Case study:
Requirements Engineering in an EEG Spelling System

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Introduction

- ALS patients have received a significant amount of attention in recent years due to Steven Hawking.
- It is a devastating disease that causes the loss of motor skills.
- In order to help patients talk to others, a non muscle communication method is necessary.
  - Is this even possible?
**Electroencephalography (EEG)**

- It might be! With the help of Electroencephalography!
- EEG is a mechanism that uses a set of metal electrodes which stick to different parts of the skull.
- It also detects a micro fraction of electrical change in one’s brain.
- This phenomenon is caused by a group of neurons that discharge simultaneously.
- Does it mean that it is possible for a machine to read you mind?
Electroencephalography (EEG)

- Unfortunately no! It is currently impossible for an EEG to read abstract human thought
- EEG methods such as Event-related potential (ERP), seek electrical patterns after a confirmed target signal from the user (such as a flashing letter on the screen)
- Event-related potential - a generalized EEG pattern which happens between the time when stimulation occurred and 800ms after stimulation
Electroencephalography (EEG)

- Event-related change is looking for change of certain type of wave on the spectrum: Upper Alpha Desynchronize (UAD)
- UAD is compressed when a confirm event happens
Electroencephalography (EEG)

Motor imagery is a kind of EEG based on detecting change in mu and beta rhythms when a subject imagines movement of hand, foot, finger, etc.

C3: left cortex

C4: right cortex
**Ongoing EEG project**

- EEG spelling system prototypes have been built in many Brain Computer Interface (BCI) labs around the world
  - It remains in the lab due to its price and learning curve
- A commercial version EEG spelling system is currently being prototyped by the Algoma University BCI lab
- The project is lead by an elite neuroscientist, and without Requirements Engineering (RE)
- I was working there, and the situation was that a super smart guy assigns job to a super stupid guy who knows nothing about it
Challenge

- It was pain on my ass! Anyway, we made it through
- However, challenges continually arise: it is inevitable that smart people deal with dumb people
  - So RE can help this situation
- Goal: Make a RE document that dumb people can understand
Requirement Engineering Process

- The process will be implemented as follows:
  - Elicitation
  - Analysis
  - Specification
  - Verification
Elicitation: Business process

- From the user perspective: the system will be treated as a black box
- User steps in training scenario:
  1. Mount and setup electrodes (may require abraded skin)
  2. Stare at the screen with flashing targets
  3. Confirm and count whenever a target flashes
  4. System adjusts weights of hypothesis
Elicitation: Business process

- User steps in spelling scenario:
  1. Mount and setup electrodes
  2. User stares at the screen with flashing targets
  3. User confirms and counts up whenever a target flashes
  4. System distinguishes user target
Elicitation: Stakeholders

● ALS patient:
  ○ Loses all motor skills including swallowing and the ability to make sounds
  ○ Normally at the final of stages of their life
  ○ Bad health situation

● Nursing staff:
  ○ Normally lacks ECE background
  ○ Steep learning curve
Analysis: System process

In a lab prototype, an EEG system:

1. Transmitts an audio or visual signal
2. Electrodes collect an EEG signal and send it to an amplifier
3. Amplifier filters out noise and enhances the signal, before sending it to a computer
4. Computer adjusts weights (learning phase) or classifies flashing targets
Analysis: Functional requirements

An EEG system contains:

1. Stimulation firing module
2. Signal capturing module
3. Signal filtering module
4. Signal Amplification module
5. Classification module
Analysis: Non-functional requirements

1. Short classification learning phase, for patients sake
2. High EEG transmission rate which increases efficiency of communication
3. Ease of use:
   a. Patient should understand how to use the EEG
   b. Nursing staff should be able to set up and administer the system comfortably
4. Affordable
Requirements Specification

- Since we’ve collected all of the requirements, it is time to specify and categorize them by different modules
- This section will try to fit requirements and technologies into a module
- Requirement specification will be made via module name, function description, inputs, source, outputs, destination, action, requirements, pre-condition, and post-condition
Specification: Signal firing module

- Critical non function requirements:
  1. High item flashing frequency
  2. Highly efficient event arrangement

- Efficient flashing mechanism:
  ○ Column/Row paradigm -> Checker board paradigm -> “Five flash” paradigm -> asynchronous paradigm

- Presenting content: letters or associated words
Specification: Signal firing module

- **Function**: Sending stimulation signal via a regular monitor
- **Description**: Letters or words will be placed in a 6x6 matrix, asynchronous paradigm should be implemented, and followed by performance guided constraints
- **Input**: Asynchronous paradigm program
- **Source**: Regular computer system
- **Output**: Flashing letters, or associated words
- **Destination**: Patients via regular monitor
- **Action**: The module flashes random combination of letters or words by following the asynchronous paradigm. A flashing section will be terminated when all candidates have equally flashed a designated n times.
Specification: Signal firing module

- **Requirement:** Refer to asynchronous paradigm
- **Pre-condition:** Signal capturing module has been set, and patient has no significant vision problem
- **Post-condition:** Patient should retrieve those visual stimulations without issue
Specification: Signal capturing module

Signal capturing module is starting point of EEG analysis. It also is the only part that has the directly physical contact with patients.

