An Empirical Review of UV Measurement Methodologies

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Abstract—Ozone layer depletion has led to an increase in UV exposure. UV radiation can be divided into three spectral bands namely UVA, UVB & UVC. Literature mentions the effect of UVA and UVB resulting in skin tanning and burning respectively. Prolonged exposure to UV Radiation can lead to different skin diseases and skin cancers. This review aims to study various UV measurement methods for precautionary purpose. UV sensitivity varies for different skin types. It is necessary to study and develop a method which evaluates how individual's skin reacts to UV radiation.

Keywords—UV radiation; Fitzpartick; UV sensor; Spectrometer; Wearable device.

I. Introduction

Ultraviolet Radiation is a part of the incident sunlight which encompasses a spectrum of different wavelengths of electromagnetic radiation. The wavelength region from 400 to 100 nm comprises of the ultraviolet spectrum of radiation. Even in the UV portion of the spectrum the biological effects of the radiation vary enormously with wavelength and for this reason the UV spectrum is further subdivided into three regions as UVA (320nm-400nm), UVB (280nm-320nm) & UVC (100nm-280nm). Apart from the sun, other sources of radiations include tanning beds, mercury vapor lamps, UV lamps and electric arcs; these mechanisms produce UV radiations artificially. Biological effects due to UV radiations are significant and its energy has a harmful effect ranging from causing damage to skin, eyes, immune system to damaging the DNA and also in some cases causing cancer.

Out of the total UV radiation incident from the sun, only 5% reaches the surface of the earth [2]. All of the UV-C radiation and up to 90% of the UV B radiations are absorbed in the stratosphere by the ozone layer. An overdosed ultraviolet exposure can lead to skin related problems. Prolonged exposure cause skin burns and increases the risk of skin cancer [5]. The most commonly observed physiological effect of incident radiation is skin tanning, however, these radiations also play a hand in leading to wrinkles, skin aging and loss of elasticity of the skin [4].

The UVB band is known to have a detrimental effect on the skin and is responsible for skin burning and inflammation if subject is exposed [2]. UV-A radiations play a beneficial role and aid in the synthesis of Vitamin D, which is responsible for maintaining body homeostasis.

Every individual skin has a different reaction to UV radiation. The Fitzpatrick scale can be used to bridge this correlation. Thomas B Fitzpatrick classified the skin texture into 6 phototypes depending upon the genetic disposition and reaction to sun exposure and tanning habits. Ranging from type I (very fair) to type VI (very dark) as shown in table I [3].

TABLE I. Skin photo-types according to Fitzpatrick Scale[3].

Photo-types	Effect of UV radiation		
	Sunburn and Tanning History	***Immediate Pigment Darkening***	***Delayed tanning***
I	Burns easily, never tans	None (-)	None (-)
II	Burns easily, tans minimally with difficulty	Weak (- to +)	Minimal weak (- to +) to Low+
III	Burns moderately, tans moderately and uniformly	Definite+	Low+
IV	Burns minimally, tans moderately and easily	Moderate ++	Moderate ++
V	Rarely burns, tans profusely	Intense(brown)+++	Strong, intense(brown)+++
VI	Never burns, tans profusely	Intense dark(brown)+++	Strong, intense(brown)+++

UV index is the most widely used parameter to measure radiation. It is indicated by a numerical value corresponding to bands of colors which gives risk levels at which skin can be damaged due to radiation. The UV index as shown in table II, usually ranges from 0 to 11+ where, 0 (green color) indicates low risk level and 11+ (purple color) indicates extreme risk level for skin [6]. A person can take precautionary measures depending upon the index specified by the Meteorological Department on a daily basis.

