Method for Monitoring Rapid Eye Movement in Hospital Patients

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Background & Motivation
What is REM and Why does it matter?

Rapid Eye Movement (REM) is a stage of sleep in which there is an increase in eye movement and paralyzation of the body.

The rapid movement is quantifiable by amplitude, frequency, and duration of the eye’s rotation.

REM is one of the most important metrics for a person’s health:

- Research brain activity/development
- Identify emotional/mental state
- Track patient recovery

![EEG Recordings During Sleep](image)
Current Sleep Monitoring Methods Do Not Suit Hospital Need

Polysomnography “PSG” Tests

The **Gold Standard** method but is **expensive and impractical** for general ward setting.

FitBits/Smart Watches

While **affordable**, they only report **correlations to REM** sleep **unfit** for patient care standards.

Dream2 Headband

An **accurate** option that is **not commercially available** for purchase as it is a stage 2 FDA research device.
An improved REM monitoring system is needed to detect the amplitude, velocity, and rotation of eyeball movement. The system must be easy to use and accurate for the duration of patient sleep.
<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification</th>
<th>Verification Status in Dec 2022</th>
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</table>
| Device must monitor the duration of REM sleep   | Continuous REM movement > 1 hr  
Continuous Eye movement for 10 hours | not tested                      |                                 |
| System must quantify sleep characteristics       | Eyeball Rotation: 0.5-13.5 degrees  
Eyeball Velocity: 120 degrees/sec  
Sampling Rate > 40 Hz | 13.5 degrees met,  
0.5 degrees not met, minimum 6 degrees detected  
120 degrees/sec met, verified for 900 degrees/sec  
system samples at 220 Hz |                                 |
| System must be able to differentiate head from eye movement | exclude head movements > 20 degrees/sec | not tested                      |                                 |
| Device must be capable of data storage and output | report data in 1s, 5s, 10s, 20s intervals | data post processing filters in range of any size |                                 |
| Device must not be affected by electrical noise   | Filter noise > 500 Hz                                                        | data post processing utilizes digital low pass filter |                                 |
| Device must be safe to use and operate           | IEC 60601 and ISO 14971                                                      | not tested                      |                                 |
| Device should fit a variety of head sizes        | weigh < 5lbs  
breaths: 147.6 to 167.1 mm  
lengths: 169.6 - 193.2 mm  
circumference 541.1 - 605.8 mm | final device weighs 0.25 lbs  
breadths from 142.24 - 246.38 mm  
lengths from 101.6 - 203.2 mm  
circumference range of 401.32 - 701.04 mm |                                 |
| Device must be easy to use                       | Device set up time for medical staff < 5 min  
Device set up for at home use < 10 min | not tested                      |                                 |
| Device must be suitable for diverse populations  | patient age > 18 years old  
adjustable for pupil distance 54 - 77 mm | met automatically               |                                 |
| Device must be comfortable during use           | sleep disturbance less than control  
non invasive | not tested                      | final device does not enter patient's body |
| Product should be environmentally sustainable    | ISO 1135 - reusability  
ISO 11607 - material toxicity  
rechargeable batteries | not tested                      | not tested                      |
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Eye Mask

Arduino + Breadboard Circuit

4ft chord
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Arduino Collects Sensor Voltage Output

Data Stored and Plotted in MATLAB
**Completed Requirements**
- System must quantify sleep characteristics
- System must differentiate head from eye motion
- Device must be capable of data storage and output
- Device should fit a variety of head sizes
- Device must not be affected by electrical noise

**Unmet Requirements**
- Device must be comfortable during use
- Device must measure the duration of continuous eye movement
- Device must be easy to use
- Data must isolate head from eye motion
ME490 Tasks to Meet the Three Requirements

**Device must be comfortable during use**
- All hardware self contained in the mask (area less than 240 mm x 35 mm)
- Device is cordless

**Device must measure the duration of continuous eye movement**
- Device is powered continuously for 8 hours

**Device must be easy to use**
- Completed instructional manual for user-testing
Version 2 Prototype

MECHENG 490 Work
Data Storage: SD Card

- Saves Data
  - Matches MATLAB at 220 Hz
  - Writes to txt file
  - Names files differently per patient

- Contains Minimal Limitations
  - SD card is write protected - no files can be deleted off SD card
  - A new 128 GB card will need to be purchased after 3000 eight hour trials
Power Supply: Rechargeable Battery

- Powered V1 Prototype at 3.3 V
  - Sample rate was unaffected
- Determined the minimum power requirement for device to monitor for 8 hrs using a Source Meter
  - 4.7 Ahr for an active SD card
  - 2.3 Ahr for a passive SD card
- Researched thin, light, rechargeable LiPo Batteries
  - 3.7 V MIKROE-4475 6 Ahr (67 x 99 x 8.1 mm)
  - 3.7 V MIKROE-4474 3 Ahr (57 x 63 x 8.1 mm)
Microprocessor: Seeeduino XIAO

- Meets all Pin Requirements
  - 2 Analog Inputs for Optical Sensors
  - I2C communication for IMU
  - SPI communication for SD card
- Operates at 3.7 V
- Interfaces with Arduino IDE
- Decreases area to one-ninth size
Circuit Construction: Custom Printed Circuit Board

- Minimizes wires needed and length
- Contains all electronics on face of mask
- Iterated Designs
  - First design mimicked mask
  - Second design minimized area
Inside

Outside
Power Supply
Results

Version 1 and Version 2 Prototype
Version 1: System Differentiated Head and Eye Movement

- Eye Data
- Head Still, Sweep Motion

Charts and graphs showing sensor output over time and Gx and Gy values.
Speed of Head Rotation Can Impact Optical Change
Concern: Mask Fit Could Impact Detected Movement

Loose Mask

Tight Mask
Version 2: IMU communication not connected

- SD card collects optical sensor data perfectly fine on PCB, battery powered

- IMU communication is unrecognized by Seeeduino on PCB
  - IMU was recognized by Seeeduino on breadboard before soldering
  - Separate Seeeduino breadboard & IMU set up is now also unrecognized
Most Likely Cause for IMU is software related

- Difference in MCU architectures has slight changes with interaction to Arduino IDE scripts
  - Version 1 Arduino is ATmega328P
  - Seeeduino XIAO uses SAMD21
- `<Wire.h>` library should work for SAMD21 but unclear if `<MPU6050.h>` sublibrary can work too
- Recommendation: rewrite IMU code without MPU6050 library
Version 2: Sweep and Static Eye Motion Detected
Conclusions

Device is comfortable during use

- Device operates without cords
- All hardware is on the eye mask

Future Work

Improve form factor security
**Conclusions**

*Device is comfortable during use*
- Device operates without cords
- All hardware is on the eye mask

*Device must measure the duration of continuous eye movement*
- Device can supply power between 5.5-10 hours

**Future Work**

*Improve form factor security*
*Report data collection in UTC time*
Conclusions

**Device is comfortable during use**
- Device operates without cords
- All hardware is on the eye mask

**Device must measure the duration of continuous eye movement**
- Device can supply power between 5.5-10 hours

**System must differentiate head from eye movement**
- IMU currently uncommunicative

Future Work

**Improve form factor security**

**Report data collection in UTC time**

**Rewrite IMU code**
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