February 22, 2005

Mr. Lakshman One
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

Re: ENSC 440: Functional Specification for a P300 Spelling Device for the Completely Disabled

Dear Mr. One:

Please find the attached document, *Functional Specification for a P300 Spelling Device for the Completely Disabled,* outlining the functional requirements for our P300 spelling device. Our project is to build an operational prototype of a brain computer interface system that uses the P300 brain response to allow completely disabled persons, such as those suffering from late-stage *Amyotrophic Lateral Sclerosis,* to communicate.

In the attached document we give a brief system overview and we outline the functional requirements of the system at its various stages of development.

ThinQ Innovation is comprised of five senior-level engineering students, each with unique strengths to complement the group and a common trait in determination. We are Jack Cha, Jae-Seok Jeon, Brian John, Min Seo and Jyh-Liang Yeh. ThinQ Innovation looks forward to consulting with you on any concerns you may have. Should you have any questions, please feel free to contact us at ensc440-project@sfu.ca.

Best Regards,

Brian John
Project Lead

Enclosure: *Specification for a P300 Spelling Device for the Completely Disabled*

Functional Specification for a

P300 Spelling Device for the Completely Disabled

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Submitted to: Mr. Lakshman One – ENSC 440
Mr. Mike Sjoerdsma – ENSC 305

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Executive Summary

ThinQ Innovation is currently developing a *Brian Computer Interface* (BCI) spelling device prototype intended to provide a communication medium for completely disabled persons, such as those suffering from late-stage *Amyotrophic Lateral Sclerosis* (ALS). Ultimately, our system may allow late-stage ALS patients to lead a more fulfilling life and will also help researchers and medical doctors to gain further insight in the patient's physiological and psychological state.

The overall development of our system consists of 3 phases. After the first phase we will have a proof-of-concept prototype that will exhibit basic functionality. Once we are satisfied with the performance of our prototype, we will move into phase 2 to further improve the performance towards a production system. In the third phase, we will develop our P300 speller to include features necessary for commercial deployment. Phase 1 completion is scheduled for April, 2005 and will exhibit the following main features:

1. Offline data detection accuracy of 99% in fewer than 10 trials using 10 data channels.
2. Online data collection and detection accuracy of 99% in fewer than 40 trials using 10 data channels.
3. Enhanced word selection using word prediction feature that will allow the user to increase speed. Word selection will be available after the first target letter is decoded.

The remainder of this document outlines the functional specifications required for the two successful prototype and production phases.

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1. Introduction

The *P300 BCI Spelling Device* is a communication system for completely disabled persons. The device uses visual stimuli in the form of flashing alphanumeric characters to invoke a response from a patient's brain to determine the intended character and display on a screen for others to see. The system can be logically divided into four modules: input module, performance module, output module and word prediction module. Each module has sets of functional requirements, which will be documented in detail in subsequent sections.

Overall development consists of 3 phases. Our immediate goal is to develop a phase 1 prototype system to achieve fast (within 10 trials) and accurate (better than 99%) spelling using offline data. Because of uncertainties regarding the quality of an available amplifier, we aim to utilize this system in a real-time implementation that can produce similar, but not identical, results as our offline system. Hence, we have broken phase 1 into two stages. In the first stage we will analyze pre-collected (offline) data in order to ensure that processing is correct and detection of known results are accurate. The second stage will involve equipping the offline machine with data acquisition capabilities and running it in a real-time fashion. Because of the division of phase 1 and various unknown data integrity issues, we find it useful to specify both the characteristics of the offline and online machines.

Once a prototype is developed and if we are sufficiently satisfied with its performance, we will move into phase 2 prototype development to improve the characteristics in preparation for a production system. Finally, once we have sufficiently improved our prototype such that it is suitable to enter the production phase (phase 3), we will further enhance the spelling device to prepare it for commercial deployment. Phase 1 is slated for completion in April, 2005.

