MUVIC

Micro ultra-violet index calculator

MARCH 15, 2015

IMPERIAL COLLEGE LONDON

TEAM NUMBER 11

SUPERVISOR: PROFESSOR MANDIC

Group members:

Petros-Alexandros Koumpas	CID: 00843267
Efstathios Alexis Voinas	CID: 00841767
Diyar Faisal Al-Yasiri	CID: 00841752
Ahmet Cirakoglu	CID: 00845925
Arda Can Ertay	CID: 00863076
Mihnea Rusu	CID: 00854928
Vlad-Petru Veigang Radulescu	CID: 00834114

Contents

Abstract

Over the course of the current term, the scope of our second year group project has been shifted. Our initial idea was to create a device with an ability to reproduce any colour it comes into contact with. Having invested time researching and designing a useful implementation of this idea, we decided to implement a new design so as to combat a more pressing global issue. We have incorporated our colour-detecting technology into a personalised Ultraviolet (UV) monitoring device in the form of a wearable bracelet.

To do that, we used our colour-detecting technology to categorise different skin shades. Thereafter, a UV sensor detects incident UV radiation and warns the user when in risk of UV overexposure, according to their skin sensitivity (I.e. complexion). A microprocessor will employ an algorithm that combines data from both sensors to determine the optimal UV exposure. This report analyses our findings and evaluates the most appropriate design components, according to our specifications. One of the challenges is to accurately classify skin shades, which was tackled through the use of a recursive averaging algorithm. Currently our individual sensors are functioning as required, leaving us with the challenge of incorporating our individual components into an integrated device.

1. Introduction

Stratospheric ozone is the most effective ultraviolet (UV) radiation absorber. It protects the earth by absorbing incident radiation from the sun and thereby reducing its temperature. Since the invention of the first refrigerants and air propellants in the early 1890's, the earth's natural ozone shield has been gradually depleting.[1] Human-produced chemicals - commonly known as Chlorofluorocarbons (CFCs) - react with the atmospheric gases in the stratosphere.[2] As a result, ozone is removed in a faster rate than it is created throughout its natural cycle as can be seen in Figure 1.

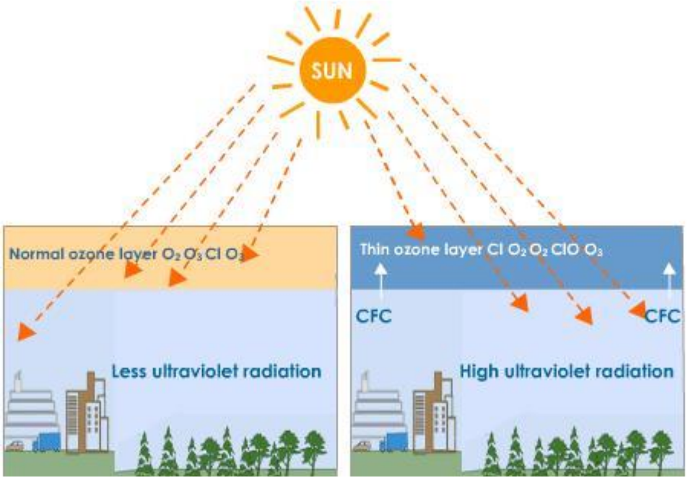

Figure 1: Impact of greenhouse gases (CFC's) on the Earth's atmosphere.

The ozone depletion results in increased UV radiation, which leads to several health problems. Scientists are mainly concerned about the increases in UV-B radiation[3], which are linked to skin cancers and other biological damage.[4]

According to the World Health Organisation (WHO), overexposure to the sun may result in acute and chronic health effects on the skin, eye and immune system.[5] It is important to note that UV radiation has been used to successfully treat a number of diseases, including rickets, psoriasis, eczema, jaundice, lupus vulgaris, and vitiligo.[6] Furthermore, a small amount of UV radiation is crucial to the body as it stimulates the production of vitamin D, which is important for osteogenesis[7], immune function and blood cell formation.[8] However, while there are therapeutic uses, the negative-side effects of UV radiation are much more severe on a global scale.

1.1 Design and Implementation

Our solution to this worldwide problem is a personalised UV-exposure optimiser to ensure that the users absorb the amount of sunlight which is most beneficial to them, without skin-related dangers.

