See UV on Your Skin: An Ultraviolet Sensing and Visualization System

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ABSTRACT

These days, as the Earth's protective ozone layer gets thinner, ultraviolet (UV) radiation threat is growing. In addition, getting tanned as a fashion leads people to wear less clothing, which increases UV intake. Excessive exposure to ultraviolet will lead to sunburn and even skin cancer. Therefore, neither insufficient nor excessive exposure is desirable. Although there are tons of UV meters on the market, a user may have a hard time to understand the unintuitive UV index reading. Thus, there is a potential demand for a portable system which can keep track of daily UV exposure dose, visualize possible sunburned consequences, and provide appropriate skin care recommendations. In this paper, we present a personalized UV monitoring and notification system. This system can continuously track UV exposure by wearable UV sensors. It can also visualize the cumulative UV exposure dose according to a predictive sunburned skin color model. Such an augmented skin color can provide a warning message to indicate the possible result of continuous UV exposure. Compared with other existing systems, our solution not only allows users to monitor their daily UV exposure, but also provides an unobtrusive UV visualization model which effectively warns users to take appropriate actions to avoid potential skin damage. The system has been tested on 9 subjects, and the evaluation feedback indicates that our system is promising for UV monitoring and sunburn prevention.

Categories and Subject Descriptors

H.5.m. [**Information Interfaces and Presentation (e.g. HCI)**]: Miscellaneous

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General Terms

Human Factors; Design; Measurement; Sensory Augmentation; Ultraviolet Monitoring.

1. INTRODUCTION

Excessive ultraviolet radiation is one of the most significant issues in these days. The overdosed ultraviolet exposure can lead to sunburn and even skin cancer, the most common type of cancers in the United States [4]. One of the shocking facts is: one in five Americans develops skin cancer in a lifetime [14], which means more than 3.5 million skin cancers are diagnosed annually [15]. According to a report [8], skin cancer is also the most costly of all cancers to treat.

Figure 1: UV Sensing and Visualization System Prototype.

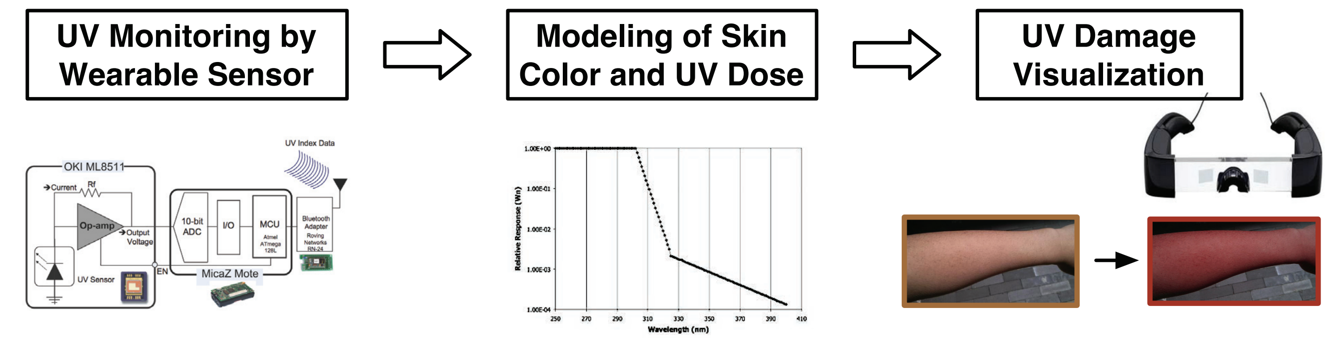

Figure 2: System Overview. Three components in the UV sensing and visualization system: UV sensor, UV-Skin Modeling and Damage Visualization.

Overexposure to sun radiation, especially within the ultraviolet region of the spectrum, is the predominant risk factor for the development of skin cancer [9]. While moderate amount of sunlight is helpful to synthesize vitamin D, excessive UV radiation can increase the chance of skin cancer and cause severe eye injuries. A field study [7] investigated UV exposure of six different outdoor activities (Tennis, Sailing, Swimming, Walking, Golfing and Gardening) in seven anatomical sites over two consecutive days. The result of high amount of UV exposure verified the necessity to monitor UV during outdoor activities in order to avoid skin and eye damage.