1.1 Scope

The scope of this document will be the description of functional requirements of a prototype *P300 BCI Spelling Device* that will be completed by April, 2005. This document also describes basic functional requirements for further prototype and production system development.

While we aim to specify most functional requirements leading to a production device, we cannot be sure that the list will be exhaustive and that more requirements will not be discovered as we near commercial deployment. Hence this document is a living document and will be updated as necessary.

1.2 Intended Audience

This document is intended for design engineers, project managers and marketing persons.
Design engineers can use this document for system development guideline.
Project managers can use this document for project schedule and milestones guideline.
Marketing persons can use this document for presenting to potential purchasers or users of the system.

1.3 Conventions

The conventions used throughout this document are as follows.

[R#] A Functional Requirement (X)

Where X refers either to 1, 2 or 3 according to the following:

(1) A functional requirement for phase 1 prototype development.
(2) A functional requirement for phase 2 prototype development.
(3) A functional requirement for phase 3 production development.

Note that phase 1 and 2 functional requirements, when not directly related to testing, remain functional requirements in phase 3.

1.4 List of Acronyms

AC	Alternating Current
ALS	Amyotrophic Lateral Sclerosis
BCI	Brain Computer Interface
CD	Compact Disk
CPU	Central Processing Unit
CRT	Cathode Ray Tube
DAQ	Data Acquisition
LCD	Liquid Crystal Display
MND	Motor Neuron Disease
PC	Personal Computer
PCI	Peripheral Component Interconnect
RAM	Random Access Memory

2. System Overview

This section outlines the basic configuration of our P300 speller. It is intended to give the reader a better understanding of the overall system operation.

In a working P300 speller, shown below in figure 2.1, a monitor is placed in front of a disabled patient who is fitted with a head cap containing probes to detect brain activities. The probes are connected to an amplifier, which then feeds the signals into an analog-to-digital converter and then further to a processor. During system operation, we ask the patient to focus on a target letter and count the number of times the letter flashes. During this time, rows and columns on the monitor will flash in a random fashion, separated by approximately 300ms. When the target letter flashes, the patient's scalp will develop a P300 response. By keeping track of when particular rows and columns flash, accompanied with the response that the patient gave after such flashes, our detection software will be able to determine the target letter. That is, a target letter will occur at the intersection of the row and column that gave positive P300 responses.

Figure 2.1: System Overview

Our system utilizes the fact that under certain circumstances, rare events elicit P300 potential. These rare events are evoked by flashing of target letters on the monitor. A sample monitor output, taken at different times, is shown in figure 2.2. In the left case, the row G-H-I-J-K-L is highlighted, and a P300 response would be evoked on the patient's scalp if he or she had either of G, H, I, J, K, or L as the chosen target. All rows and columns are flashed in random sequence. On the right of Figure 2.2, the column A-G-M-S-Y-5 is highlighted. If, for this trial, a P300 was detected by our system directly after the flashing of highlighted row and column in figure 2.2, we could deduce that the patient was trying to communicate the letter 'G'.