---

[1] Nasa.gov. NASA - An Improving Ozone Layer, Something to Sing About [Internet]. 2015 [cited 12 March 2015]. Available from: http://www.nasa.gov/centers/langley/news/researchernews/rn_ozone.html
[2] Epa.gov. The Process of Ozone Depletion | Ozone Layer Protection | US EPA [Internet]. 2015 [cited 12 March 2015]. Available from: http://www.epa.gov/ozone/science/process.html
[3] One of the three radiation types (namely UV-A, UV-B and UV-C). Covers wavelengths in the range 280-315 nm.
[4] Ucar.edu. Stratospheric Ozone: Background Material [Internet]. 2015 [cited 12 March 2015]. Available from: https://www.ucar.edu/learn/1_6_1.htm
[5] Who.int. WHO | Ultraviolet radiation [Internet]. 2015 [cited 12 March 2015]. Available from: http://www.who.int/uv/en/
[6] Healthycanadians.gc.ca. Health effects of ultraviolet radiation [Internet]. 2012 [cited 12 March 2015]. Available from: http://healthycanadians.gc.ca/healthy-living-vie-saine/environment-environnement/sun-soleil/effects-uv-effets-eng.php
[7] The early development of bones and the skeletal system.
[8] Who.int. WHO | The known health effects of UV [Internet]. 2015 [cited 12 March 2015]. Available from: http://www.who.int/uv/faq/uvhealtfac/en/index1.html

After a team member's relative was diagnosed with first-stage skin melanoma, we were inspired to employ our technology to a beneficial environmental cause. There were approximately 55,500 deaths worldwide in 2012 from a type of skin cancer called malignant melanoma[9]. Although UV radiation measurers and standard matching tables already exist, the novelty in this project exists in its creative combination with a colour scanner to make a personally optimised device.

Our project MUVIC is an acronym for Micro Ultraviolet index calculator and aims to optimise the effect of UV radiation. Figure 3[10] shows the exposure to UV radiation versus the burden of a disease (skeletal disease due to vitamin D deficiency or skin cancer due to excessive exposure). This figure illustrates the point of maximum utility labelled B, where the individual is healthy in terms of vitamin D sufficiency and blood circulation and, at the same time, has no risk of skin cancers. Ideally, this project aims to calculate point B, for each skin type, given that it varies significantly from skin to skin.

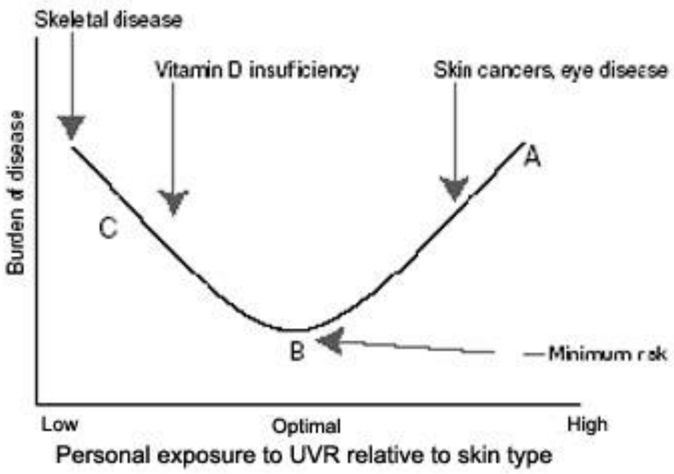

Figure 2: Relationship of exposure to UVR and Burden of Disease

Our optimising technology is founded on the edifice of the initial project's idea; the colour detecting technology will determine the user's skin colour. Then, a UV index sensor will measure the amount of incident UV radiation of that area. Finally, an algorithm will take both sets of data and give the ideal exposure time. One of the technical challenges faced was normalising the data of the colour sensor (in Red-Green-Blue number format) into standard skin colours. Also, finding the exact relationship between skin colour and exposure time required discussion with students and professors from the Biology Department.

[9] A common type of skin cancer reinforced by excessive UV radiation exposure. A common type of skin cancer reinforced by excessive UV radiation exposure. Source:
Macmillan.org.uk. Melanoma overview - Cancer Information - Macmillan Cancer Support [Internet]. 2015 [cited 12 March 2015]. Available from:
http://www.macmillan.org.uk/Cancerinformation/Cancertypes/Melanoma/AboutMelanoma/Melanomaoverview.aspx

[10] Who.int. WHO | Ultraviolet radiation [Internet]. 2015 [cited 12 March 2015]. Available from: http://www.who.int/uv/en/

Recently, an UV measuring device called UVeBand was launched in the market. 'It vibrates when it is time to apply sunscreen', by calculating an UV index.[11] Figure 2 shows the UVeBand bracelet model. In contrast, our product scans the user's skin colour and gives personalised data. In the future, different modes will be explored, and the data will take other factors into account; such as age, medical history and amount of vitamin D in the body.

Figure 3: UVeBand wristband that vibrates when user is expected to apply sunscreen.

2. Design Criteria

The following section includes the most important elements of the Product Design Specification (PDS). The full list of the PDS is included in the Appendix. The following list has changed to a great extent compared to the version in the Interim report due to the shift in the project scope.