The effect of UV exposure can first cause darken and tan [3] on surface skin. When UV radiation is abundant, Epidermis, the skin cells in the top layer, efficiently produce melanin, a pigment giving skin its natural color. Therefore, skin color change in sunburn can notify people, and is widely used as an indicator of the degree of UV exposure. Unfortunately, it is always too late to apply protection when overexposure already comes into effect. Therefore, a UV real-time monitoring and warning system is desirable to notify users before they get sunburned.

In this paper, we present the design of a wearable UV sensing and visualization system for outdoor skin protection, as shown in Figure 1. There are three main components in the system. UV radiation monitoring and recording are the first step. UV index is a commonly accepted parameter for measuring UV radiation intensity. Our system uses ML8511 UV sensors to monitor UV index and record the monitoring results. Since the damage caused by UV is accumulated over days, the sensor data should be stored in order to make personalized skin care suggestions. Also, these data can be also sent to doctors for credible recommendation. Second, a skin color model based on four different skin types is built. We refer preliminary knowledge about human skin to develop the ultraviolet responsive color model of skin. Thus we can predict and exaggerate the sunburn visual effects on a variety of skin types. Finally, participants wear AR glasses in order to see augmented sunburn effects on their body parts. Our visualization deliberately over-amplifies the effect of overexposure to better warn users the consequence of sunburn.

The remainder of the paper is organized as follows. Section 2 briefly discusses previous researches and compares our system with their systems. Section 3 describes our system architecture as a high level overview. Section 4 debriefs system design in hardware sensors, modeling and visualization. In Section 5, the experimental setup and results are shown, followed by a discussion of the results and future work in Section 6. Finally, section 7 concludes our work.

2. RELATED WORK

There are two types of products in UV monitoring. The first type products record accurate measurement with a personal UV meter. The second type provides a visual warning to users by using paper wrist strap which will change color under high UV index.

The personal UV meters [5] are normally designed as accessories on bag or clothes. Some of them may have small screens to display the current UV index. The advanced ones can connect with computer to record daily UV data. These UV meters let users know real-time UV index in current location. The measurement is more accurate than weather report, which only provides hourly forecast in a large area. However, the UV meter is not visually convincing. The best visualization it can achieve is to display UV index on a small screen. However, users have little idea about what the UV index means and how serious the damage will be.

On the other hand, a company tries to use a paper wrist strap [6] to warn users by visual effect. It changes color with UV index so that users will be notified when the UV index is high. It is a great practice as paper wristband is relatively low-cost. However, it is disposable and becomes invalid once triggered by high UV index. Thus users have to prepare several wrist straps, which can be inconvenient. Moreover, it can neither provide accurate UV data, nor record daily UV dose for long term analysis.

These attempts confirm the need of an effective personalized UV monitoring and visual notification system. They enlighten us to come up with a new system which can monitor UV dose by wearable sensors, analyze with skin model, and exaggerate sunburn effect to notify users to apply protection, such as sunscreen.

3. SYSTEM OVERVIEW

Our system, as shown in Figure 2, monitors UV index from sensors, calculates effective UV dose based on skin model, and finally visualizes UV effect to warn users. The UV sensitive sensor only provides output voltage corresponding to UV intensity; thus we have to first derive UV index from the output voltage. Then, the system accumulates UV radiation information to calculate the effective dose of UV. After the user enters his/her personal skin information, our system can choose proper skin model for the user. With personalized skin model, our system can better estimate possible sunburn effective skin color. Finally, an AR glasses visualizes over-amplified sunburn on the skin in order to warn the user. The following sections provide more system design detail in hardware, modeling and visualization.