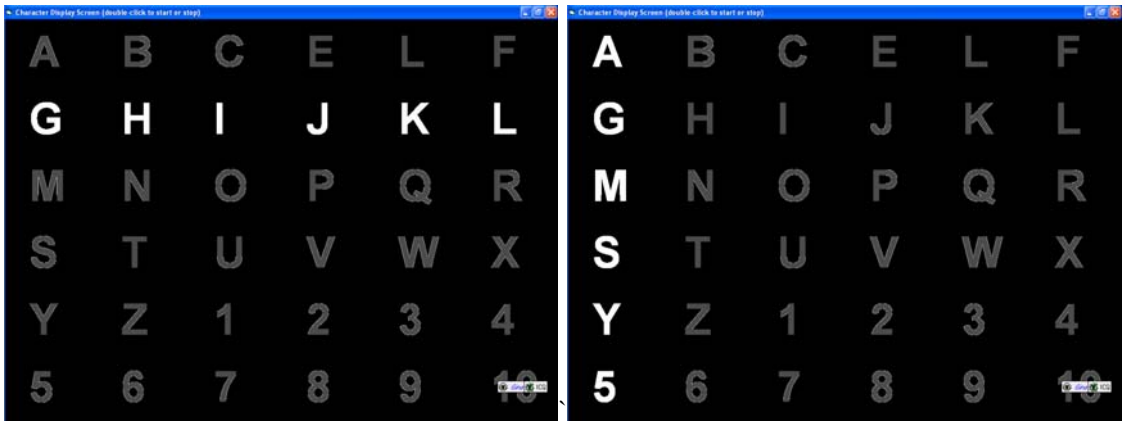

Figure 2.2: (Left) Display matrix currently flashing the second row, (right) first column

The time required between flashing rows or columns, denoted as a single "epoch", lasts approximately 300ms. For the display matrix depicted above, it would require a total of 12 epochs (6 rows + 6 columns) to constitute as a single trial. The P300 will appear approximately 300ms after the intensification of a target letter and is characterized by a prolonged positive change in scalp potential. Our system's task then reduces to the detection of which row, and which column that has elicited a P300 on a given trial.

Because the P300 is substantially smaller than the continuous electroencephalograph (EEG) activities on the scalp, it is very difficult to detect it on a single-trial basis. Thus, the detection of the P300 within a noisy EEG environment will require a series of trials averaged together to obtain more accurate detection results. A distinguishing feature of any BCI is the ability to communicate efficiently. In our system, it is clearly desirable to minimize the number of trials.

After successful detection of a target letter, the patient's monitor will be updated to reflect the choice of letter. To increase the communication rate of our system, we intend to incorporate a predictive text function. The function involves developing a database of commonly used words, ranked according to usage. When our system is able to make a guess as to the target word, it will display it on the screen as a possible user input.

Based on rank and previously chosen letters, the predictive text function will output probable word choices. Thus, the six most common words matching a partially typed word will be displayed on an additional row of the matrix screen.

3. System Requirements

The next three sections outline the general requirements of our system, as well as the input, performance, and output requirements of our system. Input requirements refer to the process of acquiring data from the patient's scalp and bringing it into a PC for processing. Output requirements pertain to the output of the system, from the monitor to the feedback to the patient. Finally, performance requirements refer to performance measures of the overall speller.

Our system has two modes of operation. The first mode, used for testing, uses pre-collected data as input and does not require a patient or real-time operation. The second mode is online mode and refers to the real-time operation of the spelling device by a patient.

3.1 General/Overall System Requirement

[R1] All software will be capable of running on a Pentium 4 or equivalent running Windows XP. (**1)**

[R2] The system will be capable of operating from standard 110V AC power outlets. (**1)**

[R3] Operation of the system requires a physically-able person to turn the system on and enable it to begin flashing letters. This person will be referred to as a helper. **(1)**

3.2 Input Requirement

[R4] The patient will be able to connect to the system using an electrode cap. (**2)**

[R5] Before an electrode cap is available or suitable, the system will take regular electrode probes as input. **(1)**

[R6] The electrode cap or individual electrodes will connect up to 10 channels to an amplifier that will amplify the inputs to a maximum range of -10 to +10V. **(1)**

[R7] Each input channel to the amplifier will have an input impedance of over 1 G-ohm. **(1)**

[R8] The amplifier will provide a gain of at least 100000. **(1)**

[R9] The amplifier's Common Mode Rejection Ratio at 60Hz will be 112db or better. **(1)**

R[10] The amplifier will exhibit typical base-line noise (referred-to-input) of 0.6 uV peak-to-peak at 100Hz and 4.5uV peak-to-peak at 10kHz. **(1)**

[R11] The output of the amplifier will be fed to a data acquisition system that will be capable of simultaneously sampling up to 10 channels. **(1)**