<u>Performance</u>: Product should be able to detect the colour of the skin it is exposed to using a sensor. For best results, the user should pull up the band to his forearm, while scanning. Figure 3 illustrates the size and functionality of the device. If the user keeps the band in the wearing position while scanning, he might scan a part of the skin being blocked from sunlight, giving a small error. This is not essential for functionality, yet it significantly improves performance. According to the customer survey (refer to Appendix) the scanning time should not be more than 5 seconds. The Red-Green-Blue (RGB) sensor used is a low-cost, moderate performance sensor and gives accuracy of 3 digits. It could attain a scanning time of 3 ± 1s without compromising neither power nor accuracy. The RGB sensor should give the colour in 3 digits accuracy. Issues related to colour constancy (colour to appear identical under different illumination conditions[12]) will be addressed through the microprocessor's algorithms. It is speculated that 6 different skin colour thresholds will give the required accuracy. If testing shows otherwise, extend to 12 thresholds. The UV sensor and microprocessor are estimated to take 1 ± 0.5s each. The product's functionality is purely electrical and is estimated to dissipate low power (<Watt).

[11] Coxworth, B. (2013). *UV-measuring wrist band lets you know when to reapply sunscreen*. [online] Gizmag.com. Available at: http://www.gizmag.com/uveband-uv-measuring-wrist-band/26559/ [Accessed 12 Mar. 2015].
[12] Sciencedirect.com. Color constancy [Internet]. 2015 [cited 13 March 2015]. Available from: http://www.sciencedirect.com/science/article/pii/S0042698910004402

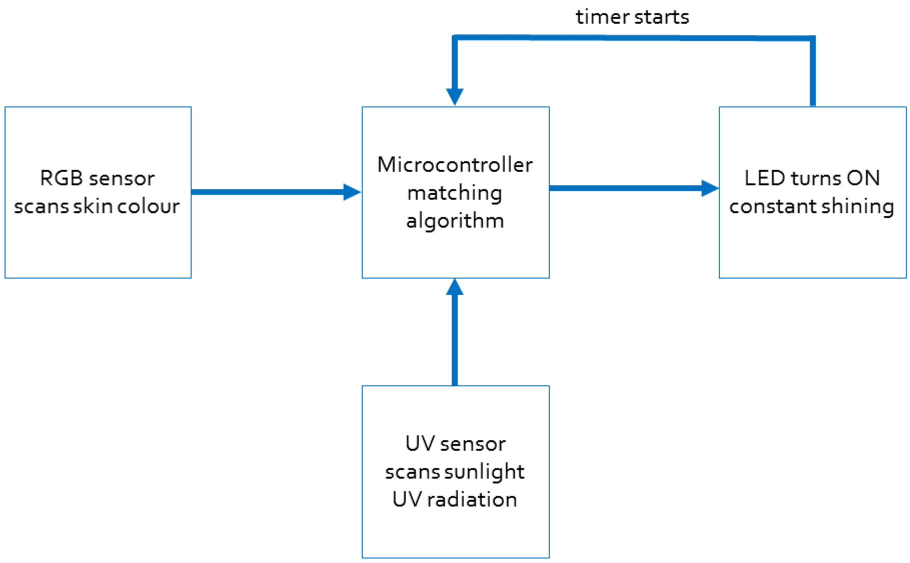

Figure 4: Illustrating performance cycle in real-time

Environment: In order to determine the product's operating temperature, the temperature range of all the components were combined to find the mutual operating range. It was found to be –40 to +85 °C. However, due to the exponential relationship of temperature with current, the ideal operating temperature was reduced to –20 to +60 °C[13]. All the components of the product should function properly throughout this range. The product is not expected to provide accurate readings if the sensing area is covered by dirt or dust. Other variables such as humidity and pressure should not affect the performance, as long as they are not extreme. Although water-resistant, the product would not be waterproof, as the sensors would be damaged (short-circuited). As a whole, the product will be resistant to environment changes in the manufacturing, shipping and storage as long as the environment temperature is between –40 to +85 °C.

Maintenance: In case the sensor surface is blocked by dust or dirt, the user should use a cloth to clean the product's surface before use. In particular, the user manual would recommend softly wiping the scanning surface before every use, to ensure accurate measurements. Users will not need regular maintenance as components should not experience wear and tear. The components used, such as the light-emitting-diodes (LEDs) or sensors, have long lifespan; therefore, the maintenance of the elements should not be of concern for the customers. The product will be robust, as sensitive components will be protected in our design. Although water-resistant, it is suggested that the user wipes the product from any liquid, before it gets absorbed, as indicated in the user manual.

Size: Both sensors and programmable chip should be contained in one compound unit. However we are willing to compromise on product's size in order to attain colour accuracy. The wristband should have a diameter of 15-18 cm for women and 18-21 cm for men. In the future, it is planned to be released in 5 different sizes. Its width should not be more than 0.4 cm. Its depth is constrained by the component size, which will take at least 1.5cm. If the creation of a single integrated arm band is not feasible, our

[13] Silabs.com. Si1132 Ulta Violet Index and Ambient Light Sensor IC | Silicon Labs [Internet]. 2015 [cited 12 March 2015]. Available from: http://www.silabs.com/products/sensors/infraredsensors/Pages/si1132.aspx

alternative design would be to create a separate unit for the sensor and microcontroller. They should both be reasonably sized in order to be light to carry and comfortable to use.

