Smart Glasses for Monitoring Eye Damage Risk from UV Exposure

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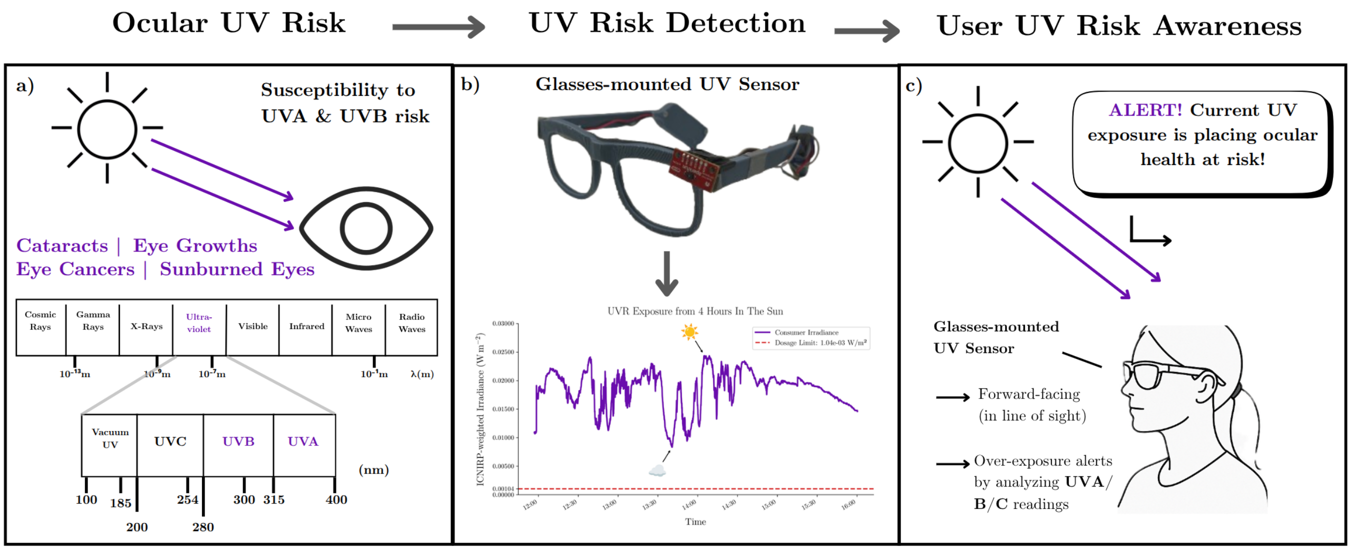

Fig 1: a) The risk of eye damage from UV radiation. b) Our UV smart glasses and preliminary results c) The future version of smart glasses that track UV radiation doses and inform proactive healthcare.

***Abstract*—Current developments in wearables and body sensors have largely overlooked measuring the risk of eye damage due to UV radiation. This work addresses that gap by designing smart glasses capable of measuring UV exposure directly incident on the eyes. Leveraging a UV sensor by AMS-Osram and a compact ESP32S3 microcontroller, our prototype collects UVA/B/C data in real time. We developed a data pipeline to convert raw sensor output into spectral irradiance and compare fluence values against established ICNIRP ocular UVR exposure thresholds. Preliminary field measurements indicate ocular UV exposure often exceeds safety limits, demonstrating the urgency of this problem and the feasibility of our approach. Our work lays the foundation for affordable, wearable UVR monitoring tools that could support preventative eye care and future smart eye-wear designs. This paper issues a timely call to the body sensor network (BSN) and physiological sensing communities to integrate UV sensors into smart glasses.**

***Index Terms*—ultraviolet radiation, ocular health, smart glasses, smart eye-wear, wearable sensors, spectral irradiance**

I. Introduction

Exposure to ultraviolet radiation (UVR) increases the risk of eye damage. In addition to causing eye cancers like ocular melanoma, UVR may lead to photokeratitis (corneal sunburns) and pterygiums (growths on the eye surface) in the near term. Over the long term, UVR contributes to cataracts and macular degeneration (progressive damage to the macula, a region in the center of the eye). These conditions impair people's vision [11], [13]. The World Health Organization (WHO) estimates 15 million people have gone blind due to UVR-induced cataracts [9].

Preventing eye damage due to UVR requires more than population-level metrics, such as the UV Index (UVI), or delayed clinical feedback from eye exams. These approaches do not capture how much UVR actually reaches an individual's eyes. Real-time, personalized monitoring of eye damage risk from UVR exposure could enable proactive care [10].

Smart glasses provide a way to measure people's risk of eye damage due to UVR exposure. Advances in sensor power efficiency and size make feature-rich smart glasses more realistic than ever [10]. At the same time, the market for smart glasses is expanding rapidly [10], with growth rates of 210% in 2024 [14].