4. HARDWARE SYSTEM

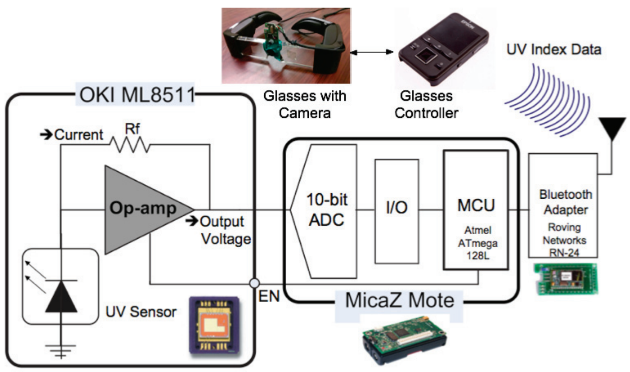

Figure 3: Hardware Design Diagram.

In this section, we discuss the hardware design of our personalized UV monitoring and visualization system. The system structure is shown in Figure 3. In our design, the system consists of three main parts: a wearable UV sensing system, a skin color computational model and a UV effect visualization glasses. Firstly, the sensor measures UV intensity and computes UV index. When a Bluetooth adapter sends UV data from sensors to an AR glasses controller, the computational model can predict the UV effect on the skin. In the end, our system augments the results on the AR glasses for users. In the following part, we will introduce hardware components in detail.

4.1 UV Sensor System

We collect UV data using portable sensors with controlling and wireless transmission system.

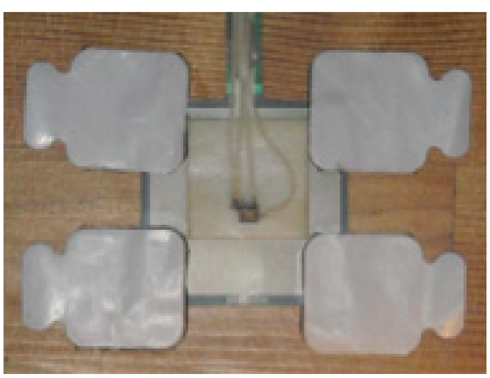

Figure 4: ML8511 UV Sensor on a Patch.

The ML8511 sensor in Figure 4 is a photo diode that measures UV intensity by thin-film Silicon-On-Insulator (SOI) Technology. The additional filter further improves the accordance with the erythema action spectrum curve of the human skin. Its current-to-voltage conversion amplifier is comprised of an operational amplifier and a resistor, which provides output voltage proportional to electrical

Sensor output voltage	ADC output	UV index
0.993	320-345	0
1.073	345-370	1
1.153	370-395	2
1.233	395-420	3
1.313	420-445	4
1.393	445-470	5
1.473	470-495	6
1.553	495-520	7
1.633	520-545	8
1.713	545-570	9
1.793	570-595	10
1.873	595-620	11
1.953	620-645	12
2.033	645-670	13
2.113	670-695	14
2.193	695-720	15
2.273	720-745	16
2.353	745-770	17
2.433	770-795	18
2.513	795-820	19
2.593	820-845	20

Table 1: UV Indices Corresponding to the Sensor and ADC Outputs (Vcc = 3.0 V).

current value. The output voltage can be sent directly to the analog-to-digital converter (ADC), where the voltage is converted into a digital signal. The resulting digital signal is processed by the Atmel ATmega128 microcontroller to lookup the current UV index from Table 1. Finally, it sends UV index data to the RN-24 Bluetooth adapter every 15 seconds.

Figure 5 shows the spectral sensitivity characteristics of the photo diode in ML8511. Due to its SOI structure, this silicon photo diode is highly sensitive and selective only in the UV-A (320 to 400 nm wavelengths) and UV-B (280 to 320 nm wavelengths). This property is useful in our UV measurement, as UV-A and UV-B are the UV radiations which do damage to the human skin. The sensor producer also takes different wavelength's spectral sensitivity into account, thus providing output voltage after correction.