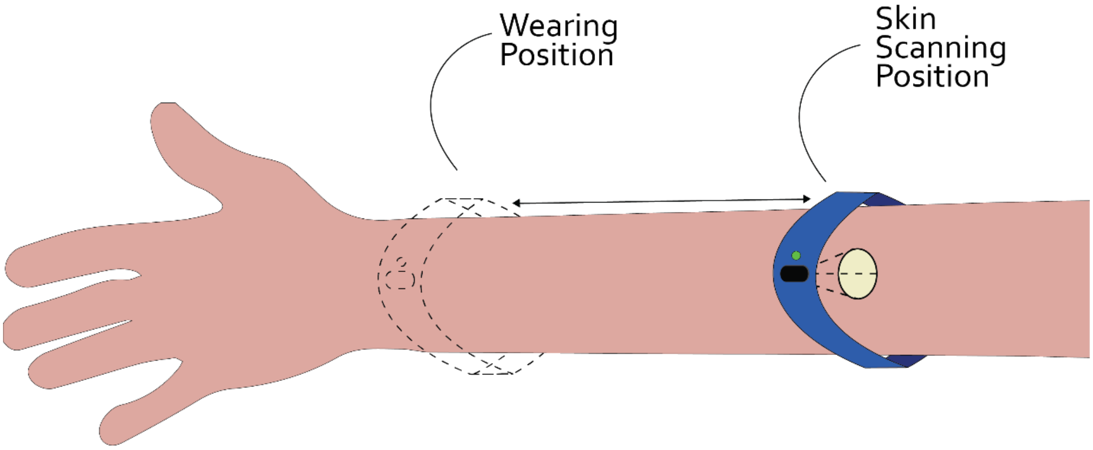

Figure 5: Showing size and functionality of device.

<u>Aesthetics, Appearance and Finish</u>: Product should be a cool, fashionable bracelet. This element is important as most people do not comprehend the importance of sun protection and sufficient vitamin D. The wristband will be visually alluring and pleasant to wear, in order to appeal to consumers. The colour of the prototype would be dark blue (an easy to match colour) and larger than the intended product. After the optimisation of the technology and appearance (according to customer feedback), it will be released in numerous colours and of minimal size. In addition, it will have a modern, smooth and curved shape and a lean texture. Given that the device is not a necessity, it should be seen as a fashionable, revolutionary and aesthetically pleasing. Figure 4 shows the appearance of the suggested prototype.

<u>Ergonomics</u>: Ergonomics is one of the most important design specifications. The product would be marketed as a wristband, which nowadays is a common wearable. Therefore it should be light, firm and comfortable. The back side should be thinner, given it does not include any electronic components. The band's rubber and plastic should have good elasticity, so that it comfortably embraces the forearm. Furthermore from one edge of the band to the other, it has a parabolic pattern, creating a wrap-around effect. The sensor triggering button should have a large contact area of about 50mm, making it visible, easy to trigger and reliable. Figure 4 shows the sensor and button positions, as well as MUVIC's symmetry and simplicity.

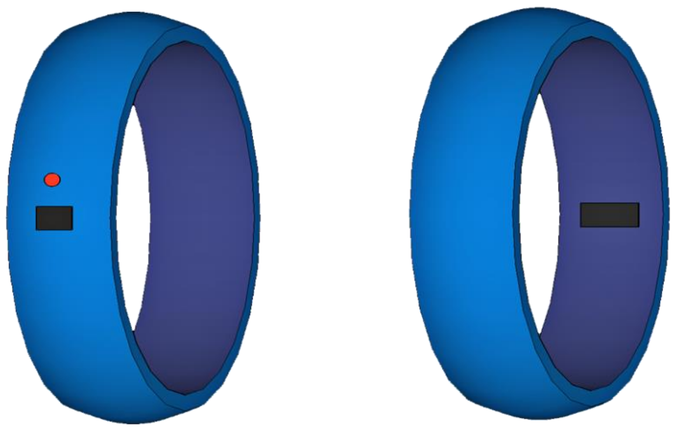

Figure 6: MUVIC's appearance and aesthetics.

Materials: The wristband should not overheat or burn at high temperatures and cause burn to the user. The material of the armband's circumference should be a light lean rubber. The external circumference should be consisting of a thick layer of plastic to protect the sensors from collision damage from everyday use and pressure. The interior includes the colour-detecting sensor, on the same line as the UV sensor (refer to figure above). Therefore, the band will mainly be made of elastic, resilient rubber. This will make the product comfortable to use, as it will be a good fit and light.