Despite the rapid adoption of smart glasses, no existing or proposed devices incorporate UV sensors specifically designed to monitor the risk of eye damage. To effectively assess UV-induced eye damage risk, smart glasses must do the following: 1) **Measure eye radiation**: Devices must track radiation incident on and perpendicular to the eyes [12], [19]; 2) **Measure UVR dose**: Devices must track the user's daily UVR exposure; 3) **Compare UVR dose with exposure limits**: Devices must compare the dose against international safety limits in order to assess a user's eye damage risk [12]; 4) **Adopt a glasses form factor**: Devices must have a form factor that supports daily use; otherwise, they do not facilitate real-time personalized monitoring of the risk of eye damage.

This paper issues a timely call to the body sensor network (BSN) and physiological sensing communities to integrate UV sensors into smart glasses. This paper makes the following specific contributions: 1) An initial **smart glasses prototype** that uses the AMS-Osram AS7331 sensor and the ESP32S3 microcontroller to collect real-time UVA/B/C irradiance measurements (Section III); 2) A **method to quantify eye damage**

risk due to UV exposure (Section IV); 3) **Field measurements** that show UV doses exceed eye exposure limits, which implies the risk of UV-induced eye damage is high (Section V). This lays the foundation for affordable, wearable UVR monitoring tools that facilitate proactive eye care and future designs for smart glasses.

II. Background & Related Work

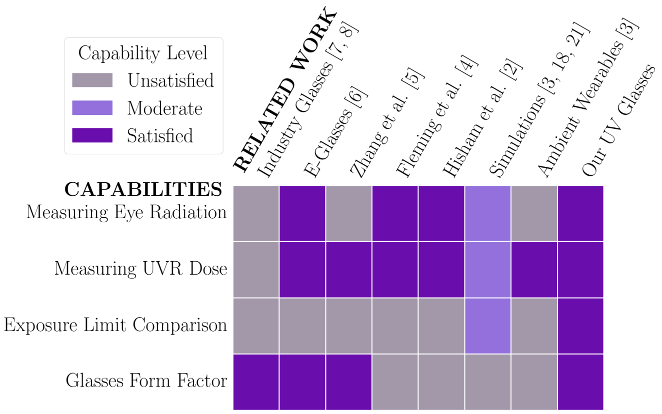

Fig. 2: Comparison of approaches to measure eye damage risk from UVR

No smart glasses in industry or academia track the risk of eye damage due to UVR. In industry, smart glasses such as the Xreal One [7] and Ray-Ban Meta smart glasses [8] provide some UV protection, but do not measure UVR. UV protection is assumed to be sufficient; however, even lenses labeled as offering 100% UV protection may fail to meet International Organization for Standardization (ISO) standards [1].

In academia, research has explored smart glasses, contact lenses, simulations, and methods to measure ambient UVR. In the smart glasses area, Lee et al. proposed E-Glasses with UV-based color-tunable lenses; however, the system neither compares UVR irradiance incident on and perpendicular to the eye, nor does it compare UVR doses against safety thresholds [6]. Zhang et al. proposed AR glasses connected to an arm strap with a UV sensor, but this does not capture irradiance reaching the eyes [5].

In the contact lenses area, Fleming et al. developed a UV sensor array that attaches to the eyelid. However, it only works when the user is stationary, and the array is uncomfortable [3], [4]. Hisham et al. proposed 3D-printed contact lenses that measure total UV irradiance. While innovative, their design is not well-oxygenated, which is essential for comfort, and it does not quantify UV doses to compare against international safety limits. [2], [12].

Research efforts explored simulations to measure UVR exposure. Anthropomorphic manikins are dummy heads with UV sensors embedded in the eye regions [3], [16], [19]. Manikins stay in place for an extended period of time, so they cannot measure differences in daily exposure to UVR attributable to dynamic human behavior, such as head turning, blinking, or movement [3]. Solar simulator experiments, which emulate the sun to test sunglasses' UV protection [16], also do not account for daily UV exposure differences. Numerical simulations which model the radiation effects of UV sources on human eyes are an interesting avenue for future research, but they are not yet usable [3].

In addition to smart glasses and contact lenses, there are other methods to measure ambient UV light, such as skin patches and wristbands [3]. However, according to the International Commission of Non-Ionizing Radiation Protection (ICNIRP), a UVR dose should measure the radiation incident on and perpendicular to the eye in order to be properly compared with ICNIRP exposure limits [12]. These guidelines reinforce the need for positioning sensors at a location and angle that reflect real-world ocular UV exposure. While glasses are placed in the user's line of sight, making them appropriate for measuring UVR reaching the eyes, alternative wearables, such as wristbands, are more appropriate for tracking the skin's UV exposure. Sasaki et al. demonstrate ocular UV exposure differs significantly due to facial anatomy [19]. The eye is shaded from above by the brow ridge and upper lid, from below by the cheeks, and from the side by the bridge of the nose, limiting direct light from many angles. For this reason, UVI cannot account for ocular UV exposure because it is based on irradiance incident on the skin and does not consider head position [19].

