A LOW COST ERGONOMIC EEG SENSOR FOR PREDICTING MENTAL ILLNESS

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Abstract: The EEG recording of a person has been considered as one potential component within an overall wearable sensor system that predicts the onset of mental health problems. Such a smart EEG sensor should provide detailed sensory information, be easy to use, and to put on and take off and whilst being very ergonomic the design should aim at a very low final end user cost to ensure the widest possible take up by the e-Health community. The work reported here describes the design of such a sensor, the performance and its use during extensive clinical trials aimed to establish the rules that link physiology sensing to mental health prediction.

1 INTRODUCTION

This work relates to a 5 electrode Electro Encephalogram (EEG) sensor developed within the EU research project OPTIMI. The project's aim is to provide on-line predictive tools for the early identification and intervention during the onset of a mental illness, in particular depression, following the inadequate coping with day to day stress.

The EEG sensor is part of a set of wearable sensors to be worn by a large number of volunteers (130) during two phases of trials. The EEG sensor will be used to measure Alpha band brain activity and EEG signal C0 complexity. These measurements will be calibrated and used in a data fusion process to predict the onset of depression.

During the trials the EEG sensors must be used every day for a period of around five minutes. In order to ensure that volunteers comply with the daily testing procedures, that will take place every day for 4 weeks, this daily activity must be as quick and simple to perform as possible. At the same time high EEG recording accuracy is necessary. If there are difficulties or discomfort when using the sensor, volunteers may drop out of the trials and the longer term viability of the commercialisation of the sensor will be left in doubt. If the sensor is not placed well on the head the quality of the data may be compromised. Therefore ergonomic design must be considered at each stage of the development process.

Since a very large number of EEG sensors, as high as 55 units, are required to meet the needs of the trials, a low cost sensor is needed to ensure the project keeps within its limited budget. Likewise, in order to allow such technology to become mainstream and used by large numbers of citizens, low unit cost must be a central design criteria.

The sensor must provide equal data quality and resilience to noise as the commercial off the shelf EEG sensors that the OPTIMI psychologists currently use in the laboratory and medical clinics and the sensor data should be easily integrated into the OPTIMI data processing systems that include wearable Electrocardiograph and Actigraphy sensors.

This paper describes the need, usage, design, development and testing of the EEG sensor covering the electronics, software, ergonomics, economics and accuracy.

Section 2 describes the OPTIMI architecture and the EEG usage. Section 3 describes the development of the sensor hardware and section 4 discusses the results obtained during laboratory and the first phase of OPTIMI trials.

2 SENSOR ARCHITECTURE

The OPTIMI project incorporates a number of smart wearable sensors. The following summarizes the sensors and their target function:

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- EEG for stress and depression
- Activity Sensor for ambulatory activity
- ECG for Heart Rate and HR Variability
- Sub Dermal Cortisol Level Sampler
- Speech Analysis for depression score

The ECG and Activity sensors are worn 24/7 while the EEG sensor is to be worn once a day in the evening for a few minutes in order to perform an EEG recording and then removed. Data from all the sensors is received wirelessly from each sensor by a netbook computer called the HomePC. The HomePC encrypts the data and transmits it to a central server which processes the results.

Trials are to be conducted in Switzerland, Spain and China over 4 weeks in order to collect physiological data, volunteers' self-reported data and therapist interview data. By analysing the data the plan is to derive heuristic rules linking physiology to mental health prediction. When the clinicians are satisfied with the rules the sensors will be used as part of a Cognitive Behavioural Therapy based on-line system. This system will be tested as part of resilience treatment trials to be conducted in the UK and Spain using the same sensors.

2.1 The Role of the EEG Sensor

The EEG is a record of the electrical potential gradient oscillating around the brain and recorded from electrodes on the human scalp and is often labeled according to apparent frequency ranges detected in the EEG signal power spectrum: delta (1-4Hz), theta (4-8Hz), alpha (8-13Hz), beta (13-20Hz), and gamma (roughly >20Hz). The scalp electric potential amplitude is typically 20 to 100 μV with a specific shape depending on the subject's state of relaxation (Srinivasan, 2006). Recent studies have suggested that alpha rhythm is an oscillatory component of the human EEG and applied widely in many application fields, such as mental illness, biometric identification, E-learning, etc. Both wake and sleep EEG can provide biomarkers of depression and anti-depressive therapy, respectively (Tang, 2009). Within OPTIMI the resting EEG is recorded at three points on the forehead (FP1, FP2 and FPZ) referenced to the two ear lobes (A1 and A2).

