A WIRELESS EMBEDDED DEVICE FOR PERSONALIZED ULTRAVIOLET MONITORING

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Abstract: The skin care product market is growing due to the threat of ultraviolet (UV) radiation caused by the destruction of the ozone layer, increasing demand for tanning, and the tendency to wear less clothing. Accordingly, there is a potential demand for a personalized UV monitoring device, which can play a fundamental role in skin cancer prevention by providing measurements of UV radiation intensities and corresponding recommendations. This paper highlights the development and initial validation of a wireless and portable embedded device for personalized UV monitoring which is based on a novel software architecture, a high-end UV sensor, and conventional PDA (or a cell phone). In terms of short-term applications, by calculating the UV index, it informs the users about their maximum recommended sun exposure time by taking their skin type and sun protection factor (SPF) of the applied sunscreen into consideration. As for long-term applications, given that the damage caused by UV light is accumulated over days, it displays the amount of UV received over a certain course of time, from a single day to a month.

1 INTRODUCTION

The skin is the largest organ of the body in both mass and surface area and skin cancer is the most common cancer among all existing cancers. Unfortunately, the incidence of skin cancer has been increasing dramatically (Ferguson 2005, Sue 2002) and more than 1 million cases of skin cancer are reported annually in the United States. There are three different forms of skin cancer: Basal cell carcinoma, squamous cell carcinoma and melanoma. Basal cell carcinoma is cured by a local operation, but squamous cell carcinoma and melanoma are more dangerous, as they metastasise to other parts of body. Melanoma is considered as the most lethal form of skin cancer and its incidence and mortality rates have increased dramatically in the past few decades in the United States (Boscoe 2006). In the year 2008, about 62,480 persons are expected to be diagnosed with melanoma resulting in the death of an estimated 8,420 individuals (ACS 2008). Alarmingly, the incidence of melanoma is increasing rapidly in children (Strouse 2005).

Overexposure to solar radiation, especially the ultraviolet (UV) region (wavelengths 280–400 nm) of the solar spectrum, is the predominant risk factor for the development of all forms of skin cancer (Hu 2004, Jemal 2000).

While some sunlight is needed to synthesize vitamin D, which is necessary for human health, increased exposure to UV radiation is harmful; it is well known that apart from the skin damage, the solar UV radiation is extremely injurious regarding the eyes (DeFabo 1983). During a field study involving 94 volunteer subjects, the UV exposure of seven anatomical sites during six different outdoor activities was investigated (Herlihy 1994). The results of this study verify the importance of UV monitoring during outdoor activities to avoid skin and eye damage.

Currently there is an internationally accepted parameter, UV index, for measuring the intensity of UV radiation (Wong 1995). A ground-based instrument that measures the amount of UV light from the sun at 5 different wavelengths between 306 and 320 nm is Brewer Spectrophotometer (RMI 2008) which is very widely-used to calculate UV index. However, the price is too expensive and for the correct operation an expert technician is required. Another method used is the solar light 501 biometer which is a wide-band UV radiation measurement device (Solar 2008). Although it is

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easy to use, its high energy consumption and heavy weight prevent it from being exploited in wireless and small embedded devices.

The use of lightweight embedded systems to assist in biomedical applications is being pursued by many researchers and will become available as soon as required sensors are made available. Hence, given that the damage caused by UV light is accumulated over days, there is a potential need for an embedded device that monitors the amount of UV received over a certain course of time, from a single day to a month and gives corresponding advice. In recent years, the concern over personal exposure to solar UV has led to the development of numerous personal (e.g., lapel or wristband) or hand-held devices. These come with a variety of features, but in general require input on skin type and degree of protection and subsequently provide an audible warning when sun exposure should cease. The aforementioned devices solely show the current UV index and they are not able to make accurate measurements (OS 2008, EPP 2008). Further, none of them has taken the received amount of UV during for instance, one week, into consideration.

This work highlights the development and initial validation of a wireless and portable embedded device for personalized UV monitoring which is based on a novel software architecture, written in Python and is compatible with all Symbian OS cell phones, a high-end UV sensor, ML8511 introduced in 2008 by OKI Semiconductor (OKI 2008), and conventional PDA (or a cell phone). The main market for this wireless embedded device includes: 1- Children, since reducing UV exposures in early life is fundamental to skin cancer prevention in children. 2- Sun protection of outdoor workers in occupational situations. 3- Sun protection of the general population in recreational situations. 4- Beach users and 5- Protection of photosensitive patients.