III. Initial Prototype

Fig. 3: Our smart glasses prototype with UV sensor

Our goal is to use off-the-shelf, low-cost components to build smart glasses that provide users with real-time feedback on their UV exposure. To measure UVR, we selected the AS7331 sensor [20]. It captures irradiance in three spectral channels: UVA, UVB, and UVC. Each channel on the AS7331 has individual photodiodes with interference filters, allowing for accurate, continuous measurement of each band.

The sensor is connected to a XIAO ESP32S3 microcontroller [21], chosen for its compact size and Bluetooth Low Energy (BLE) capabilities. Power is supplied by a compact 3.7V lithium battery mounted behind the ear. All components are embedded within a custom 3D-printed glasses frame designed to balance weight and ensure comfort.

IV. Comparing Against Dosage Limits

In addition to a smart glasses prototype, we designed a pipeline to convert broadband irradiance (or the total irradiance of a UV band) into a quantity that can be compared against dosage limits (Fig. 4). The UV sensor collects raw UV data, which is converted to broadband irradiance (μW/cm^2). The UV sensor collects raw data in units of digital counts (Fig.

4i). For some set quantity of UVA/B/C irradiance the UV sensor detects, it increments its count [15]. The sensor's library converts digital counts into irradiance (Fig. 4ii). (μW/cm^2).

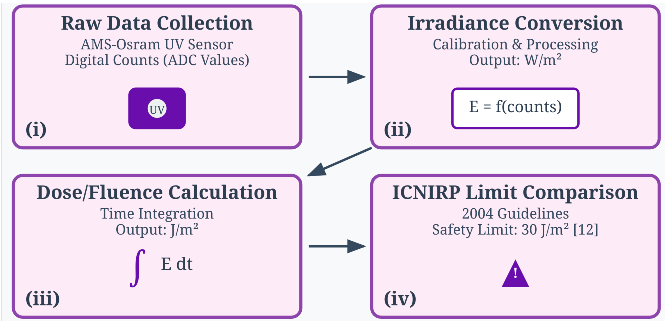

Fig. 4: Our data pipeline takes raw UVR data and determines whether a user is at increased eye damage risk.

Broadband irradiance (W/m^2) can be converted to global irradiance (W/m^2) in two steps (Fig. 4iii). First, we decompose broadband irradiance using the Tropospheric Ultraviolet and Visible (TUV) model. The TUV model is a widely used method to estimate absolute spectral irradiance (irradiance at a given wavelength) at a given location and time [22]. We defined a relative spectral distribution:

$$tuv_{\text{rel}}(\lambda_1, \lambda_2) = \frac{\big(tuv_{\text{abs}}(\lambda_1), \ldots, tuv_{\text{abs}}(\lambda_2)\big)}{\sum_{\lambda \in [\lambda_1, \lambda_2)} tuv_{\text{abs}}(\lambda)}$$

where λ represents a specific wavelength, and $tuv_{\text{abs}}(\lambda)$ is a function that takes a wavelength and outputs estimated irradiance. If $f_{\text{band}} = tuv_{\text{rel}}(\lambda_1, \lambda_2)$, where λ_1 and λ_2 are the boundaries of UV bands, and E_{band} is the band's irradiance, we find a function that takes broadband irradiance and outputs spectral irradiance $E(\lambda) = E_{\text{band}} \cdot f_{\text{band}}(\lambda)$.

Second, we weight each UV wavelength according to an action spectrum [12], [16]. Given $S(\lambda)$ is a function that maps UV wavelengths to their relative harm on human eyes, the equation for weighted global irradiance is $E_g = \int_{\lambda_1}^{\lambda_2} E(\lambda)S(\lambda)\,d\lambda$ [16]. The integral of weighted global irradiance E_g with respect to time t is referred to as fluence H (J/m^2): $H = \int_{t_1}^{t_2} E_g dt$.

Fluence values must be lower than 30 J/m^2 over 8 hours (Fig. 4iv) [12]. Otherwise, one may be at increased risk of eye damage. These dosage limits are published by the ICNIRP. They are the most recent published quantitative eye safety limits for UV radiation (that the authors could find). Two studies assessing the effectiveness of sunglasses at assuring eye safety from UV radiation use ICNIRP limits [16], [17]. Critiques of the ICNIRP action spectrum that argue it underestimates damage say there is a consensus on these dosage limits [18].