The majority of studies targeting depression report characteristic differences in EEG asymmetry, especially in the alpha band, recorded from electrodes placed on frontal locations. In particular the study performed by Miguel A. Diego supports previous findings that indicate that greater relative left frontal EEG alpha activity is evident in people with depressive symptomology (Diego et al., 2002). In addition the findings of Vuga et al support the view that resting frontal EEG asymmetry reflects a moderately stable individual difference in adults, irrespective of sex and history of depression. [4]

Another good candidate for predicting depression is the measurement of EEG signal complexity. J L Nandrino et al. found that the EEG dynamics of major depressive subjects is more predictable, that is less complex, than that of control subjects(Nandrino et al., 1994). Tang et al. showed that alpha rhythm entropy in depressives is increased during resting compared to when perfroming mental arithmetic and when compared to healthy control group (Tang, 2009).

Within OPTIMI the two above measures, Alpha asymmetry and C0 Complexity, will be of particular interest as well as Beta/Alpha and Alpha/Theta power band ratios which can reflect a person's mood.

The EEG sensor must reliably record the user's EEG signals over periods of approximately 90 seconds in order to obtain sufficient data for the above algorithms. To achieve this the sensor must meet certain electrical specifications which will be described later. Additionally the sensor should provide a means to grade the quality of contact between the electrodes and the skin on the forehead since this contact quality must be sufficient if the raw data is to be useful.

Artefacts due to eye movements and forehead muscle movements are often detected in EEG raw data. Both 50Hz noise from electrical power lines and artefacts must be removed by a denoising algorithm to provide pure data before the algorithms are applied.

At first the algorithms and de-noising will be computed on the HomePC with the sensor purely acting as a wireless EEG recorder controlled by the HomePC. However once the results of the calibration trials are fully interpreted the aim is to move many of these data processing tasks to the sensor, including a neuro feedback mode, making it less platform dependent and highly portable.

3 SENSOR HARDWARE

The sensor electronics is depicted in Figure 1. The 5 electrodes on the left are connected first to a signal conditioning circuit to clamp any voltage spikes that may arise due to electrostatic discharge. In addition passive filtering is performed to remove 100Hz or higher input noise.

The electrodes connect to A1, the left ear lobe, FP1, the left hand side of the mid forehead, FP Zero,

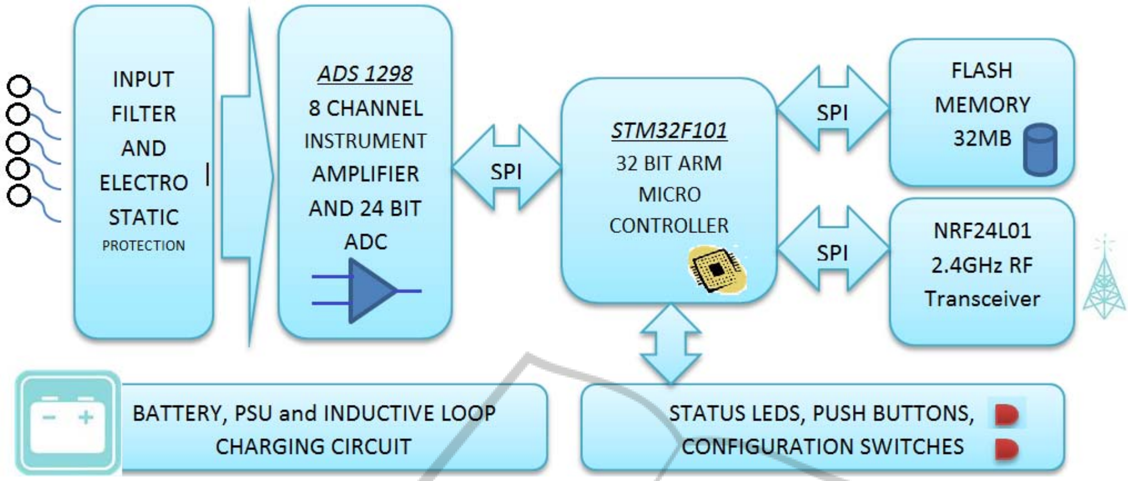

Figure 1: EEG Sensor, primary hardware components.

the middle of the forehead, FP2 the right hand side of the middle forehead and A2 the right earlobe.

These signals are used to drive the 8 channels of the ADS 1298 instrumentation amplifier ADC from Texas Instruments (Texas Instruments). This device provides 8 high impedance separate inputs for multi-channel amplification and multiplexing and digitizing any selected channel to a resolution of 24 bits.

The 5 input leads are inter-connected in a manner so as to obtain the following channel combinations:-

- FP1 relative to A1
- FP0 relative to A1
- FP2 relative to A1
- FP1 relative to A2
- FP2 relative to A2
- FP1 relative to FP2

At the centre of the sensor is a STM32 F101CB, (from ST Microelectronics) (ST Microelectronics) which is an ARM 32-bit Cortex™-M3 CPU with a maximum 36 MHz clock, 1.25 DMIPS/MHz (Dhrystone 2.1) performance. It includes 128 Kbytes of Flash memory, 16 Kbytes of SRAM, two SPI data buses and a generous number of general purpose I/O lines.

