Pupil Size and Movement Tracking Through Closed Eyelids

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Background

Problem:

Sleep is critical for physical and mental health [1], yet more than 25% of U.S. adults do not get enough sleep [2]. Poor sleep can result in cardiovascular, cognitive, and neurological disorders [1]. Pupil size and movement provide key insights into sleep stages and autonomic nervous system activity [3].

Limitations With Current Solutions:

- EOG detects eye movement but not pupil size [4]
- Camera-based tracking requires open eyes [5]
- No wearable system for pupil tracking during sleep

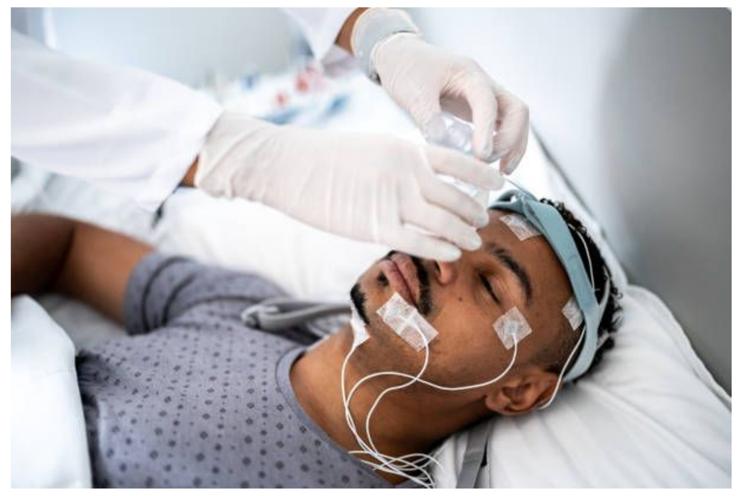

Figure 1: Current methods of preparing a patient for a sleep study (polysomnography) requires extensive wiring and clinical environments

Methods

System Design

- Augmented sleep mask designed in SOLIDWORKS and 3D printed in black PLA
- Foam lining for user comfort and ambient light blocking
- Embedded Raspberry Pi 3B+ for data acquisition
- Arducam IMX290 (NoIR) camera set over right eye

Infrared (IR) Illumination

- LED arrays assembled with 5 LEDs connected in series
- Wavelengths tested: 850 nm, 890 nm, and 950 nm

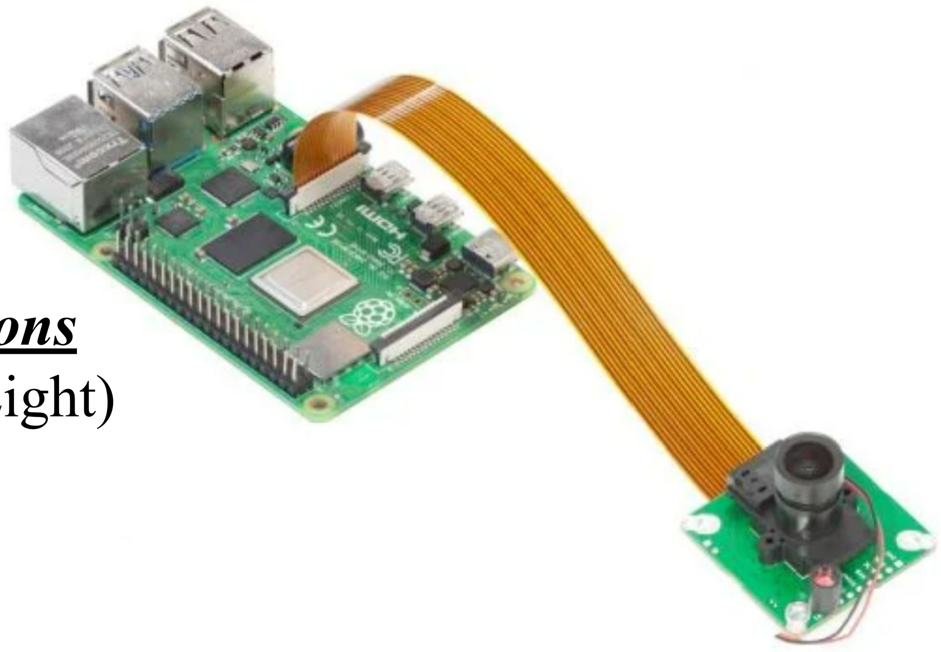

Figure 2: Camera module connected to Raspberry Pi 3B+

Experimental Conditions

1. Baseline (Room Light)
2. Open Eye + IR
3. Closed Eye + IR

Evaluation Metrics

- Pupil Visibility (detectable vs non-detectable)
- Image Contrast (pupil vs surrounding region)
- Clarity (edge definition and distortion)