II. Methods Used For Measuring UV Exposure

Various methods are used to determine UV exposure. Some of them are described below,

A. UV Index Measurement using Spectrometer

The most traditional method of calculating UV radiation is by measuring UV index. This method was developed by World Health Organization (WHO) and World Meteorological Organization (WMO) in 1994 [7]. The effect of different UV wavelengths and human skin sensitivity to them are taken in consideration while calculating UV index. The calculations for UV index are performed using scientific instruments namely ground base spectrometers, broadband filter and multi filter radiometers. These instruments primarily consider geophysical conditions like column ozone, cloud cover, sun deviation, reflection from snow and local pollution while determining UV index. UV index is a unit less quantity which is obtained from following equation [6],

$$UVI = Ker \int_{250}^{400} E(\lambda) * Ser(\lambda)\, d\lambda \quad \text{...equation (1)}$$

Where,

E is solar spectral irradiance in W/m^2nm

S_{er} is wavelength of erythema reference action spectrum
K_{er} is a constant equal to 40W /m^2.
λ is wavelength in nm.

The terms related to radiation measurement are radiation intensity and radiance. The term irradiance, which is the most commonly used term in photobiology, relates to the object (e.g., patient) struck by the radiation. The time integral of the irradiance is strictly termed the radiant exposure, but is sometimes expressed as exposure dose or, even more loosely, as dose. The term minimal erythema dose (MED) is a ''measure'' of erythemal radiation. MED is in fact, not a standard measure of anything but, on the contrary, encompasses the variable nature of individual sensitivity to UV radiation.

The result displayed by the spectrometer is the UV Index, which is a generalized form of radiation measurement. This method may not be useful for getting an idea of personalized real time UV exposure, in addition it may not warn an individual about the risk level responsible for his skin damage.

TABLE II. UV INDEX INTERPRETATION[10]

EXPOSURE CATEGORY	*UVI RANGE*
LOW	< 2
MODERATE	3 TO 5
HIGH	6 TO 7
VERY HIGH	8 TO 10
EXTREME	11+

B. UV Meters using Sensor

Multiple UV measuring devices such as watches, outfits and handheld devices are currently available [9]. The core components of these devices are UV sensor and microcontroller to sense and integrate the real time data generated. The sensor consists of silicon photodiode, the photocurrent from this sensor is converted into corresponding voltage levels as they are proportional. The output voltage and the UV index are linearly proportional and multiplied by a scaling factor of K. The intensity of illumination can be determined by following equation,

Illumination Intensity= K * output voltage. …equation (2)

Where,
K is scaling factor.

These devices need to be handheld constantly in order to detect accurate readings for UV measurement. This method does not directly yield personalized results for individual skin type.

C. UV Patch Method

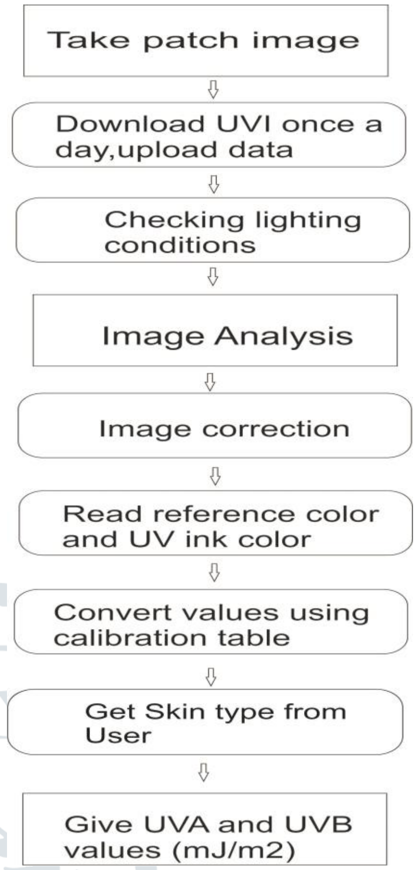

Fig. 1. A brief explanation of the algorithm for UV patch Method [8]

One of the recent advancements in measuring UV radiation include compact wearable sensors which are integrated to mobile applications [8]. These methods use a UV photosensitive patch which changes its color when exposed to UV radiation. The UV patch is scanned by mobile app and changes in its color are detected by an image processing algorithm, which then quantifies the amount of UV exposure for different skin types. The software application has an algorithm for quantification of personal UV dose and a reference color chart for basis of result produced. The algorithm is divided into 4 further sub-algorithms for purpose of shape distortion corrections, optimum lightning conditions and accurate recommendations of UV dose. This method considers inclusion of many parameters. They are as follows:

1. Shape recognition and feature location
2. Lighting condition correction
3. Colour quantification
4. UV dose determination

The color changes are correlated with UV dose and compared to existing risk levels for dosage by standard lookup table already incorporated in application. This method can be explained from a summarized flow chart given in fig 1.

