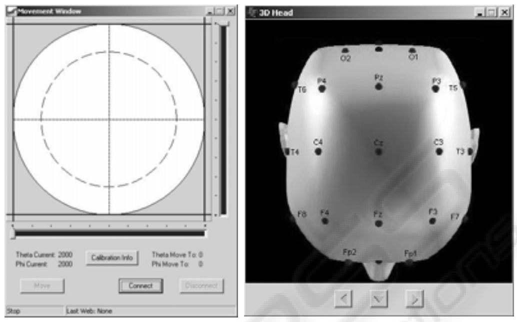

Figure 1: Move and Head Modules

By version 6 the control signal framework was ready to be defined and by the final version, the additional features such as Connect/Disconnect and the Movement Control options were introduced. The Connect/Disconnect was used to secure a COM port for communication to the PIC controller. The Movement Control buttons moved the arm for the initial calibration. Rather than use buttons to move on an axis, slider bars and the original head model from version 1 were used to visually select a point. In the final version a button has been added to show the maximum step readings sent by the PIC after a full calibration has been performed. This also allowed the software to request a full or a quick calibration, as shown in Figure 1.

2.3 Hardware Design Process

The scope of the system hardware was centred on a PIC18F6720 microcontroller, which was responsible for moving the robotic arm and communicating with the GUI. Firmware prototyping was done on a PIC18F8720 EVB. Microchip MPLAB 6.63 was used with the MC18C compiler for fast firmware development and advanced debugging with the use of the Microchip In Circuit Debugger (ICD 2) tool. The following firmware modules were prototyped on the EVB:

- RS232 communication structures / modules
- Interrupt driven Shaft encoder module.
- Stepper Motor control module.
- Most system algorithms, including the arm movement and RS232 packet constructor and de-constructor algorithms.

Schematic and PCB design was done in Portal DXP where many advanced features of the software package were used to minimize error in the final design. Due to the small track size and complexity of the final PCB artwork and advanced PCB etching process was used. Placement and soldering of the surface mount

3 FINAL DESIGN SYSTEM

The final design system was once again divided into three major parts: Mechanical, Software and Hardware Design.

3.1 Mechanical Design

From the 1st design to the final design, the robotic arm had undergone significant changes. Figure 2 below shows the final design of the robotic arm. It was made up of a main frame (an arc), which could rotate on its middle axis and a plate attached to it, to move along the arc. The most vital factor was the ability to rotate the robotic arm on its middle axis as well as moving the plate to its full extent.

Figure 2: Move and Head Modules

In the initial design, a normal 180° arc was designed to move the plate around. The U-shaped corners allowed the plate to move to its full extent, while the side of the U-shape corners could support the full weight of the robotic arm. To hold the EMF source (coil), a plate with a stepper motor attached to it was designed. The plate has a holder constructed of lightweight and strong aluminium, consisting of non-magnetic properties. The stepper motor was attached to a cog, which rotated and moved the whole plate up and down the mechanical structure. A laser pointer was also attached to the middle of the plate. Figure 3 shows the EMF coil positioned at top and side head positions.

Figure 3: EMF Coil Positioned at Top and Side Head Positions.

To enable the user to position the robotic arm directly on top of subject's head, a base was constructed to slide forwards and backwards and be locked to specific position. To limit the movement of the robotic arm to 180° on its X & Y-axis, micro-switches were attached to the sides. Once the arc or plate touched a switch, the software would register that point as the limit. This was particularly useful for auto-calibration and ensuring that the arm did not exceed its maximum movement.

3.2 Software Design

The Control Software was composed of 7 main modules. Each of these performed too many functions to mention them all, but the main functions they perform were: select a point; save a reference to that point; alter arm reference point (Position to move to); and move arm to reference point.

A functional block and directional arrows diagram is shown in Figure 4 above, indicating flow of data or an instruction.

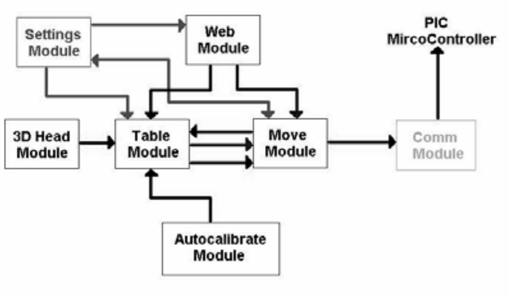

Figure 4: Software Functional Block Diagram

The TM held arm reference locations for the 19 electrode placement points. It also held the currently selected point and could be instructed to change the selected point via the user interface or the 3D HM.

When the selected point has been changed, it sent the arm reference locations to the MM for display. If an empty point has been selected and the button “Calibrate Point” was selected, the current reference position of the arm was saved to the selected point and updates the table. If by any chance a point was selected that already has a reference position saved to it, the button changes to “Reset Calibration” and if selected, it will delete the reference position for that point. The only function the 3D HM provided was to update the selected point on the TM.