Customers: For all our decisions, we have consulted our customers' opinions. The customer survey in the Appendix illustrates some opinions that were considered. Consumers were consulted on the features they would like included in our product as well as the functionality (response time, dimensions). It was concluded that elder people would be more willing to use it, as they are more aware of the UV radiation risks. However, a majority commented on their inability to use new technology. Consequently the product will be released in many modes and variations. Having heard about the elders' inconvenience with the internet, it was decided that upon purchasing the wristband in store, an employee would configure it for them (scan skin colour and deactivate "advanced mode"). Then, elder users would simply need to click the on button when exposed to the sun. The figure below[14] illustrates the direct relationship between skin cancer deaths and age in the UK. Given that elders are more vulnerable to skin cancer, they are one of our main audiences.

[14] Cancerresearchuk.org. Skin cancer mortality statistics : Cancer Research UK [Internet]. 2015 [cited 12 March 2015]. Available from: http://www.cancerresearchuk.org/cancer-info/cancerstats/types/skin/mortality/uk-skin-cancer-mortality-statistics

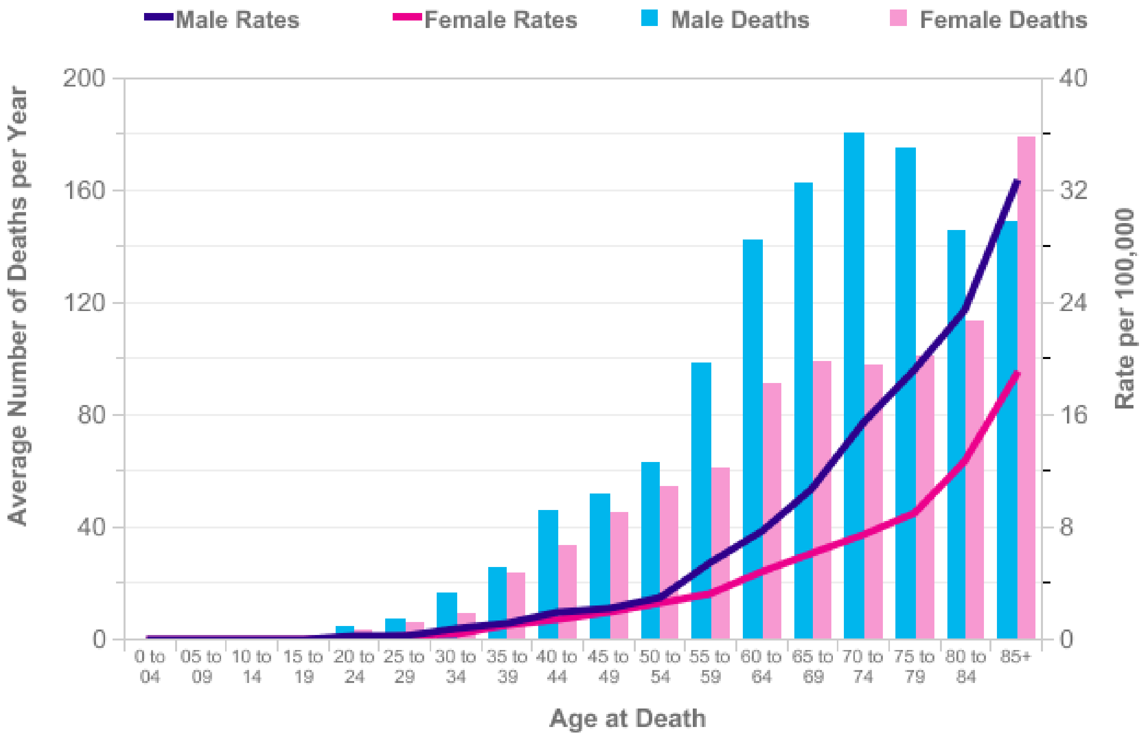

Figure 7: Malignant Melanoma (C43), Average Number of Deaths per Year and Age-Specific Mortality Rates, UK, 2010-2012

In addition, 'pregnant women are more sensitive to high temperatures' and should avoid the sun.[15] Similarly, the product will be configured in that mode upon purchase in store. In fact, changing from mode to mode would simply involve downloading the computer application, connecting the band with a USB cable and changing the "Mode" field accordingly.

Sun exposure in childhood develops to deadly skin cancer.[16] Therefore, mothers should purchase the specific wristband to protect their children. Depending on the child's age, they may place the band on their wrist or their child's wrist.

It is noteworthy to refer to the difficulty of achieving this because of the very high responsibility involved. There might be cases of a defective sensor or controller, leading to UVR overexposure and eventually to skin-cancer or other related diseases. The same effect might be triggered by personal sensitivities or others external factors. Putting the blame on our product would be avoided by declaring a no responsibility policy for health problems caused by malfunctioning products in our terms and conditions. The band should vibrate by default in a one hour period after activation, in the case that both sensors fail. Also, the terms of use should extensively explain the self-responsibility that everyone has on using the product. In case they observe a sunburn or unexpected spot, they should stop using the product and consult their doctor immediately. It should be clarified that the product is simply a helpful estimation.