The CPU communicates with the ADS 1298 via a dedicated SPI bus configured to operate at the highest speed available. The second SPI bus is connected to a block of flash memory and an RF communications front end.

The 32MB of flash memory provides the main storage for the sensor. The amount of memory is only restricted by PCB real estate and memory cost.

The RF frontend allows the CPU to accept commands from the HomePC as well as exchange EEG raw data or processed results. In order to maintain compatibility with other sensors in the OPTIMI project, the RF front end is based on the nRF24L01+ low power 2.4GHz ISM (Industrial, Scientific and Medical) band RF Transceiver from Nordic Semiconductor (Nordic Semiconductor WEB Site). This method of communications was preferred over traditional methods such as Bluetooth because the hardware platform is extremely accessible and allowed one to develop energy efficient communications protocols.

The standard EEG channel specifications required by such typical applications are mentioned in the review of Tan, Ibrahim and Moghavvemi (Tan et al., 2007) in which they suggest:-

- Input impedance: 47Mohms
- Bandwidth: 1 to 30Hz.
- CMRR: 80dB to 90dB
- Gain: 100,000
- Power: 3mW per channel

Commercial products such as the Nexus-4 (from Mindmedia) (Mind Media, WEB Site) and the ENOBIO (from Starlabs) (Starlabs WEB Site) quote similar or better figures.

The ADS1298 is derived from a family of multichannel, simultaneous sampling, 24-bit, delta-sigma analogue-to-digital converters with built-in programmable gain amplifiers, internal reference, and an on-board oscillator. This component has an extremely low input bias current of 200pA (typical) and an input-referred noise of 4µVPP (typical). The CMRR is about -115dB, 500Megohm input impedance, effective gain of 1,000,000 and the power is very low in the order of 0.75mW/Channel. The data rate is from 250SPS to 32kSPS. The chip is 9mm x 9mm and requires few external components. Therefore a very compact design may be achieved.

In this sensor, the gain is set to 6, the reference voltage at 2.4V and the sampling rate is 260Hz which can also be easily set to other rates if necessary.

The sensor incorporates a 470mAh Lithium Polymer single cell battery. This allows the sensor to be used continuously for approximately 6 hours. Since the trials are planned to include twenty four sessions each lasting 5 minutes a single full charge should ensure the sensor never needs to be recharged during the whole trial period.

3.1 Firmware Functionality

The sensor software currently comprises a number of critical firmware functions. These include:-

- Accepting commands from the HomePC over the wireless communications link.
- Performing a signal quality check and relaying this to the HomePC
- Recording a specified length of EEG data into a simple multiple file structure
- Streaming raw EEG data for test purposes
- Downloading data files to the HomePC over the RF link
- Erasing data files

An important feature of the sensor is the ability to perform a signal quality check. This feature is necessary to provide the HomePC application a means of verifying that the user has put the sensor onto their head, in a manner that ensures the data recorded is true EEG data with little noise.

When any EEG sensor is used to record very low voltage brain waves activity, care must be taken to ensure the electrodes are in good contact with the skin such that the electrode to skin impedance is as low as possible. This ensures an optimal detection of the brain potentials. In addition it ensures that any ambient electrical potential, such as generated by nearby electrical lamps and office machines is less likely to interfere due to the fact the electrodes measure the potential originating in the human body rather than the potential gradient in air space.

The signal quality check is performed in a fully standalone manner by the sensor following the reception of a GetSignalQuality command by the HomePC. It first records 4 seconds of EEG data and then carries out a detailed analysis in which the sensor determines the Variance in the time series data as well a power spectral analysis.

A value for signal quality is calculated based upon:

- the variance in the signal which should be between a set of typical limits
- the spectral power at 50/60 Hz
- the brain activity in the Alpha band
- the brain activity in the Delta, Alpha and Beta bands as compared to the Gamma and higher frequencies to 60Hz.

By a combination of ratios and limits a signal quality value is calculated between 0 and 100 and this value is sent to the HomePC which instructs the user to check or reposition the sensor if the quality falls below 70.

3.2 Choice of Electrodes

In recent years a great deal of work has been applied to developing active dry EEG electrode technologies both in the research and commercial domains [12. The aim has been to achieve a number of advantages over the traditional approach. In the traditional approach a conductor such as a stainless steel or gold plated electrode is brought near the surface of the skin. Then a wet gel such as NUPREP™ EEG skin prepping gel is used to lower the skin conductance. The gel is rather messy and is particularly annoying if it gets into ones hair. Normally the electrodes are connected to relatively long and heavily shielded expensive cables which go off towards the amplifier device next to a patient's bed.