Results

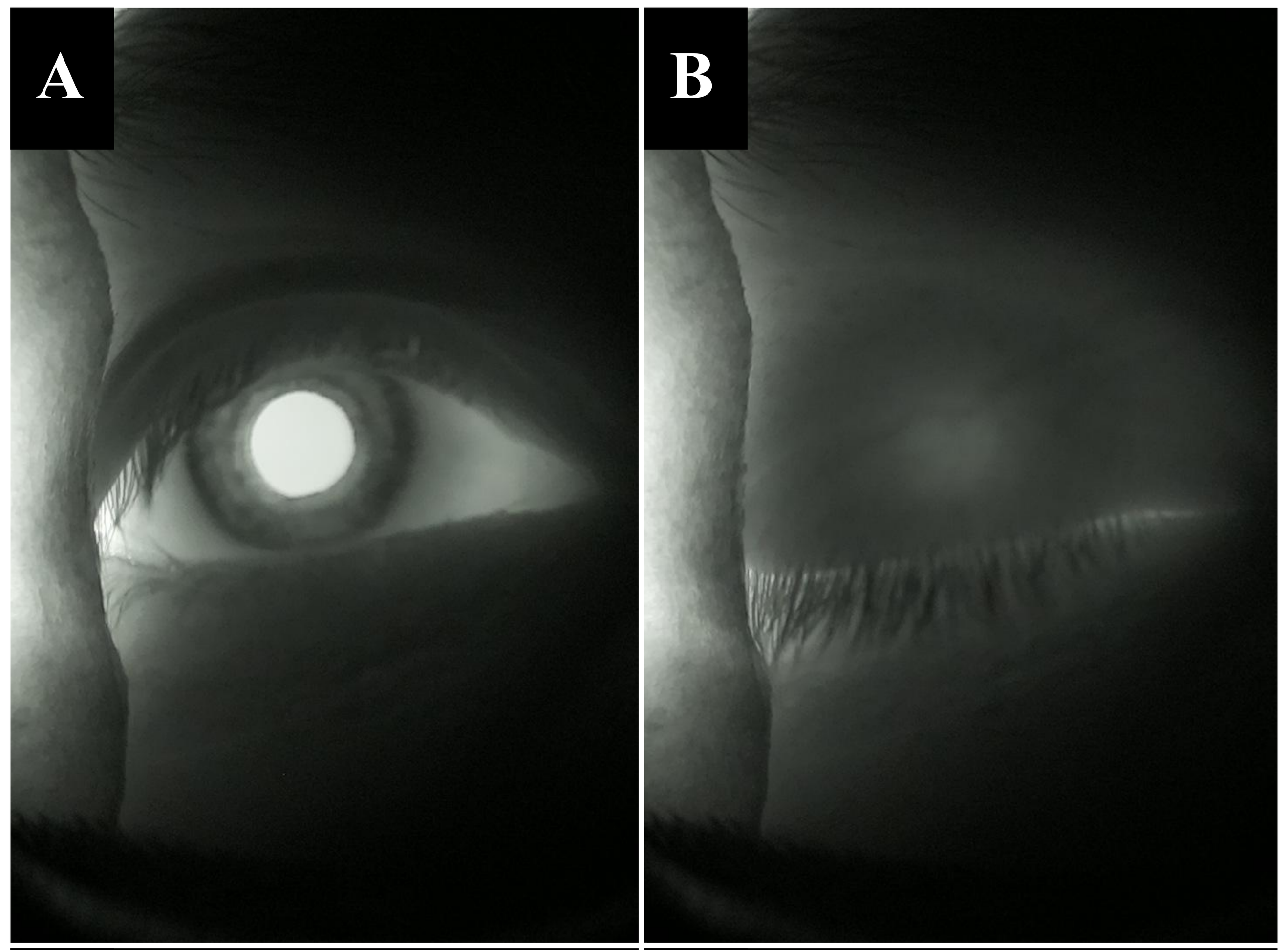

Figure 3: (A) Open eye image taken with an augmented sleep mask with an 850 nm 5-LED array placed on the temple **(B)** Closed eye image taken with an augmented sleep mask with an 850 nm 5-LED array placed on the temple