[15] http://www.dailymail.co.uk/femail/article-461377/Pregnant-women-avoid-sun.html
[16] Causes S. Skin cancer risks and causes | Cancer Research UK [Internet]. Cancerresearchuk.org. 2015 [cited 12 March 2015]. Available from: http://www.cancerresearchuk.org/about-cancer/type/skin-cancer/about/skin-cancer-risks-and-causes

Testing: Product will be tested to determine ways in which design can be improved upon completion of first proto-type. This is very important for minimising the size of the wristband. More efficient wiring, sensors or on-band chip configurations might be possible, which require appropriate testing. The voltage levels of the sensor must be tested in response to different surfaces and shades, to determine the appropriate driving current for the components. The colour sensor must be tested on multiple skin colours to estimate its accuracy. If propagating error leads to an error of more than 10%, improve the colour-constancy algorithm by increasing number of iterations. This means that the data from the sensor will be a better average of the incident colour, which minimises the random error. In case the same error persists, repeat the procedure for a low-power RGB sensor of double the pixel resolution.

3. Concept Designs considered

3.1 Concept 1 – Photodiode array (PDA) with lens

A PDA image sensor will detect the colour. Although it has the lowest cost amongst other image sensors, it has high readout noise in low light applications. To minimise that issue, we will use a white light-emitting-diode (LED) for additional illumination on the incident surface. Also, an optical system will be attached in front of the sensor to blur the incident colour, giving an averaged value. This will minimise the error of non-uniform surfaces. This system will complement the algorithm and give greater accuracy.

Use a UV index/Ambient light sensor to measure UV radiation and output a UV index. With the UV index provided by this sensor, we can directly determine the level of danger on human skin, with respect to the skin colour.

3.2 Concept 2 – UV Sensor digital output and reproduction through USB

A simple photocurrent-to-voltage sensor will be used to calculate UV intensity, which will then be fed into an ADC converter and the UV index will be determined. The UV intensity measurements (after being programmed to convert voltage to UV intensity by an Arduino board, shown in figure 8) can be transferred to a computer using serial or USB ports. Firstly, this can be useful for testing the accuracy of the UV radiation measure on the computer and secondly, for using it on the digital medium in data processing applications. While importing the data into the computer, MUVIC will also be charged through a USB port. An android app will need to be created to store the data and process them accordingly.

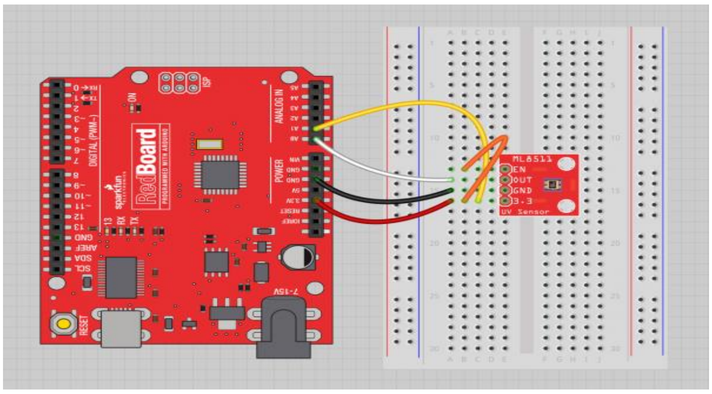

Figure 8: The sensor connection to an Arduino board to convert voltage value to UV intensity.

3.3 Concept 3 – Colour sensor testing and White-Patch processing algorithm

Before creating an algorithm to monitor the information and warn the user respectively, we need to test the (skin) colour sensor and ensure it gives accurate readings. A White-Patch algorithm will then be used to solve the problem of colour-constancy[17] by sampling a surface multiple times. Then, a bilinear interpolation algorithm will use previously obtained colour samples to determine the observed colour. This is achieved by taking the average of the four adjacent pixels of some point A(x, y) and from that, estimating a new pixel value at A.

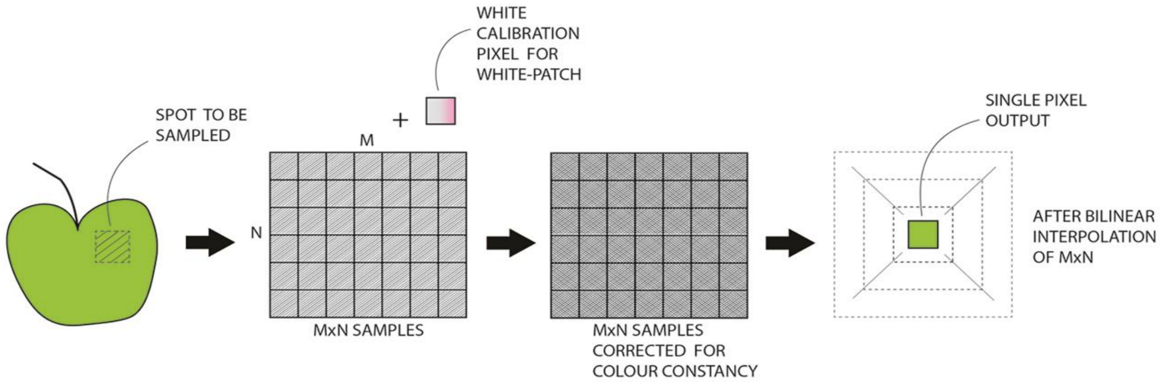

Figure 9: Illustrating how the White-Patch algorithm corrects colour-constancy issues.