As a result research teams have aimed to place active electronics into the electrodes so that they could pre-amplify and match impedance close to the skin and remove the need for a gel as well as avoid the need for active shielded cables.

In the commercial solutions now available and known to the authors, it would appear that active electrodes result in a more expensive design due to the higher complexity, additional amplifiers and power. The electrodes are also larger than the smallest passive electrodes.

For economic and ergonomic reasons the sensor developed here did not incorporate active electrodes and instead makes use of very low cost disposable skin friendly solid gel pads. Solid gel pads provide all the electrical benefits of wet gel and do not leave any gel or fluid on the skin which is often the complaint during EEG usage. When the recording is completed the pads are simply removed and discarded, providing a higher level of hygiene.

3.3 Ergonomics and Economics

From the very start of the OPTIMI sensor development, two things were made very clear to the designers. Firstly, the EEG sensor's final assembled and tested unit cost would have to be below 90 Euros. Secondly the design would have to pass a usability acceptance rate of 39 out of 40 users invited to use it as deployed in the trials. That meant that only 1 in 40 subjects should be likely to refuse to use the sensor on ergonomic grounds. This set extremely difficult economic and ergonomic constraints in addition to the normal functional design constraints of the sensor.

Economics

In order to achieve low cost the designers reviewed the state of the art and determined different cost scenarios for alternative designs, manufacturing methods, battery charging methods, user interface and packaging. A core base functionality was necessary and was achieved through the value line STM32 F101 device, a limited 32MB of serial flash memory and the compatible nRF24L01+ RF transceiver.

After studying different options it became clear that the single ADS 1298 device, encapsulating all the functionality of the EEG front end and ADC, would save money over the use of discrete components and the associated assembly cost.

Active dry electrode sensors were considered in the design. However since it became clear that the sensor would be worn on the forehead, with very short electrode cables there was no technical reason to implement this higher cost solution. In addition it was decided that disposable solid gel pads, which cost a few cents each, were to be used to optimise skin conductance while maximising hygiene.

Battery charging is performed using a non-contact inductive method. This is done to maintain compatibility with all OPTIMI sensors which must be hermetically sealed, as they are worn for long times near the body.

The final packaging of the device is kept very simple, with the overall PCB being coated in an encapsulating two part epoxy resin (ALH Systems Ltd., U.K.) that has been chosen to provide maximum water resistance and maintain hardness to over 80 degrees C. The encapsulated board is then primed and coated with a thin conductive coating paint and then varnished. This conductive layer helps to reduce the effects of ambient electrical potentials being detected. In fact due to the small size of the final sensor and direct coupling of the ADS 1298 to the shielded electrode cables, the effects of ambient noise are surprisingly small.

The sensor is worn on a low cost head band which was chosen for economic but also strong ergonomic reasons.

Ergonomics

To assist in the design of an ergonomic sensor a usability study was commissioned to run in parallel with the R&D work. This study consisted of a developers' session, two focus group sessions and a detailed survey conducted in each of the trial sites.

To start with the sensor design and developers group were invited to highlight concerns and constraints of developing these sensors. Then in the first focus group session the OPTIMI philosophy and mock up sensors were presented to 14 volunteers 7 male, 7 female with age ranges from 18 to 64.

Figure 2: Early mock up of the EEG sensor.

By studying the response to the mock ups and scenarios of use, the concerns of the developers were matched against the concerns of the focus group to highlight important design goals and constraints.

Following this, design specifications were created and prototype work commenced. During the second focus group, working prototypes were presented to 18 volunteers who were asked to wear and use the sensors. As a result further feedback was obtained, prioritised and several design changes resulted.

Finally questionnaires were sent out to 50 people representing typical volunteers in each trial site. These questionnaires further clarified if there were significant cultural adjustments that needed to be made given that the focus groups were held only in Switzerland.

As a result of this usability study a large number of design modifications were made to the developers original design ideas. In the end it was felt the design satisfied the specific needs of the people in the focus groups as well as the points derived from the regional surveys. The following describes a few of the important conclusions coming from this usability study:

Figure 3: EEG sensor, from front, from behind. Note the electrodes are carried on the black elastic headband. The weight of the electronics is supported on a solid band worn as eyeglasses.

Figure 4: Sensor worn by a volunteer.

- 10 seconds to put on or remove
- Quick Recharge every 1 to 2 months
- All cables must be short and ultra-flexible
- Very light pressure, light weight ear clips
- Light weight headband and small electrodes
- Electronics separated from the band
- High preference for disposable solid gel pads
- No skin allergy reaction
- Use soft feel hook and loop straps
- Lady's long hair must never get caught
- LEDs to tell what the sensor is doing
- Simplest HomePC application

4 PERFORMANCE RESULTS

The EEG sensors developed and finally manufactured have recently begun deployment in large numbers (45 currently) in the calibration trials in Spain, Switzerland and China.