V. Field Testing

Field testing determined whether humans were at risk of eye damage. Before conducting field testing, we validated the AS7331 UV readings against the measurements of a commercial-grade Martin Allen sensor [24]. We kept both sensors stationary, pointed them at the sun, and collected hourly data samples over a full day in September in Evanston, Illinois.

To compare our sensor's outputs (UVA/B/C broadband irradiance readings) against the Martin Allen sensor (UV Index), we convert UVA/B/C to UVI. First, we decompose broadband irradiance into spectral irradiance using the TUV model (as explained in Section IV), and second, we plug in spectral irradiance into an equation consistent with the WHO definition of the UV Index [23]. In Fig. 5, the output of the AS7331 is closely related to the Martin Allen sensor. Moreover, the AS7331 tracked the commercial-grade sensor with a bias of -2.6% and an RMSE 28.2%, acceptable for dose estimation.

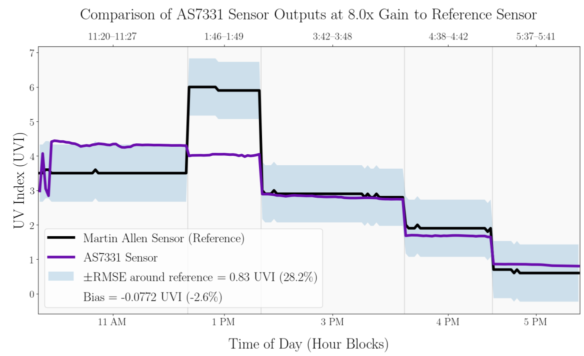

Fig. 5: Data samples collected from the consumer-grade AS7331 sensor with 8x gain and the commercial-grade Martin Allen sensor over a day.

After validation, field testing indicated humans exposed to sunlight for long periods are at risk of UV-induced eye damage. As shown in Fig. 6, one author stood outside with the UV glasses, stationary, in the sun for 4 hours, from 12:00 PM to 4:00 PM, on a slightly cloudy September day. The author was exposed to ~270 J/m^2 of UVR weighted by the ICNIRP action spectrum, which exceeds the safety limit of 30 J/m^2 over 8 hours. On the other hand, when the author was indoors for 2 hours, the total weighted UV dose was ~0.25 J/m^2.

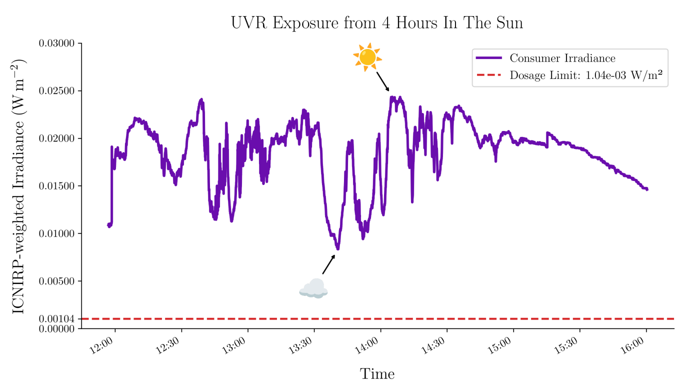

Fig. 6: UVR sampled over a day, compared against dose limits (30 J/m^2 divided by 8 hours is 1.04e-03 W/m^2). At peaks, it was sunny, at troughs, it was cloudy.

VI. Discussion & Future Work

This work paves the way for future work integrating UV sensing in smart glasses. While smart glasses currently cost ~$300, this prototype uses components that keep the cost under $45. The AS7331 provides sufficient granularity to track general trends in UV exposure over time. However, several key avenues must still be explored to scale this technology: 1) **User studies**: We plan to conduct user studies to validate that our system is wearable and that battery life is sufficient; 2) **Sensor position**: We plan to verify that our sensor position properly measures UVR on the eye; 3) **Sunglasses compatibility**: To ensure accurate UV dose estimation when users wear sunglasses, we will investigate two approaches: modifying the data pipeline to account for lenses that have UV protection or positioning the sensor behind sunglass lenses to better capture UVR exposure.

VII. Conclusion

We developed smart glasses that monitor ocular UV exposure. This offers a promising solution for long-term monitoring of factors that impact eye health. It uses an UV sensor AS7311 to capture raw UVR data, which is compared against published ICNIRP dose limits using our data pipeline. Field testing revealed ICNIRP dosage limits were exceeded even during relatively short periods, warranting alarm over the impact of UV radiation on eye health. We urge the BSN community to consider future research to integrate UV sensors into smart glasses.

VIII. Acknowledgment

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