4. Concept Selection

Aspects \ Concepts No.	1	2	3
Ergonomics	✓	✓	✓
Performance	✓	✓	✓✓
Manufacturability	✗	✓✓	✗
Power Saving	✓✓	-	✗
Safety	-	✓	-
Aesthetic Appeal	✗	✓	✓
Cost	✓	✗	✓
Net Score	**3**	**5**	**3**

Figure 10: Concept selection method; Controlled Convergence matrix

[17] The perceived colour of a surface remains constant despite changes in the spectrum of the illumination. Source: Sciencedirect.com. Color constancy [Internet]. 2015 [cited 13 March 2015]. Available from: http://www.sciencedirect.com/science/article/pii/S0042698910004402

Figure 10 compares our three main concepts along our design parameters. It is worth noting that a variation of the controlled convergence method was used. In particular, the concepts compared were to a great extent complementary. Moreover, we decided to evaluate each one's contribution in relation to our final product idea. For example, concept 3 scored +2 in performance because it proposes a White-patch algorithm that improves both the colour accuracy and is speed efficient.

It was decided to include concept 1 because of the reading noise rejection provided by the white LED (performance), the minimal power dissipation and reduced cost. Concept 2 was integrated to our project due to the USB's simplicity in use and design. Likewise, concept 3 plays a central role in our design, due to its notable performance, as mentioned, and minimal cost. A full analysis of the component costs is included in Appendix 2.

5. Concept development

5.1 Concept 1: From the first concept we have selected to maintain the idea of the PDA sensor and a white LED, which provides additional illumination on the incident surface. The use of a white LED will minimise the effect of readout noise in low light applications.

The PDA sensor must read the colour of an incident area and output the RGB components of that colour. We chose the TCS3472 model instead of ISL29125[18] because of its high sensitivity, wide dynamic range and Infra-Red (IR) blocking filter. This will significantly boost our device's performance by having a high spectral response on high UV frequencies (i.e. damaging to the skin). It can have a high degree of precision according to the integration time that it is adjusted to. Although it costs 7.25GBP, while the ISL29125 costs 4.66GBP, it will detect UV-B radiation more accurately and will simplify testing with the algorithm.

Additionally, the UV index light sensor is to be used as our UV sensor, due to its configuration and functional simplicity. The best model that fits our design criteria is model SI1132 that integrates multiple photodiodes, an analogue to digital converter (enables long battery life), a signal processor, and a digital I2C control interface.[19] It is a low-cost sensor with an average current of 1.2 μA. It can determine real-time UV sun exposure as well as cumulative UV sun exposure. The photodiode response and associated digital conversion circuitry provide excellent immunity to artificial light flicker noise and natural light flutter noise.

These strong noise rejection characteristics enable extremely accurate measurements. The characteristics of low-cost, energy efficiency, high performance and tiny size (2 mm x 2 mm), all perfectly fit our design specifications. The full analysis and functionality of the SI1132 model is included in Appendix 4.

[18] Intersil.com. ISL29125 [Internet]. 2015 [cited 13 March 2015]. Available from: http://www.intersil.com/en/products/optoelectronics/ambient-light-sensors/light-to-digital-sensors/ISL29125.html

[19] Silabs.com. Si1132 Ulta Violet Index and Ambient Light Sensor IC | Silicon Labs [Internet]. 2015 [cited 12 March 2015]. Available from: http://www.silabs.com/products/sensors/infraredsensors/Pages/si1132.aspx

5.2 Concept 2: The important elements of the second concept are the following: a) the possibility of using a photo-current-to-voltage sensor instead of a UV index one and b) charging the device through an USB port.

A great candidate for the sensor would be the ML8511 model. It uses an internal amplifier to convert photo-current to voltage depending on incident UV intensity. The ML8511 sensor gives an analogue output voltage value. Assuming the use of an ADC, we can calculate the UV intensity by using the UV Intensity versus Output voltage linear relationship (explicitly referred to in Appendix 5). It avoids the use of an I2C protocol[20] and it is mounted on a board which simplifies the soldering process. Also, it has a very high spectral responsivity at 280-390nm. In fact, this is a part of the UV-B (280-315nm) and UV-A spectra (320-400nm), which means that it will effectively scan UV radiation being harmful to the human body (consistent with performance design criterion).