Before this the sensors were rigorously tested and data from the sensors was used in laboratory experiments to ensure the EEG data obtained was of the highest quality for use in the trials.

For this paper the performance will be described by first showing the time and frequency domain results obtained under different conditions. Then a comparison will be presented between the OPTIMI EEG sensor and a well-known commercial product. Finally some initial results obtained from the on-going calibration trials will be used to indicate the ergonomic performance and acceptance by users.

Time and Frequency Domain

In order to compare the sensor under different noise conditions recordings were made of volunteers in the resting, eyes closed position.

Two environments were tested. First the recordings were taken in a public wilderness park near Zurich where there are no visible sources of electrical power usage. With several volunteers to record, this was simpler, faster and less costly exercise when compared to using a dedicated Faraday cage system. Secondly a typical office environment was arranged with several running desk top computers, lamps, printers and copiers in the room.

Raw EEG data was gathered using the sensor alongside a PC based test application software. The raw data was then processed using MATLAB for visualisation and for the time and frequency domain analysis (TD and FD).

Analysis of Raw Data

Figures 5 to 12 relate to the recorded signal from a single channel (FP1 relative to A1). Figure 5 shows the TD signal with the sensor left to rest in free space and not placed on the head of the volunteer.

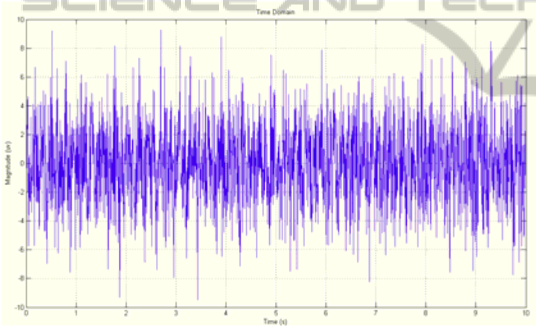

Figure 5: Forest, Off head, Noise, Time Domain.

The peak amplitude is 9uV with an RMS value of 4uV. This noise includes white noise in the environment as well as sensor produced noise.

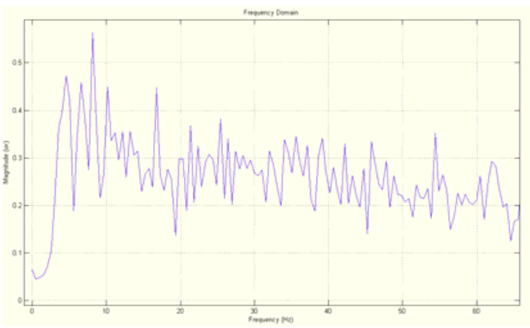

Figure 6: Forest, Off head, Noise, Frequency Domain.

In Figure 6, the FD power spectrum for the signal is shown. In general the noise power is distributed over all frequencies, with some amplification at around 8Hz with no frequency exceeding 0.6uV.

In Figure 7, the sensor is worn on the head, in the forest environment. The volunteer keeps their eyes closed and rests in a calm state of mind and body. The primary aim is to verify the typical EEG pattern in a noise free environment. The signal peaks at 60uV with a typical RMS value of 25uV. We assume 4uV RMS of noise is embedded in this signal.

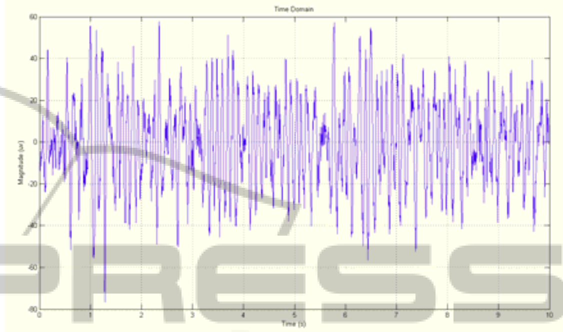

Figure 7: Forest, On head, Resting Eyes Closed, Time Domain.

Figure 8 shows an excellent and typical noise free EEG resting eyes closed FD spectral plot. With the eyes closed the FD plot clearly shows the Alpha Band peaking around 10Hz, with additional Theta band activity and low Beta band activity.