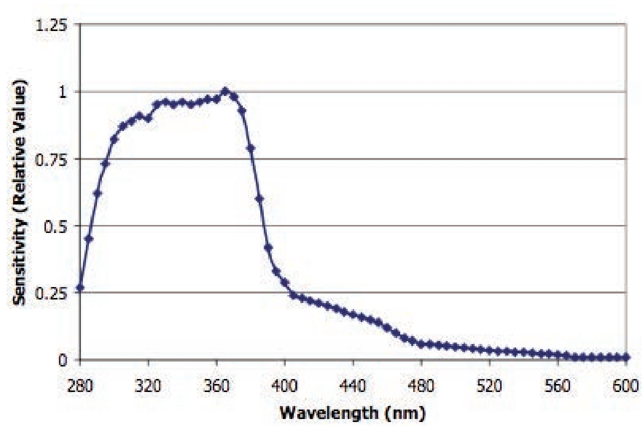

Figure 5: Spectral Sensitivity Characteristics of ML8511. It is Highly Sensitive and Selective to UV-A and UV-B.

The calculation of the UV index is: UVI = $\lceil(ADC - 320)/5\rceil *$ 0.2. In the darkness, the sensor output is 0.993V and ADC output is 320. Therefore, we should subtract 320 from the current ADC output and scale it. This equation determines that our UV index calculation precision is 0.2 unit.

Incidence angle	Sensor output voltage	ADC output	Corresponding UV index
0°	1.811	574	10.0
20°	1.731	550	9.2
45°	1.473	472	6.8

Table 2: Sensor Output for Different Incidence Angles.

Furthermore, we should consider the effect of incidence angle. If the sunshine is not vertical to the sensor, the UV measurement will be less than the real value. According to our experiment Table 2, we find the incidence angle less than 20 degree is acceptable. As a result, we put two UV sensors on the user and take the largest measurement value of the measurements.

4.2 Augmented Reality Glasses

The visualization part is made possible by an augmented reality glasses. In our system prototype, we choose Epson Moverio BT-100, a light-weighted augmented reality glasses shown in Figure 6. This pair of AR glasses has see-through display for each eye; thus we can display a sunburn effect layer on top of the skin. Its head display connects with a controller running Android system. Thus, it is easier to develop our client app and later port to other hardwares also running Android system. Moreover, a head mounted camera is necessary to fetch the user's skin image and then visualize the UV effect. As the glasses is not equipped with a camera, we add a CMOS Camera Module (resolution 728x488) which connects with the glasses controller. The user can touch the trackpad on the controller to interact with the glasses. In the future system implementation, we aim to take advantage of the lighter, more wearable Google Glass for better wearing experience.

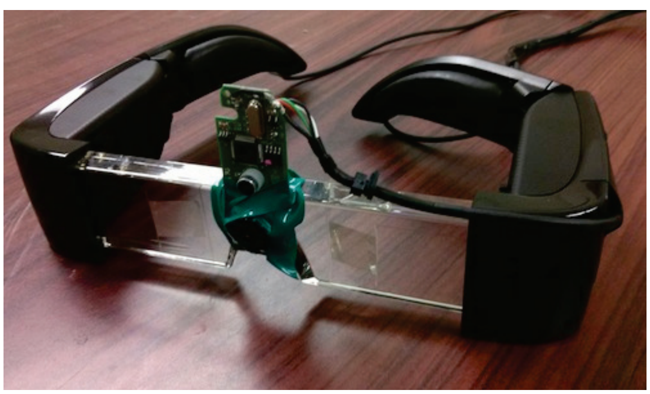

Figure 6: Epson Moverio BT-100 AR Glasses with Camera.

5. MODELING AND VISUALIZATION

The glasses controller receives UV index data via Bluetooth. According to the user skin model, the client app processes UV index data and generates an AR layer of sunburn effect visualization on the skin. Thus, the user can be warned to take sunburn protection in time.

5.1 Modeling

In order to predict and visualize the sunburn effect on skin, we need preliminary knowledge about human skin, and then develop the ultraviolet responsive color model of skin.