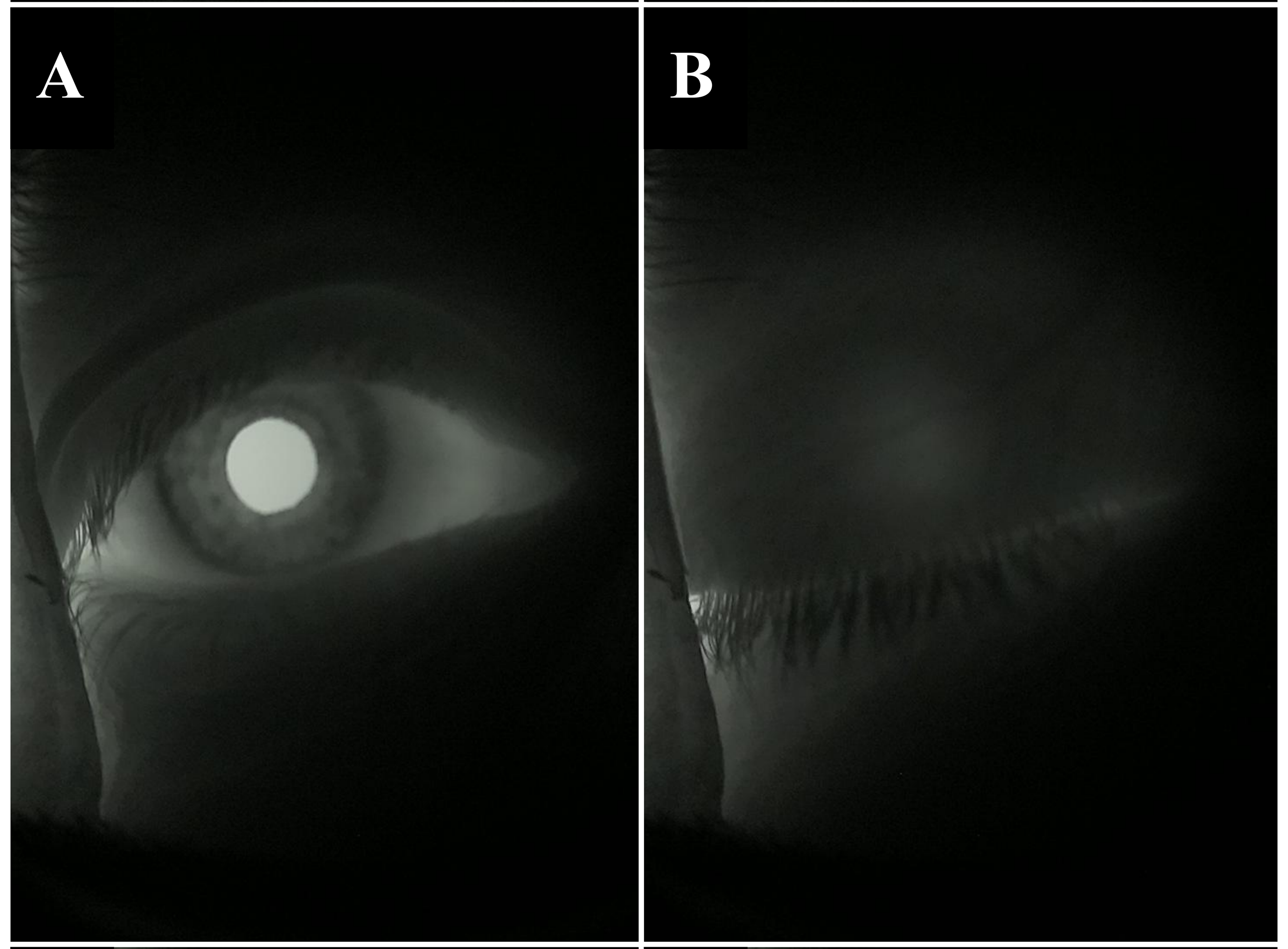

Figure 4: (A) Open eye image taken with an augmented sleep mask with an 890 nm 5-LED array placed on the temple **(B)** Closed eye image taken with an augmented sleep mask with an 890 nm 5-LED array placed on the temple