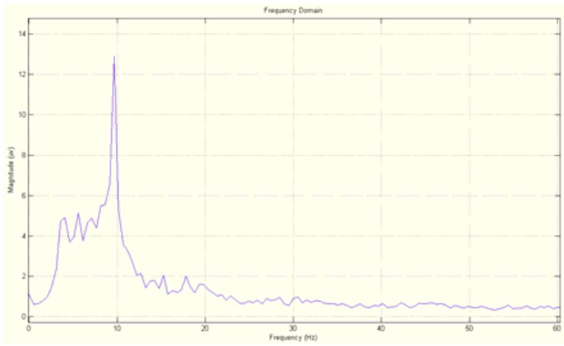

Figure 8: Forest, On head, Resting Eyes Closed, Frequency Domain.

In the office with the sensor left to rest in free space, the sensor records airborne electrical potential gradients from the office machines. Figure 9 shows the TD signal, peaking at 200uV with a typical RMS of 170uV. Figure 10 shows the FD plot clearly indicating that the major energy is detected at the 50Hz band.

In the office with the sensor left to rest in free space, the sensor records airborne electrical potential gradients from the office machines. Figure 11 shows the TD signal, peaking at 200uV with a typical RMS of 170uV. Figure 7 shows the FD plot clearly indicating that the major energy is detected at the 50Hz band.

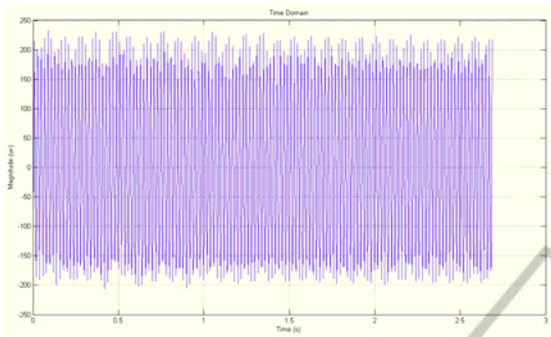

Figure 9: Office, Off head, Noise, Time Domain.

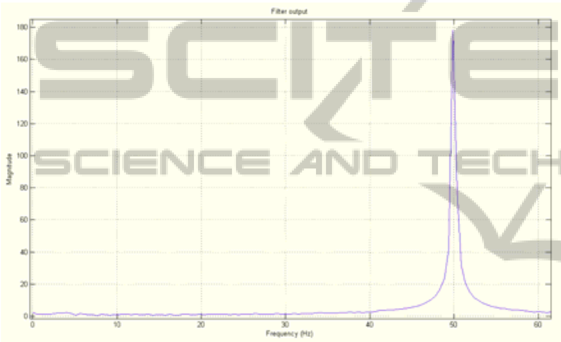

Figure 10: Office, Off head, Noise, Frequency Domain.

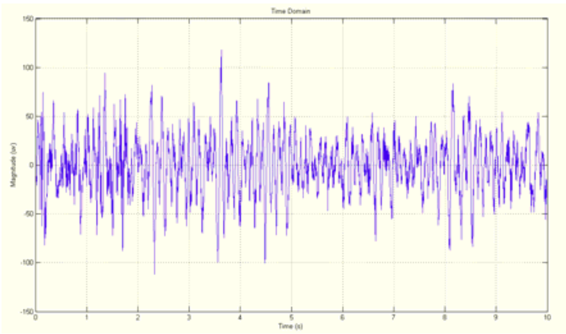

Figure 11: Office, On head, Resting Eyes Closed, Time Domain.

Figure 11 and 12 show the results of recording in the office with the sensor worn correctly in the eyes closed resting position. What is now clear is that the office noise at around 50Hz is very apparent within the EEG FD plot. However the noise in the office has not in any way compromised the response at the frequencies of interest namely the Alpha and Theta bands. The 50 Hz noise measured here is largely due to the potential gradient set up in the human body and measured between the two electrodes. These gradients are due to tiny electrical currents arising from the capacitively coupled voltages on equipment in the nearby environment entering the body and passing through it towards the earth or another nearby equipment. Since these are truly human body voltages there is no real method to supress them other than to add a 50Hz band stop filter on the processing stage of the raw data.

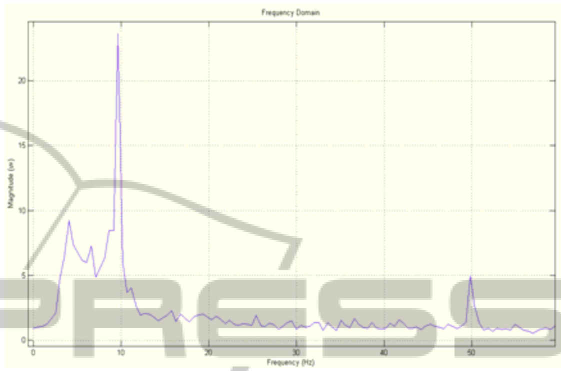

Figure 12: Office, On head, Resting Eyes Closed, Frequency Domain.