5.1.1 Damaging UV Radiant Flux Calculation

We calculate damaging UV radiant flux based on McKinlay-Diffey erythema action spectrum curve shown in Figure 7. The calculations are weighted in favor of the most sensitive UV wavelengths to human skin. We derive the UV index by integrating human body erythema action spectrum and the intensity of solar UV radiation at different wavelengths.

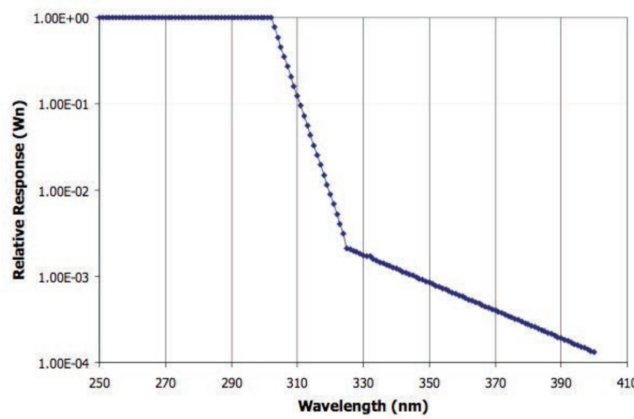

Figure 7: McKinlay-Diffey Erythema action spectrum.

As seen in McKinlay-Diffey erythema action spectrum curve, skin damage due to sun exposure is dependent on wavelength over the UV range (295 to 325 nm), as the shorter wavelength can cause around 30 times damage of the longer one's.

UV dose $= \int_0^T \int_{190}^{400} W_{\mathrm{n}} * E_\lambda d\lambda dt$

This equation calculates the effective dose of UV in general form. To get the effective irradiance, we integrate the multiplication of weighting of the erythema action spectrum (W_n) and the solar spectral irradiance radiated on the surface (E_λ) in the UV radiation hazard bandwidth (190 to 400 nm). The time integral of the effective irradiance is called effective dose; the unit of effective dose is W/m^2.

The studies of the erythemal influence are frequently based on the minimum dose of UV erythemal radiation, which can produce a noticeable reddening on human skin. This dose is known as the MED (minimum erythemal dose) and is always related to a specific skin type. If the UV irradiance is 1 MED/hour, it should take an hour to receive the minimum erythemal dose when a person is exposed to this irradiance. 1 MED corresponds to a total dose of 210 J/m^2. Thus 1 MED/hour = (210 J/m^2)/3600 s = 58.3 mW/m^2 = 2.33 UVI.

5.1.2 Skin Type

People with different skin types skin react differently towards UV exposure. At present, the majority of countries has adopted four skin types for tanning capacity, on the basis of COST-713 [2] recommendations. The principal characteristics of these skin types indicate the tolerable MEDs and maximum exposure time per UVI, which are defined by the DIN 5050 standard in Table 3.

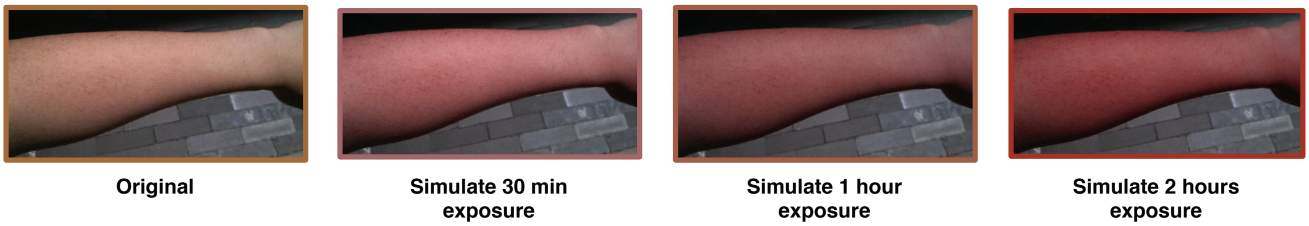

Figure 8: Normal arm skin and sunburn effect visualization after 30 mins, 1 hour and 2 hours.