This method has the limitation of showing real time values of UV dosage. The patch needs to be scanned every time for viewing the exposure value and risk level. There is a constant need of mobile application to display the readings.

D. Spectroradiometry

Spectro radiometry is the mechanism for measuring the spectral power distribution or spectral irradiance (absolute measurement showing shape and power) of a source of optical radiation. A Spectroradiometer has a culminative requirement three fundamental block units. They are as follows:

I. OPTICAL INPUT

It includes a set of lenses, diffusers, and filters that interact and filter light upon entry. For measurement of spectral irradiance, the first entrance slit should be prevented from being directly irradiated. This particularly applies when the extended sources such as linear arrays of fluorescent lamps or daylight is used for testing purposes. The spectral transmission characteristics given by the monochromators depend on the angular distribution, polarization of the incident radiation and also the position of the beam on the entrance slit.

II. MONOCHROMATOR

The main function of the monochromator is to produce monochromatic light by sampling the wavelengths of light from source. This analysis of the source radiation creates a spectral response. It accomplishes this by through application of entrance and exit slits, collimating and focussing lens and diffraction gratings.

III. DETECTORS

Photomultiplier tubes, incorporating a photocathode with an appropriate spectral response, are normally the detectors of choice in spectroradiometers. However, if radiation intensity is not a problem, solid-state photodiodes may be used, since they require simpler and cheaper electronic circuitry.

E. Colorimetric monitoring of UVR

Spectrally selective monitoring of ultraviolet radiations (UVR) is of paramount importance across diverse fields, including effective monitoring of excessive solar exposure. Current UV sensors cannot differentiate between UVA, B, and C, each of which has a remarkably different impact on human health. In this method, spectrally selective colorimetric monitoring of UVR by developing a photoelectrochromic ink that consists of a multi-redox polyoxometalate and an e^- donor is applied for skin colour-specific and spectrally-selective naked-eye dosimetry of UVA, B and C radiations. The ink is combined with simple components such as filter paper and transparency sheets to fabricate low-cost sensors that provide naked-eye monitoring of UVR, even at low doses typically encountered during solar exposure.

F. UV Dosimetry

Dosimetry is another of the methods used to measure radiations. People are exposed to natural or artificial UV radiation in different ways: unintentionally or intentionally, at their workplace or in their spare time. To quantify the amount of individual UV exposure, a personal dosimetry is necessary. In research, polysulphone film (PSF) dosimeters are the most frequently used personal UV dosimeters. In polysulphone films, incident UV radiation results in an alteration of transmittance T (absorbance A). The spectral sensitivity of the effect in PS is similar to action spectra.

III. CONCLUSION

The quantification of exposure to UV radiation is important from the point of view of applying and suggesting protective measures. And thereby, preventing damage at levels commencing from skin to DNA. This can be done by monitoring irradiation and dosage exposure as demonstrated by the different methods in the review. Keeping in mind the rate of ozone depletion, further research in the fields of improving these pre-existing methodologies are under way; the drawbacks of the existing methods being, they are applicable over a generalized population. In addition, at individual levels, numerous variables come into picture which may cause irregularities in the readings obtained by application of these methods. Therefore, there is a need for development of personalized measurement devices that will allow us to study the reaction of the skin due to UVR. This will improve our understanding of the effects of UVR and contribute towards building a database on a personalized level. It will allow a preventive care routine rather than cure treatment pathway.

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