Comparison with Commercial Eeg

In order to determine if the sensor was performing as well as an off the shelf commercial sensor, a test was carried out in which a volunteer wore both the OPTIMI sensor and a NEXUS-4 EEG sensor from Mindmedia (Mind Media, WEB Site). The NEXUS-4 device is a very popular wireless Bluetooth based device used in many research groups and clinical settings and has an impressive specification. It is rather larger than the OPTIMI sensor and cannot be worn as ergonomically. It is limited to 4 electrodes and would be harder to integrate seamlessly into the OPTIMI wireless system. It is priced at around 3000 Euros.

Figure 13 shows the volunteer wearing the OPTIMI EEG headband on her forehead. Above the band can be seen the single electrode from the NEXUS-4 EEG sensor stuck near the OPTIMIT EEG sensor electrodes. Lower down one can see the NEXUS-4 processing unit being held in her hand.

Figure 14 to 16 show the time domain and frequency domain results comparing the signals recorded from the two sensors. In Figure 14 and 15 is shown the time domain raw data plot. In the first figure one can see that the general amplitude, DC drift and general shape of the two waveforms are more or less identical. On close inspection one can see that the phase of the two signals is very synchronised while the amplitude in some cases varies significantly. Since the two sensors do not share the exact same physical location and impedance contact with the skin, some differences are likely to occur.

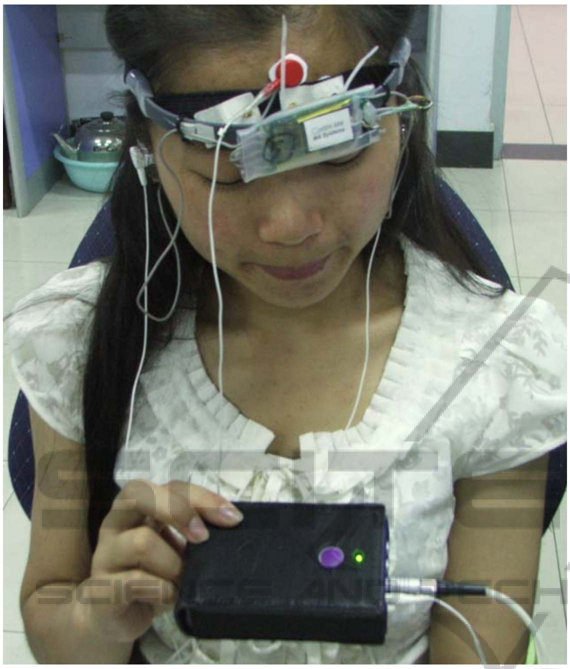

Figure 13: Comparison of NEXUS-4 and OPTIMI EEG Sensor.

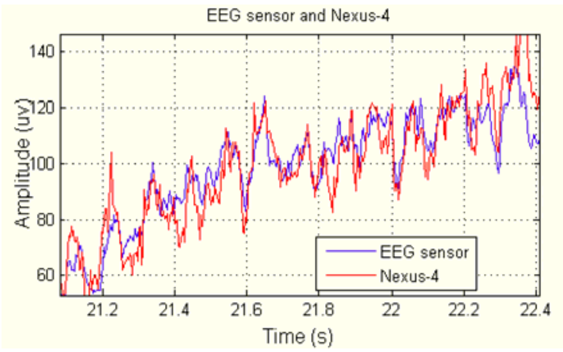

Figure 14: Drift comparison with NEXUS-4.

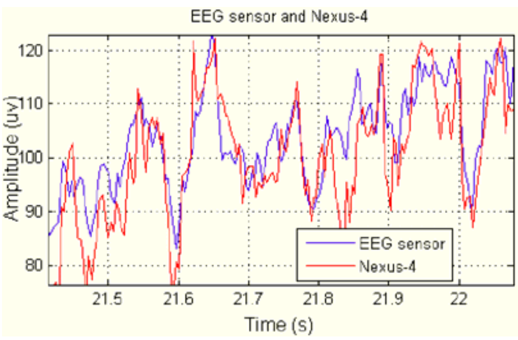

Figure 15: Phase Amplitude Comparison with NEXUS-4.

From the frequency response shown in Figure 16, one can see that both sensors manage to provide similar FD plots, especially highlighting the peaks in Alpha, Theta and Beta bands. The amplitude across the spectrum is very close suggesting very similar input response functions.

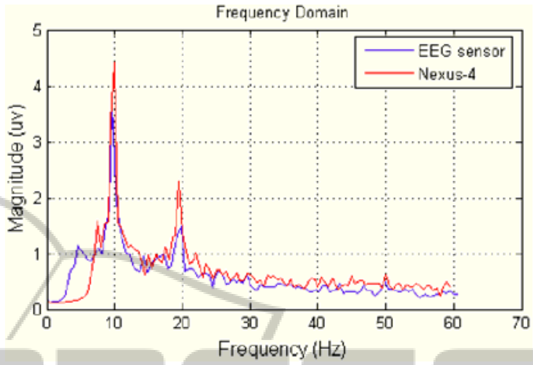

Figure 16: Frequency Response Comparison with NEXUS-4.