For example, an unprotected type 3 skin person will start to have sunburn in just 20 minutes, under UVI 10 sun exposure: [200 (min) / 10 (UVI) = 20 min]. If the same person uses an SPF 30 sunscreen, the time will be extended to 600 minutes, or 10 hours: [20 (min) x 30 (SPF) = 600 min].

Skin type	Color, burning and tanning in the sun	Tolerable MEDs	Maximum exposure time
1	White, always burns, never tans	2 hecto J/m2	67 min / UVI
2	Yellow and white, usually burns, sometimes tans	4 hecto J/m2	100 min / UVI
3	Yellow and black, sometimes burns, usually tans	5.75 hecto J/m2	200 min / UVI
4	Black, rarely burns, always tans	8.5 hecto J/m2	300 min / UVI

Table 3: Skin types with corresponding tolerated MEDs and maximum exposure time.

5.1.3 Skin Color

Every person has a different response to sunburn, so there exists no model that fits perfectly for everyone. Instead we build models based on four skin types and positive correlation of the dose - response curve.

Based on skin type and UV dose, we can predict when the user will start to sunburn on the skin. Human's skin has two kinds of colors: constitutive and facultative [1]. Constitutive skin color (see the underside of the arm) is the natural, genetically determined color of the epidermis. It is hardly influenced by ultraviolet light or hormone exposure. As the result, our research focuses on facultative skin color which, in contrast, results from exposure to UV light and other environmental factors. Tanning, for instance, changes the composition of melanin in the skin and increases the amount and size of melanin produced by melanocytes. Thus, facultative skin is normally darker than constitutive skin.

In daily life, we assess the level of severity of sunburn damage based on the unusual "redness" we see on the skin. According to medical researches [12], the redness of the skin is increased by UV-induced erythema. Moreover, another research [16] indicated positive correlations between UV dose and increase of redness. Also, in lightly pigmented skin, the dose-response curves were steep, whereas in darkly pigmented skin the curves were much flatter.

5.2 Visualization

Based on skin model, our system can visualize sunburn effect on the user's arm. However, our visualization is not an exact match or perfect prediction of sunburn effect. Our primary goal is to bring caution towards possible outcomes; thus, the visual effect is a bit over-amplified to better warn users.

From our model, we first notice the positive correlations between UV dose and the increase of redness. From experimental data of [16], we approximate their correlation as linear relationship.

In real life setting, the UV index will change with user's activities. For example, a user may only stay outside for 1 or 2 minutes and then go indoor. Under these circumstances, we should not disturb the user by alerting unnecessary sunburn information. Thus, we use method in Section 5.1.1 to integrate UV index and UV dose every 5 minutes. Based on average UVI, we can follow the example in Section 5.1.2 to predict how long it will take to sunburn.

In order to analyze skin color and increase redness, we introduce HSV, a commonly chosen color model in computer vision research and application. HSV stands for Hue, Saturation and Value. The Hue channel obtains robustness to lighting changes or removing shadows. This property is useful for us to find and analyze a specific range of color. In this case, using HSV in skin color analysis is better than using the normal RGB color space. During our experiment on participants' normal skin colors, we find the Hue channel ranges from 0 to 43 and 338 to 360 (maximum value 360). We also collect mild sunburn photos, and find the Hue channel ranges from 0 to 12 and 355 to 360. We can see the Hue range in Figure 9. In order to present sunburn starting effect, we use a fitting equation to convert Hue channel: $((\text{Hue}_{\text{Sunburned}} + 6) \bmod 360) / 17 = ((\text{Hue}_{\text{Normal}} + 22) \bmod 360) / 67$. We can use this relation to calculate the sunburn effect of Hue of skin.