The biggest challenge of this module is to set the entire electrode set to a certain low impedance.

Solution: High impedance signal retrieve part on amp

Challenge No. two: number of electrodes

Solution: less electrodes with precision distribution witch corresponding to stimulated potential is sufficient.
Specification: Signal capturing module

Impedance checking function: easy to use feature.

Component, location, LED color schematic

- Function: Signal capturing module, impedance indicator
- Description: Setup on patients' head, then capture EEG signal from patients' skull
- Input: Raw EEG
- Source: Patients' head
- Output: Raw EEG
- Destination: Signal filtering module
Specification: Signal capturing module

- **Action:** During the setup phase, impedance indicator checks current impedance, and flashes LEDs to indicate the detected figure in an intuitive way. During the spelling phase, electrodes capture and conduct raw EEG signal to signal filtering module.

- **Requirement:** LEDs' color scheme setting should be coherent

- **Pre-condition:** Impedance indication during the setup phase requires assistance from other stakeholders, spelling phase requires setup

- **Post-condition:** Input impedance of signal filtering module should be high impedance
Specification: Signal filtering module

Noise could totally cover the signal, thus it is necessary to put a filtering module there.

**Physical filter:** low-pass filter

**First stage amplify:** reduce noise-to-signal ratio

Software filter could be an backup option.
Specification: Signal filtering module

- **Function**: Hardware signal filtering module
- **Description**: Filters out signal noise, especially the 60Hz noise, and increases signal workload
- **Input**: Raw EEG signal
- **Source**: Electrodes
- **Output**: Purified, and amplified EEG signal
- **Destination**: Amplification module
Specification: Signal filtering module

- **Action:** The hardware filter can filter out noises by manipulating capacitor charging time
- **Requirement:** Size of the capacitor should be carefully selected
- **Pre-condition:** EEG signal is captured by electrode
- **Post-condition:** EEG signal is purified
Specification: Signal amplification module

Three requirements for the amplifier:

1. Diminish the chance of noise amplification
2. Signal retrieval part should be a high impedance device
3. Restrict and specify the range of input voltage
Specification: Signal amplification module

- **Function**: Signal Amplification module
- **Description**: Second stage of filtering, and final amplification
- **Input**: EEG signal after first stage processed
- **Source**: Noise filter module
- **Output**: Amplified digital signal
- **Destination**: Classification module
Specification: Signal amplification module

- **Action**: Amplify EEG signal to digitalizable level
- **Requirement**: Second filter, high impedance signal retrieval function
- **Pre-condition**: Signal voltage in a proper range
- **Post-condition**: Digitalized signal could be recognized by computer port
Specification: Classification module

- Lots of machine learning algorithms can be applied: LDA, NN, SVM, etc.
- Two requisites: classification accuracy, computing power requisite
- They mostly perform equally well, SVM has slightly better performance, but consider the small training set and asynchronous paradigm, LDA would be a promising choice
Specification: Classification module

- **Function**: Classification module
- **Description**: Classify EEG signal to two categories: target or non-target, then match it to corresponding flashing group
- **Input**: Digitalized EEG
- **Source**: Amplification module
- **Output**: Classified user target
- **Destination**: Monitor
Specification: Classification module

- **Action:** Module classifies digitized signal by using LDA method. It measures n flashes, then returns the intersection of flashing groups which have been marked as targets

- **Requirement:** Efficient algorithm, and sufficient training set

- **Pre-condition:** Learning phase has been done, and EEG signal is clear and recognizable

- **Post-condition:** For each flashing set, there is only one target omitted by the system
Verification

Validity checks -- The specified requirements clarify the functional requirements explicitly.

Consistency checks -- The document presents coherency, and no significant conflicts.

Completeness checks -- The document fits in all requirements from user, ie, “easy to use”.

Realism checks -- Technologies implemented by the system are verified, and proven realistic.

Verifiability -- Test case for each module. From user perspective, it works when it works.
Conclusion

- RE made a similar approach to the original project
- RE documents make requirements more explicit and less ambiguous
- RE makes job subletting easier