P08050 Remote EEG Sensing

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Project goal:
Interfacing an EEG acquisition system with a Wireless Mesh Network

Justification:
In standard EEG systems, noise and artifacts are generated by the movement of wires. The elimination of wiring from the analog system helps to alleviate this problem.

This project is a proof-of-concept design directed towards the eventual development of a wire-free EEG system wherein each electrode is a miniature self-contained microprocessor node in wireless mesh network.
Customer Requirements

• Needs to acquire sufficiently accurate digital representation of an EEG signal
• Needs to transmit output wirelessly to a base station
• Needs to be scalable for multiple channels
• Needs to operate for at least 24 hours of continuous use on a mobile power source
• Needs to avoid using live mains due to safety considerations
• Needs to allow base station user to control and configure network
• Needs to display visual representation of acquired data
• Needs to cost less than $500.00 per unit to manufacture

Implementation

• Analog amplification and filtering of the EEG signal using custom designed hardware
• Digital sampling of analog signal and encapsulation of data using TelosB mote
• Transmission of data over wireless mesh network using TinyOS platform
• Receipt and visualization of EEG data at base station PC using custom software application
Functional Diagram

Chosen Concept

Energy Storage
- Alkaline Batteries
- Lithium Batteries
- Nickel-Ion Batteries
- Nickel-Metal Hydride Batteries

Signal Acquisition
- Gold Plated Silver Plated Copper-Medicated Electrodes

Signal Filtering
- Single-band Pass Filter
- Butterworth Low-Pass Filter
- Dolyfon Low-Pass Filter
- 60 Hz Notch Filter

Mote/Digital Board
- Crossbow Imote2
- Crossbow TelosB
- Motive TmoteSky
- Motive TmoteMini

Wireless Specifications
- 802.15.4
- 802.11
- Bluetooth

Networking Topology
- Ring
- Star
- Tree

Error Correction & Detection
- Custom Error Detection & Correction

EEG Visual Feedback Generation
- BrainBay
- NeuronServer
- Custom Software or Hardware from Open-Source

Visualization of Wireless Network
- Crossbow Motelive
- Custom Built Software
- AJAX Web Interface

Error Correction & Detection
- Supplied with the system

ESD Protection / Safety
- Current Limiter
- Optoisolator Circuit
- ESD Protection Diode

Analog Amplification
- Instrumentation Amplifier
- Linear Amplifier
- Multi-stage Combination

Signal Filtering
- Single Band-Pass Filter
- Butterworth Low-Pass Filter
- Chebyshev Low-Pass Filter
- 60 Hz Notch Filter
Design Revisions

• Revisions to analog design
  – Switched to low power voltage regulator
  – Added Zener diode at output to protect ADC
  – Used Zener diode for ESD protection in place of transistor network
• Revisions to software design
  – Assigned highest priority to sampling thread
  – Added sample buffer

Integration Procedure

• Independently verify functionality of analog and digital systems

• Verify desired operation of combined system

• Mount analog circuit and mote in modified COTS enclosure
Budget

• Total Cost: $230
  – Analog board: $125
  – Digital Mote: $70
  – Electrodes & Miscellaneous: $35

• Final cost is 46% of projected $500 per unit budget

Tests Performed

• Square-Wave Calibration Test
• Anti-Aliasing High-Filter Test
• Low Filter Test
• Common Mode Rejection Ratio (CMRR) Test
• Power Consumption
• Simulated EEG Waveform Test
• Digital Frequency Verification
• Amplitude Range Verification
• Wireless Transmission Reliability Test
• Software Functionality Test
• Multihop Verification
• Scalability Test
Results – Analog Board

- Two Channel EEG signal acquisition and processing system successfully designed.
- Surface mount components used for the design
- Single supply, low power battery operation successfully implemented

Results – Analog Board

- The designed differential gain is attained and constant throughout the pass band
- The -3dB cutoff frequencies are within specified limits
- The gain can be adjusted from 1000V/V to 7000V/V at the adjustable gain stage to suit individual user needs
Results – Analog Board

- The CMRR meets the IFCN standards of 110dB per channel
- The use of the right leg driver greatly increased the CMRR with minimal additional power consumption

Results – Analog board

- Clinical EEG data is modeled in MATLAB and applied as an input
- The gain and frequency response of the output is as expected
Results – Digital Output

- A simulated EEG input of magnitude 100μV is applied to the amplifier input. The processed signal is wirelessly transmitted to the base PC and reconstructed.

Results – Power Consumption

<table>
<thead>
<tr>
<th>Input Signal Amplitude (μV)</th>
<th>Voltage Applied (V)</th>
<th>Current Drawn (mA)</th>
<th>Power (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.327</td>
<td>5.504</td>
<td>34.82</td>
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<tr>
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<td>5.960</td>
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<tr>
<td>1000</td>
<td>6.327</td>
<td>8.210</td>
<td>51.94</td>
</tr>
</tbody>
</table>

- Power consumption of the analog board is observed to increase as input magnitude increases
- Worst case analog board power consumption is 52mW
- Worst case digital board power consumption is 82mW
- Total consumption is 134mW, which is well below the 150mW specification
Design Strengths and Weaknesses

• Strengths
  – Modularity
  – Availability of Components

• Weaknesses
  – Digital and analog components using different power supply magnitudes
  – Lack of an automatic gain adjustment circuit in the analog board
  – Mote characteristics sub-optimal

Future Development

• Miniaturization of digital and analog boards for use as subdural implants.
• Superior quality digital board – faster processor – more RAM
• Automatic gain adjustment on analog board
• Uniform supply voltage for digital and analog boards
• Improvements to physical design
• Improvements to graphical user interface
• Active electrodes
Questions & Comments