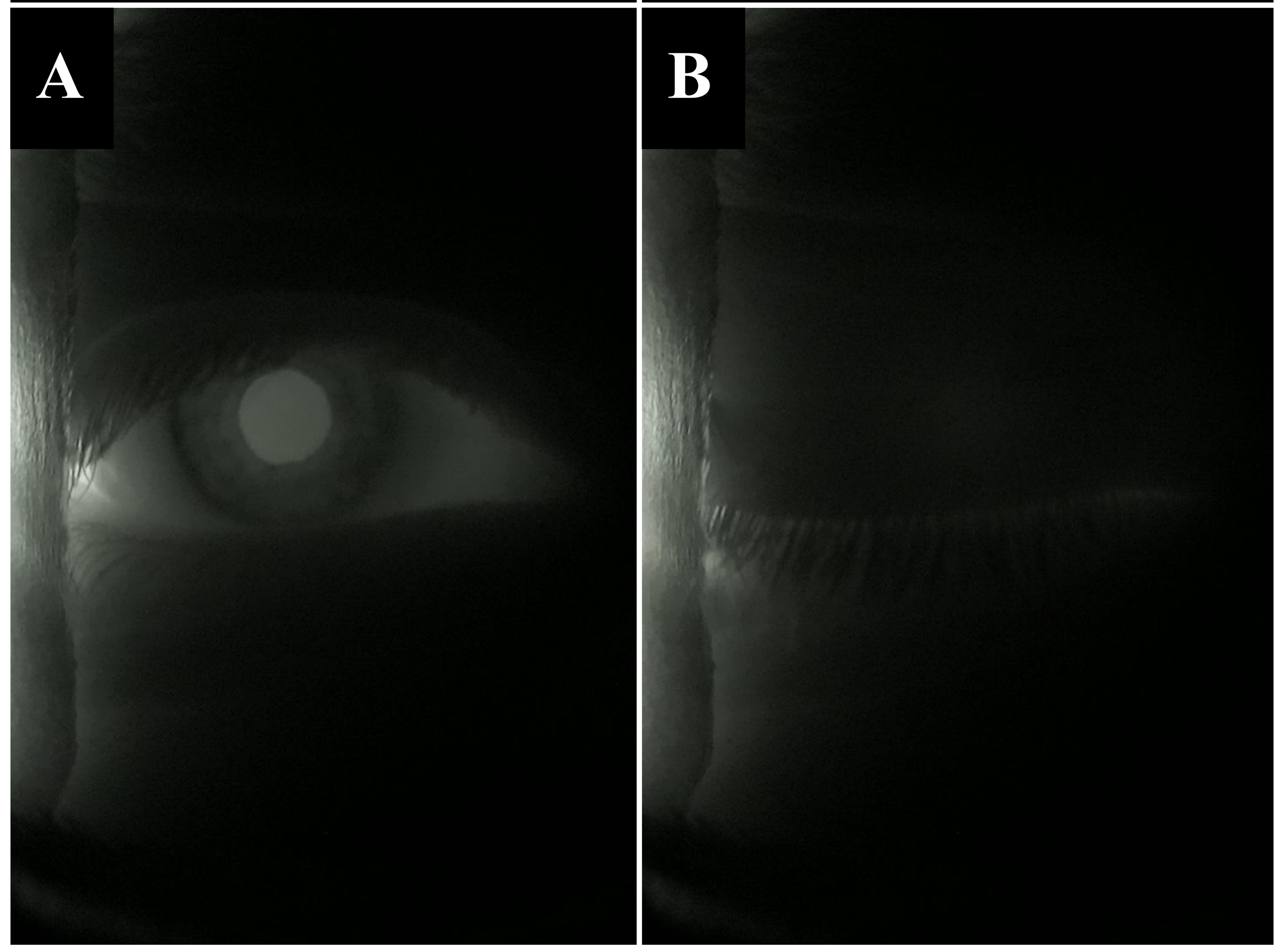

Figure 5: (A) Open eye image taken with an augmented sleep mask with an 950 nm 5-LED array placed on the temple **(B)** Closed eye image taken with an augmented sleep mask with an 950 nm 5-LED array placed on the temple