[R12] Each input channel to the data acquisition system will be sampled at 240 Hz. **(1)**

[R13] Data epochs collected will be streamed to the processing system within 300ms of when they are collected. **(1)**

3.3 Performance Requirement

[R14] The system will be able to achieve 99% accuracy of detection of offline data within 10 trials or less using 10 channels. **(1)**

[R15] The system will be able to achieve 99% accuracy of detection of online data within 40 trials or less using 10 channels. **(1)**

[R16] The system will be able to achieve 99% accuracy of detection of online data within 5 trials using 10 channels. **(2)**

[R17] The system will be able to attempt to predict the target word being spelled by the user after the first letter has been correctly detected. Word prediction will continue until the target word has been deciphered. **(1)**

[R18] Words spelled that are not in the database will be added to the database at the user's option. **(1)**

[R19] The system will be capable of storing different sets of training data for various users and is able to switch between optimal detection characteristics depending on the user. **(1)**

3.4 Output Requirement

[R20] The system will be able to present input to the user (i.e. flash rows and columns of letters) at a rate of at least 300ms/flash. **(1)**

[R21] The primary monitor will display at a minimum resolution of 1024x768 at 16 bit quality. **(1)**

[R22] The primary monitor will display at least 36 alphanumeric characters in six rows and six columns. **(1)**

3.5 Physical Requirements

Our P300 BCI Speller integrates three main physical components—one PC, an amplifier, and one electrode cap or set of electrodes. During testing and depending on the configuration desired by the users, an alternate monitor may be required to increase the viewing capabilities by a person other than the patient (e.g. for debugging purposes).

R[23] The data acquisition system will be integrated into the casing of the PC. **(1)**

R[24] When two displays are required, the alternate monitor may be of any size or type. **(1)**

R[25] The system includes one primary display monitor that is flat 19", CRT type for user stimulus purpose. **(2)**

R[26] The system includes one standard keyboard and a mouse for input for use by a helper. **(1)**

R[27] The data acquisition system will connect to the main PC via a standard PCI slot. **(1)**

R[28] The transmission cable from the amplifier to the data acquisition cable will be shielded. **(1)**

4. Documentation and Training

Primary application of *P300 BCI Spelling Device* will be providing communication medium to those who are otherwise not able to communicate such as people suffering from late-stage ALS. Secondary application will be providing medical professionals and researchers a unique tool to gain insight into MND such as ALS.

This section provides primary users, the patients, brief introduction to capabilities of the system and what they can expect. For secondary users, general specifications, capabilities, installation and setup procedures, maintenance and troubleshooting are provided.

4.1 Documentation and Training for Primary Users

[R29] We will provide on-site training for each user of the spelling device. **(3)**

4.2 Documentation and Training for Secondary Users

[R30] A technical user manual will be provided in English and French. **(3)**

[R31] The user manual will be written based on customers with minimal practical knowledge or experience in electronics devices. **(3)**

[R32] Installation and setup procedures will be provided. **(3)**

[R34] Extra training will be provided upon requests. **(3)**

[R35] Any documentation will contain the company's contact information. **(1)**

[R36] All information required for use of the speller, plus reference documents will be available on our website. **(3)**

[R37] A troubleshooting guide and general help section will be included in the user documentation. **(3)**

[R38] Manufacturer's warranty details will be included in the documentation. **(3)**

[R39] Basic functions, features, and operating modes of the system will be described in the documentation. **(3)**

[R40] Procedure documents on training the disabled will be provided. **(2)**

5. Conclusion

The functional requirements for *P300 BCI Spelling Device* defined throughout this document are meticulously outlined such that both of our prototype and production devices will have the performance previously defined in the project proposal. The functional requirements for prototype will be completed for April 2005. Upon completion of the prototype, assessment will be made to determine the feasibility of further development. Further functional requirements for production device may be completed thereafter.