The primary responsibility of the MM was to hold the selected arm reference position to be transmitted to the PIC Controller. The arm reference position could be altered by selecting a point with a saved reference position or by manipulation of the controls in the MM. Since the ‘Communication Module’ (CM) has no direct user interface, the MM has some extra buttons to provide that interface. The “Connect” and “Disconnect” captured a COM port for the software to use for communication to the PIC. When it was connected and the “Move” button was selected, the selected reference position of the arm was transmitted to the PIC. The axes used to reference the arm positions were common circular polar axes.

A small HTTP server has been integrated into the software. This allowed a wireless enabled PDA with a Web Browser to transmit move instructions, allowing the operator to precisely conduct control commands. Using ‘Auto-calibrate Module’ (AM) and by calibrating the points listed, the remaining reference positions could be estimated. This saves the operator time by only having to save 6 reference positions instead of the entire 19 points. The reference positions were calculated by an approximate estimate. The Settings Module served to fine tune settings of the other modules.

The Communication Module (CM) was responsible for interfacing between the MM and the serial communications port. The Windows API functions for the serial port were used to transmit and receive data. A communications class for Borland Builder C++ has been used as an interface for the Windows API. When the “Calibration Info” button on the MM was selected, it brought up a window containing the current calibration data. If “Yes” was selected then a full calibration request was sent from the CM and the calibration data was updated. If “No” was selected then a quick calibration request was sent from the CM and arm moved to a known position. If the “Move” button was selected on the MM, a move request was sent via the CM. The final testing the CM and parts of the MM, required knowledge of the serial output. This was accomplished by the creation of a PIC Emulator program, which has been set up to test all functions of the software program.

3.3 Hardware Design

The PCB was implemented with mostly surface mount components and connectors. The hardware’s PIC18F6720 microcontroller had an ability to move the arm to any position, determine the current position and direction of movement and communicate with the GUI. Figure 5 shows the functional block diagram of the hardware subsystem interconnections to the micro controller.

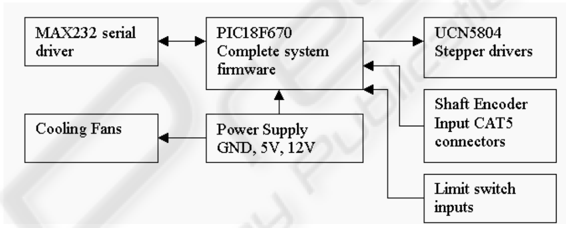

Figure 5: Hardware Interconnections

The PIC18F6720 controller provided the following functionality to:

- Handle both RX and TX communications with the GUI.
- Drive the system stepper motors, via the UCN5804 high power stepper motor drives.
- Determine current location from quadrate output shaft encoders.
- Sense a domain limit changes on the limit switch inputs.
- Move the arm to the required position as instructed by the GUI.

The UCN5804 high power stepper drivers were used to rotate the stepper motors at variables speeds in both forward and reverse directions. There were two UCN5804 drivers on the final design. These drivers controlled the X and Y movements. The PCB has prevision for a third driver to control automated Z-axis movement if required in the future. Due to the high power requirements of the stepper motors, an average of 0.5A was passed though each of the UCN5804’s, thus processor controlled cooling fans were positioned over the drivers to avoid heating beyond their specifications.

The PCB contained a MAX232 serial driver for signal conditioning and data transmission. The

MAX232 interfaced with the PIC18F6720 USART and serial crossover was done on the PCB to make the hardware more compatible with standard PC's. Communication to and from the PCB was done via packet transmission and reception (9600 bps, 8 data bits, parity none, stop bits 1 and no hardware flow). The packet structure was a fixed length with an identifier and data field. Bluetooth communications module was attached to the RS232 DB9 connector which then interfaced the USART module in the PIC18F8720, enabling wireless communications between the hardware and GUI.

4 PERFORMANCE & RESULTS

To test the hardware performance, a sequential test procedure was constructed in a proceeding order where the following test procedure required the previous test to be valid. Arrays of small firmware testing applications were written to exercises specific components of the subsystem under test. Once the automated system was finalised and fully operational, particular measurements were taken to determine the accuracy and speed of our system. It was observed that the system had an accuracy of 0.1mm for both X and Y-axis. The speed of the X-axis was 0.211 cm/sec and the speed of the Y-axis was 0.827 cm/sec, as shown in Table 1.

Table 1: The Accuracy and Speed of X and Y-Axis

	X-axis	Y-axis
Accuracy (mm)	0.1	0.1
Speed (cm/sec)	0.211	0.827

5 CONCLUSION

The automated system was designed and developed for accurate and fast localisation of extremely low frequency (ELF) electromagnetic field (EMF) exposure to any particular brain region. The automated system consisted of mechanical, software and hardware designs which all passed through a development process of refinement and improvement. The final design of the robotic arm was constructed of a main frame (an arc), which could rotate on its middle axis and a plate attached to it, to move along the arc. A general user interface (GUI) was also developed to precisely control and move an EMF coil via robotic arm to any EEG electrode position or region. The software was able to initially store the estimated 3-D EEG electrode positions. The 3-D movements of the robotic arm were controlled via a serial linked motor driver board that controlled two motors.

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