Results

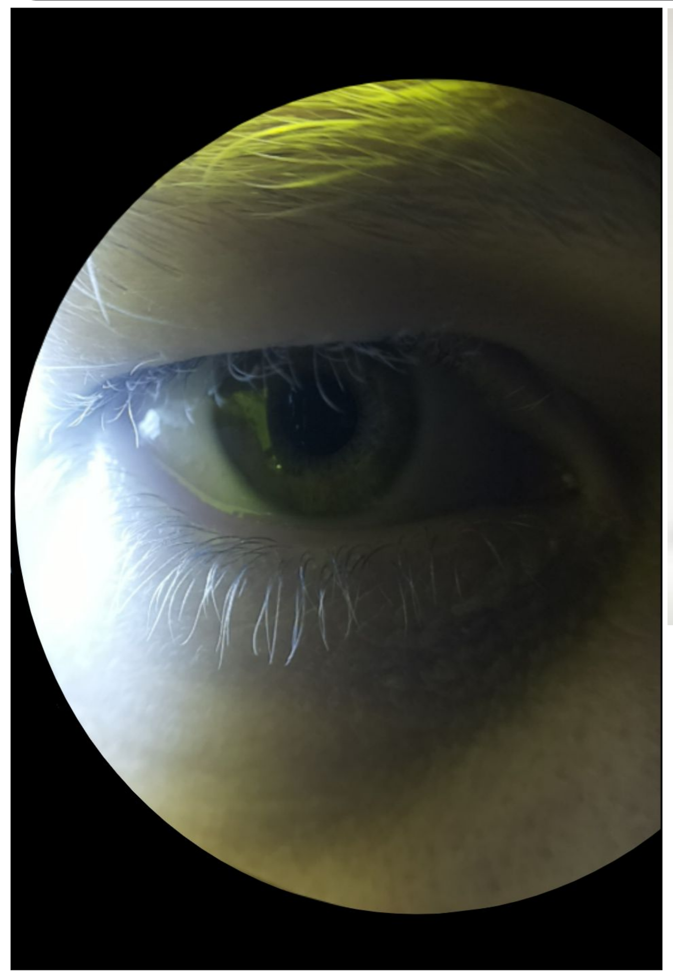

Figure 6: Baseline image taken with NoIR conditions

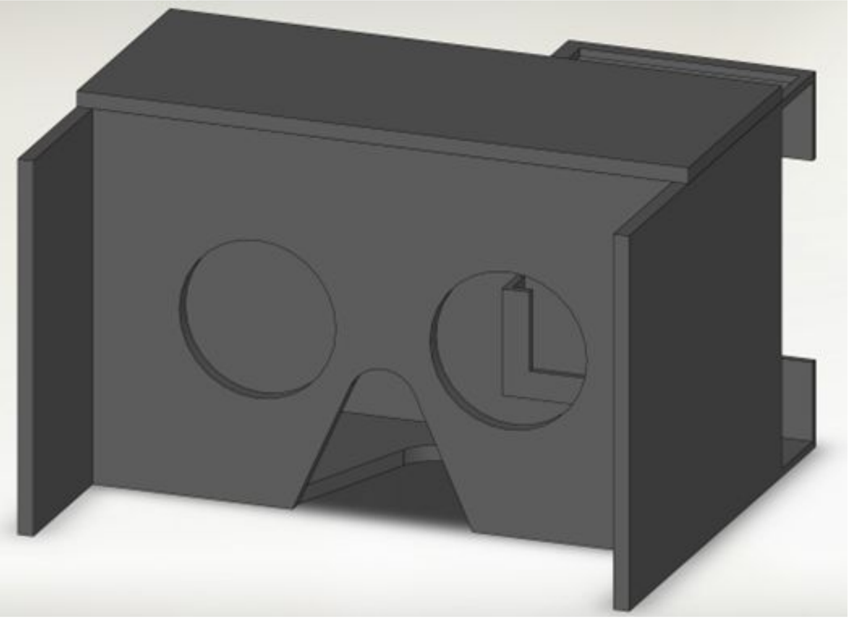

Figure 7: Augmented sleep mask construction designed in SOLIDWORKS. Incorporates mounts for the camera module and Raspberry Pi for portability and consistent imaging

Discussion

- 850 nm wavelength (Fig. 3A, 3B) produced the highest image clarity and contrast
- Image quality is limited by tissue scattering and signal attenuation, affecting pupil edge definition
- Future work will focus on dual-eye imaging, improved light isolation, and optimized IR illumination
- Establishes a foundation for wearable, noninvasive sleep monitoring

Acknowledgements

I would like to thank Dr. Daniel Gulick and Dr. Jennifer Blain for their mentorship and insights throughout this project.

References

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