This paper will start with preliminary notions concerning the UV monitoring embedded device in Section 2. Afterwards, the hardware and software structure of this device will be presentred in Section 3. An example of the gathered data in a typical day will be demonstrated in Section 4. Finally, Section 5 concludes this paper and discusses future research directions.

2 PRELIMINARIES

This section presents the definition of related concepts used in the design of the personalized UV monitoring device.

2.1 UV Index

The Global Solar UV index (UVI) (Maddodi 2008, HKO 2008) describes the level of solar UV radiation at the Earth's surface. Generally, providing the public with an easy-to-understand daily forecast of UV intensity is the main purpose of the UV index. The values of the index range from zero upward – the higher the index value, the greater the potential for damage to the skin and eye, and the less time it takes for harm to occur. An index of 0 corresponds to zero UV irradiation (darkness). The UV index is an open-ended linear scale defined as follows:

$$UVI = k_{er} \cdot \int_{250nm}^{400nm} E_{\lambda} \cdot s_{er}(\lambda) d\lambda, \qquad (1)$$

where E_λ is the solar spectral irradiance (see the previous section) expressed in $W/(m^2nm^1)$ at wavelength λ and $d\lambda$ is the wavelength interval used in the summation. $s_{er}(\lambda)$ is the erythema reference action spectrum, and k_{er} is a constant equal to 40 m^2/W.

The determination of the UVI can be through measurements or model calculations. Two measurement approaches can be taken: The first is to use a spectroradiometer and to calculate the UVI using the above formula. The second is to use a broadband detector that has been calibrated and programmed to give the UVI directly.

Although the weather stations assign a unique UVI to a large area, for several reasons, the measured noon UV index can be different from the forecast, sometimes by as much as 100%; the forecasted UV index does not include the effects of atmospheric pollutants or haze which can substantially decrease UV intensity, especially in urban areas. On the other hand, the forecast does not take into account variable surface reflection (e.g., sand, water, or snow), which can substantially increase individual's exposure at the beach or on ski-slopes. The following facts demonstrate how the environment or terrain affects the level of UV radiation that we are exposed to (UNEP 2008):

1- Wet fresh snow can reflect as much as 85% of UV radiation this means that snow reflection can double overall UV exposure. Similarly, white

water and sand can intensify the UVI by up to 50% and 20% respectively.
2- Every 100 meters increase in altitude results in the UVI increase of 100%. This is because at higher altitudes a thinner atmosphere absorbs less UV radiation.
3- 25% of the UV is reflected from white-water reflection.
4- 80% of UV rays pass through a cloud. Therefore, even with cloud cover, the UVI can be adequately high.
5- Concrete buildings reflect 15% of the received UV.
6- Shade can reduce UV by 50% or more.

The foregoing facts show that quantitative measurements and research on UV radiation in different environments and settings are vital in developing and assessing UV-preventative strategies for the reduction of skin cancer and other UV-related problems for humans.

The UV index measurements and forecasts for cities in many countries around the world are now routinely posted on the internet by various meteorological agencies (see Table 1 for UV index categories). In summer in Europe, the solar UV index typically peaks at values from 5 at high latitudes (Scandinavia) to around 7 in central regions such as the United Kingdom, France or central Europe and up to 9 or 10 in Southern Europe. In the United States maximum measured UV indices range from 10 to 12 in the Southern continental United States to 5 in Alaska while in Canada peak values reach 8 in the southern cities. Generally, the highest reported UV index measurements in the Northern hemisphere have been recorded at high altitude. For example, Bogota in Colombia, at over 2500m above sea level, has registered a UV index of 16 and for Mauna Loa volcano in Hawaii, at 3400m above sea level, a UV index of 17 has been reported (Parisi 2000).

Table 1: UV index intensity.

UV index	Extent
0-2	Low
3-5	Moderate
6-7	High
8-10	Very high
11+	Extreme

2.2 Sensor Characteristics

The spectral sensitivity characteristics of photo diode used in ML8511, which are based on thin-film Silicon-on-Insulator Technology (SOI), are shown in Figure 1. Although this is a silicon photo diode, it is highly sensitive and at the same time is selective only to the UV-A (wavelengths of 320 to 400 nm) and UV-B (wavelengths of 280 to 320 nm); this is because of its SOI structure.