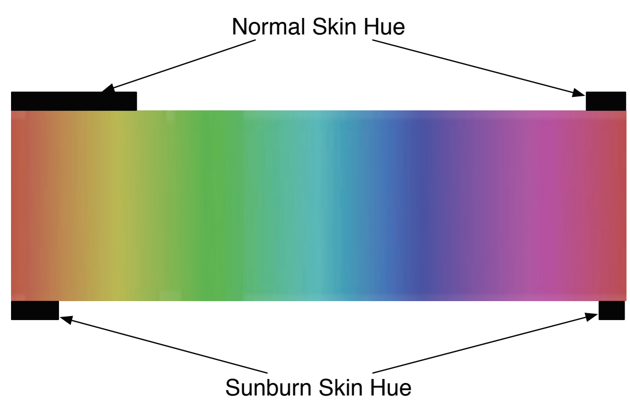

Figure 9: Hue range of normal and sunburned skin.

Mild and heavy sunburn mainly differ from their Value channel, which takes charge of skin brightness. The heavier the sunburn is, the darker the skin is. Thus, from linear correlation of dose-response, we can decrease Value channel by 2% for every 50mJ/cm^2

dose.

Figure 8 is an example of sunburn warning effect. The normal arm is near yellow-brown. When we apply the fitting equation on Hue channel, the arm turns out to be red and similar to mild sunburn. After this, we decrease Value channel based on a UV dose to show different levels of sunburn during different time periods under this UV.

After the user sees sunburn effect layer, our system provides detailed information in case the user hopes to learn more to take protective actions.

6. EVALUATION

After implementing our system, we evaluate the system with participants for feedback and design improvement suggestion. A total of 9 healthy UCLA undergraduates took part in the experiment. Before the experiment, we debriefed our procedure to participants. We also told them that we would only collect UV data from sensors, without recording any private information from our camera.

Participants' personal information is needed to select a proper skin model. As different users have different skin types, their ultraviolet tolerance may also be different. When a user logs on to our system first time, we will ask the user for his/her skin type. The user can look up for skin type from Table 2. In order to better monitor UV intake for individual users, we recommend users to confirm their skin information with their doctors.

We encourage users to take sunscreen in order to protect themselves. Thus our model needs to consider SPF (Sun Protection Factor) of sunscreen to better predict the UV effect. Every time a user launches our client app, we will provide local weather forecasts (from Yahoo! Weather API). Based on the UV index, we will recommend whether the user should use sunscreen and which SPF is necessary. If the user decides to use sunscreen, he/she will need to enter its SPF in our system before he/she uses.

6.1 Participant UV Result Analysis

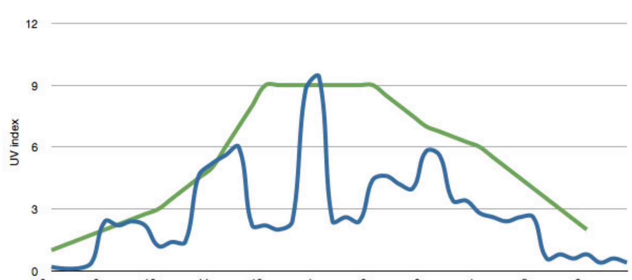

Figure 10: UV Index Monitoring Result from Local Weather Forecast(Green) and Our Wearable Sensor(Blue).

Figure 10 shows UV index monitoring result in one day. The local weather forecast (green line) can best provide an hourly report. In contrast, our sensor makes measurement every 15 seconds. Higher sample rate can provide better measurement of UV dose during user daily activities. Moreover, the forecast curve is an approximate result of outdoor UV index across a large area, so the forecast is not applicable to each person's activity range. Most importantly, as we can see in the plot, the user may not always stay outside, so the UV index forecast cannot accurately indicate cumulative UV dose. These are the reasons to use wearable UV sensor.

6.2 Participant Experience in Visualization

We asked each participant to wear our system for two days and give us their feedback. During the first day, we only equipped our UV sensor on the user's arm and allowed him/her to check the UV index on our website. We sent a questionnaire to the user for feedback at the end of that day. On the next day, we provided AR glasses to the user for the visualization functionality. At the end of the day, we sent the same questionnaire to the user; thus we can compare the subjective experience with and without visualization.