Ergonomics and User Acceptance

Approximately 45 EEG sensors are now deployed in three trial sites around the world. In certain cases the sensor is shared between two or more volunteers in dormitory scenarios. Over the past 5 weeks 52 volunteers have now used the sensor as required. We can report that to date not a single user has found any difficulty in putting on the sensor and performing a recording. Some difficulties have been experienced in operating the HomePC application to start and end the recording. In a specific case of our experiments, in which audio clips were played to volunteers during the recording period, the volunteers were required to wear headphones at the same time. This lead to the user dislodging the reference ear clip from the ear lobe and resulting loss of data. As a result adhesive dry gel pads are used behind the ear at M1 and M2. In some cases the ear clip itself was broken as users pulled on the cables to remove the electrode. The ear clip has therefore been redesigned.

5 FURTHER WORK

The current version of EEG sensor will be modified to include the noise and eye movement filtering that is established post calibration trials.

In addition it is planned to add a neurological feedback functionality in which the sensor will identify the current level of mental stress of the user. This level will be presented on a simple level indicator, such as an audio signal. The sensor may then be used as a simple assistive tool to practice Cognitive Behavioural Therapy based biofeedback aimed at relaxation before going to sleep.

The sensor will also be used as a low cost diagnostic tool by project partners to evaluate other forms of assistive diagnosis of stress and anxiety.

6 CONCLUSIONS

During the first year of the OPTIMI project a low cost ergonomic sensor has been developed and manufactured, from the bottom up, to meet the needs of a large e-health trial.

The need to ensure volunteer compliance and tight economic controls has been met to a high degree in the work reported. This has been achieved by designing the sensor in parallel with the guidance of a user needs analysis that includes the views of developers, the views of user represented by focus groups and the views of typical end users in the country of deployment.

Economic targets have been met by using state of the art solutions combined with sophisticated embedded software. The sensor is now in use in high numbers and will soon be adapted to meet the needs of customised usage scenarios by firmware upgrade.

ACKNOWLEDGEMENTS

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REFERENCES

Paul L. Nunez Ramesh Srinivasan, Electric fields of the brain. *The Neurophysics of EEG,* OUP US (2006).

Tang Y., Li Y, Tong S., Li Y, Zhu Y .*Entropy analysis of the EEG alpha activity in depression patients*. Sheng Wu Yi Xue Gong Cheng Xue Za Zhi,26(2009),739-742.

Miguel A. Diego B. A., Tiffany Field Ph.D, Maria Hernandez-Reif Ph.D., " CES-D depression scores are correlated with frontal EEG alpha asymmetry.", *Depression and Anxiety.Volume 13*, Issue 1(2001),32–37., Physicians Postgraduate Press, January 2002, pages 6-31.

Vuga, M., Fox, N., A., Cohn, J. F., George, C., J., Levenstein, R., M.,Kovacs, M. Long-term stability of frontal electroencephalographic asymmetry in adults with a history of depression and controls, *International Journal of Psychophysiology* 59(2006),107–115.

Nandrino JL, Pezard L, Martinerie J, el Massioui F, Renault B, Jouvent R, Allilaire JF, Widlöcher D. Decrease of complexity in EEG as a symptom of depression. *Neuroreport.* Jan 12;5(4)(1994),528-30.

Texas Instruments WEB Site Analogue Front End http://www.ti.com/ww/en/analog/ads1298/.

ST Microelectronics WEB Site Microcontrollers http://www.st.com/internet/mcu/class/1734.jsp

Nordic Semiconductor WEB Site RF 2.4GHz http://www.nordicsemi.com/eng/Products/2.4GHz-RF/nRF24L01P

Tan, Y., Ibrahim, F., Moghavvemi, M., “Two electrodes low voltage input EEG amplifier for brain-computer-interface”, *International Conference on Intelligent and Advanced Systems*, Kuala Lumpur, 2007.

Mind Media, WEB Site, Nexus-4 http://www.mindmedia. nl /english/nexus4.php.

Starlabs WEB Site, http://starlab.es/products/enobio

Fonseca, C., Cunha, J., Martins, R., Ferreira, V. M., de Sa, J., Barbosa, M., da Silva, A. M., “A Novel Dry Active Electrode for EEG Recording”, *IEEE Transactions on Biomedical Engineering*, Jan. 2007, Volume: 54 Issue:1 162 – 165.