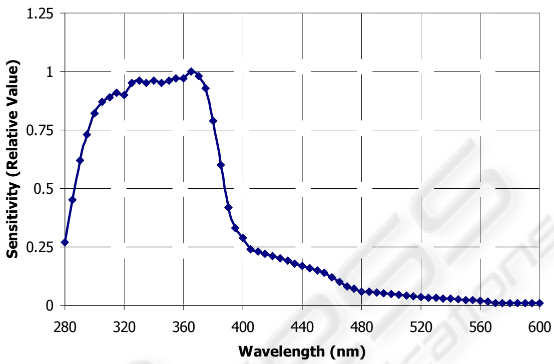

Figure 1: Spectral sensitivity characterisitics of the ML8511.

3 THE UV MONITOR DEVICE

In this section the hardware and software structure of the personalized UV monitoring device is explained.

3.1 System Design

Figure 2 shows the schematic diagram of our personalized UV monitoring system. The UV sensor shown in the figure is a photo diode that uses a thin-film SOI. With an additional filter, the accordance with the erythema action spectrum curve of the human skin has been further improved. A voltage proportional to the amount of electrical current is output by a current-to-voltage conversion amplifier, comprised of an operational amplifier and resistor, Rf. The output voltage can be linked directly to the analog-to-digital converter (ADC), where it is converted into a digital signal and input into the processor of Atmel ATmega 128L microcontroller via an interface (I/O). The resulting digital signal is processed by the microcontroller to determine the current UV index (see Table 2 and (2)) and thereafter it sends the UV index data to the RN-24 Bluetooth adapter. The Bluetooth adapter sends its received data without any changes to the Nokia N95 cell phone where the main software of our embedded device is running. The software was written in Python and is compatible with all Symbian OS cell phones. As mentioned before, the software has two parts. First, it shows the current

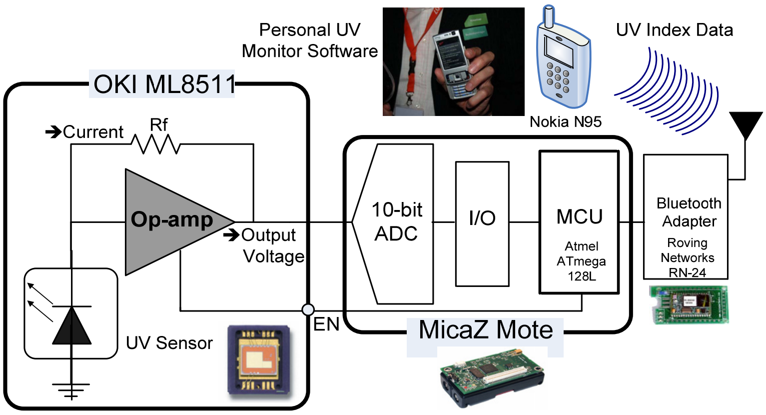

Figure 2: Schematic diagram of the personalized UV monitoring system.

UV index (from 0 to 20) and maximum exposure time based on the skin type of the user, SPF of the applied sunscreen and current UV index. Second, it shows the UV history of the person together with the amount of UV (UV dose) that the person received during the past day/week/month. The software also saves the average of UV indices during one hour of operation.

The calculation of the UV index is performed using equation (2); in the darkness, the sensor output and corresponding output of the ADC are equal to 0.993 V and 320 respectively. Therefore, in order to derive the UV index, it is required to subtract 320 from the current ADC output and scale it as shown in (2). In this equation, the ceiling function and the multiplication by 0.2 show that our accuracy in UV index calculation is not better than 0.2.

The software takes the skin type of the user and the SPF number (from 0 to 100) of the applied sunscreen (0 in case of no sunscreen), respectively as the input.

$$UVI = \left\lceil \left(\frac{ADC_{OUTPUT} - 320}{5}\right) \right\rceil \times 0.2 \qquad (2)$$

The information in the Table 3 were used in the software to calculate how long one can stay in the sun without sunscreen before he/she starts to burn (i.e., before minimum erythemal dose, occurs). Table 3 also shows the tolerable MEDs with respect to solar light for each of four possible skin types.

The flowchart of the software is shown on Figure 3. In addition to the UV history, both the current UV index and maximum exposure time are shown on the cell phone screen.

Table 2: UV indices corresponding to sensor and ADC outputs (Vcc = 3.0 V).

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

3.2 Exposure Time

At present, the majority of countries, on the basis of the recommendations of the COST-713 (Vanicek 2000), have adopted four skin types as a function of tanning capacity.