6.2.1 Questionnaire.

(Q1) I can better protect myself under sun with this system.
(Q2) The interface is easy to interact with.
(Q3) The hardware system is heavy and cumbersome.
(Q4) I feel my skin is healthier and less likely to burn.
(Q5) (Only for AR glasses) The visualization is effective to warn me.
(Q6) (Only for AR glasses) The visualization effect disturbs my daily life.
(Q7) (Open Question) It will be great if the system includes this feature:

All these statements were answered with a 9-point Likert scale [13], where 1 = strongly disagree, 3 = disagree, 5 = neither agree nor disagree, 7 = agree, and 9 = strongly agree.

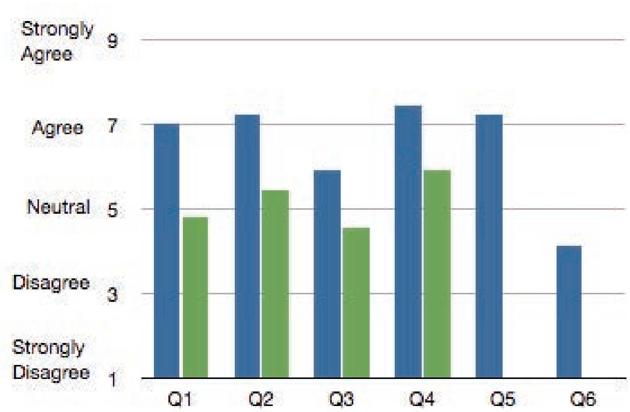

Figure 11: The Participants' Average Response in With(blue) and Without(green) AR Glasses Settings.

Figure 11 shows the average response from participants in both with and without AR glasses settings. We use t-test for a population mean for AR glasses setting. The response without AR glasses is also on the plot for comparison. Our null hypothesis is μ=5, which means that according to our participants' feedback, our visualization system is unlikely to have an obvious positive effect on others. Our alternative hypothesis is $\mu >5$, which means our visualization system has an obvious positive effect on others. For Q6, as the sample mean < 5, our alternative hypothesis turns out to be $\mu <5$. We choose 0.05, an often chosen fixed number, as our significance level.

Q1 (AVG=7, STDEV=1.72, p-value=4.23e-3) reflects the subjective experience in UV protection. We found that the null hypothesis is rejected due to small p-value(much smaller than 0.05), which validates our visualization has a positive impact on UV protection.

Q3 (AVG=5.89, STDEV=1.67, p-value=5.31e-2) reflects users' consideration about the weight of the system. The null hypothesis is not rejected, which indicates that users are not particularly worry about the system weight and understand that the finalized solution will use even lighter AR glasses. However, we can still find p-value is not significantly larger than 0.05, so we need to consider this problem seriously.

Q4 (AVG=7.44, STDEV=1.56, p-value=1.14e-3) reflects the users' feeling of their skin. The null hypothesis is rejected, which indicates that users satisfy with our system to improve their skin health.

Q5 (AVG=7.22, STDEV=1.83, p-value=1.37e-3) rejects the null hypothesis and validates that visualization is an effective warning notification.

7. CONCLUSION AND FUTURE WORK

We designed, implemented and evaluated our UV monitoring and visualization system. Our wearable sensor works well in UV monitoring, and successfully uses Bluetooth to synchronize data for further analysis. The four skin models help us estimate damaging UV dose for individual person. According to damaging UV dose, our visualization system successfully warns users beforehand by over-amplified sunburn visual effect on the user's arm. During the experiment, our participants gave positive feedback on visualization and UV monitoring. It effectively warns users to take protection and avoid possible sunburn. Based on their feedback, our next step is to develop a way to make the whole system more light-weighted and portable for future deployment. Google Glasses and other wearable displays like iWatch can be possible choices in the future. Also, we can consider integrating UV glasses with other wearable system, such as Smart Insole [17], Smart Glove [10, 11], Personal Activity Monitoring (PAM) [18] for comprehensive and individualized health status monitoring in life.

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