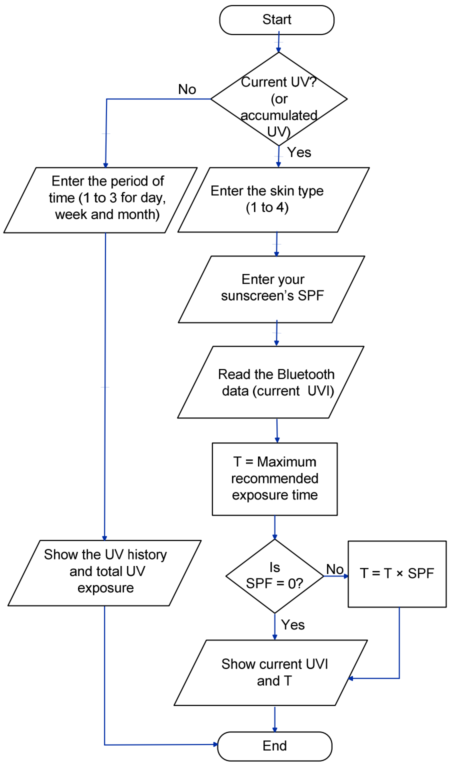

Figure 3: Software operation (it receives the new UV index each 15 seconds and stores to average for each hour).

The principal characteristics of these skin types, defined by the DIN 5050 standard, were shown in Table 3, which also indicates the dose (in J/m2) needed to produce one MED.

According to Table 3, a person with a skin type of 3, in a UV index of 10, will start to sunburn after just 20 minute of unprotected exposure to the sun:

$$[200\ (\text{min}) / 10\ (\text{UVI}) = 20\ \text{min}], \quad (3)$$

and by using an SPF 30 sunscreen this becomes 600 minutes, or 10 hours:

$$[20\ (\text{min}) \times 30\ (\text{SPF}) = 600\ \text{min}]. \quad (4)$$

4 EXPERIMENTAL RESULTS

In this section we see an example of the gathered data in a typical day. Figure 4 and Table 4 show an example of our personal cell phone software. The data were gathered on a partially cloudy day in June in Los Angeles and we kept the device fixed on the roof of an eight-story building. Therefore, it can represent the amount of UV that an individual has absorbed in a typical day.

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

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

In Table 4, as it can be seen, the first row values are the UV indices at the exact hours of 8:00, 9:00, etc. However, the second row shows the average amount of UV index during each hour.

Moreover, for each day we calculate the parameter UV dose that is:

$$\text{UV Dose} = \text{Average UV} \times \text{Exposure time}. \quad (5)$$

While the UV index is a measure of UV intensity, it is the accumulative dose that is important for human exposures to solar UV.

5 CONCLUSIONS

In this paper we adopt OKI ML8511 UV sensor to implement a real-time and personalized UV monitoring.

The personalized UV monitoring device explained in this paper can be put on the hat, can be a necklace, skin patch and even a clip-on. Therefore, it is not obtrusive and can decrease the incidence of the skin cancer in an efficient way. Since the system is small and accurate, it proved to be a very feasible commercial product.

This device will enable users to embed UV sensor functions in a variety of portable devices, offering them the ability to check their UV exposure wherever they are.

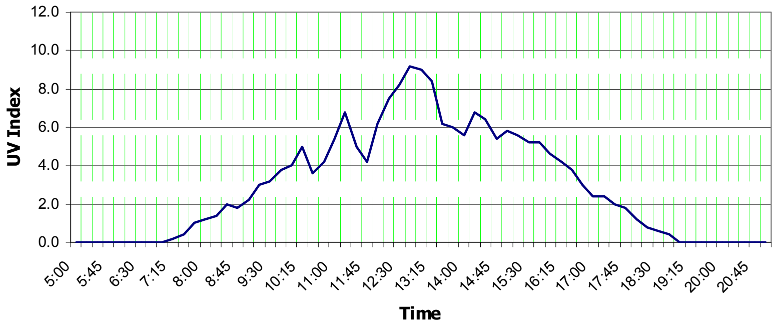

Figure 4: Example of personal UV monitor software (UV index was updated each 15 seconds throughout a partially cloudy day).

Table 4: Example of personal UV monitor software (average data).

Time	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
UV index (ending on the hour)	1.2	2.2	4	5.4	6.2	9	5.6	5.8	4.6	2.4	1.2	0.0
Hourly mean UV index	1.6	3.1	4.2	5.4	7.8	7.4	6.1	5.5	3.9	2.2	0.8	0.0

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