In order to use the analog sensor on a microcontroller, we would need to perform a number of steps to calculate the UV index from the UV intensity (Steps 1-3 should be done in Matlab, and their results stored in the microcontroller's flash memory):

1) Study the responsivity of the sensor in the datasheet[21] and scale it by its integral to turn it into a valid probability density function (pdf).
2) In order to account for non-flat spectra, we will need to assume a specific incoming light source e.g. the sun, and create a plot of its spectrum between the wavelengths of the responsivity graph in 1), relative to the maximum intensity within this range.
3) Discretise the pdf with a given step size (in nm) and obtain the cumulative density function (cdf) at each step by integrating.
4) Discretise the relative spectrum of the incoming light source from step 2 with the same step size.
5) Discretise the weighting function with the same step size.
6) For each step, multiply the sensor value by the cdf and the relative spectrum of the incoming source, at that step. Store each value.
7) For each step, multiply and accumulate the respective value from 6) by the value of the weighting function. This is analogous to integrating across all contributing wavelengths.
8) Finally scale the final answer, as required by the formula.

These steps are redundant in the case of model SI1132, which uses the CIE erythemal action spectrum, shown as green in Figure 11 to determine the UV index.

[20] Only the case in serial data transfer
Source: http://www.robot-electronics.co.uk/acatalog/I2C_Tutorial.html
[21] Semiconductor R. ML8511-00FCZ05B Rohm Semiconductor [Internet]. Digikey.co.uk. 2015 [cited 12 March 2015]. Available from: http://www.digikey.co.uk/product-detail/en/ML8511-00FCZ05B/ML8511-00FCZ05BCT-ND/4259547

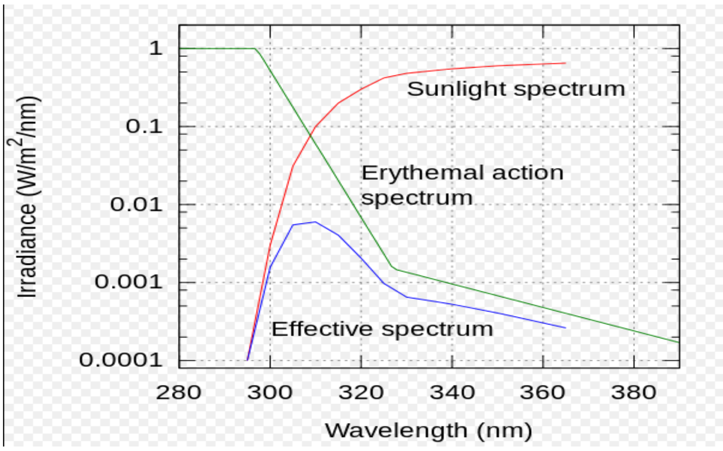

Figure 11: Irradiance versus wavelength of the spectra under consideration

UV index is found by integrating the weighted power spectrum along the whole spectrum.

$$UVI = \frac{1}{\frac{25mW}{m^2}} \int_{286nm}^{400nm} I(\lambda) w(\lambda) d\lambda$$ [22]

Where $I(\lambda)$ is the irradiance and $w(\lambda)$ is the weighting function.

A detailed analysis of how the final UV index is calculated is included in Appendix 4.

As far as the power issues are concerned, we will charge our final product with a Lithium-Polymer (Li-Po) battery of charge current 15 mA to 500 mA at 4.20V. This will give us a maximum power dissipation of 2.1 Watts, ensuring low-power as dictated by the performance specification. A Li-Po charger IC (Integrated Circuit) will be charging the battery from a computer's USB port. A proprietary circuit disables the battery from powering the circuit while USB is connected, and charges the device instead. Battery/USB voltage is fed to a regulator before going to the rest of the circuit, which ensures safety.

5.3 Concept 3: The primary limitations of the White Patch algorithm are the RAM capacity on the microcontroller and the integration time[23] of our sensor. In order to test the algorithm, we will get data from colour sensor model TCS3472[24] models. The TCS3472 model has been chosen instead of ISL29125 for the testing part of the algorithm because it allows testing different precisions levels by varying the integration time. Furthermore, bilinear interpolation will be used instead of bi-cubic because it offers far greater speed in the expense of a small loss in colour precision.

In order to model and visualise data from the colour sensor, we created a real time simulation in Matlab that displays the current colour (RGB filtered photodiodes) and overall light levels (unfiltered photodiode), both as images and as real time graphs of the individual components.

We added various commands to the serial interface, which enable us to change parameters such as sensor gain, integration time, and LED intensity without the need to reprogram the microcontroller.

---

[22] NOAA-EPA Brewer Network. Instantaneous UV Index and Daily UV Dose Calculations [Internet]. 2015 [cited 13 March 2015]. Available from: http://www.esrl.noaa.gov/gmd/grad/neubrew/docs/UVindex.pdf
[23] Integration time refers to the time it takes for the sensor to perform the ADC conversion of the raw photodiode output.
[24] Digikey.com. TCS3472 - AMS-TAOS USA Inc - Specialized | Online Catalog | DigiKey Electronics [Internet]. 2015 [cited 15 March 2015]. Available from: http://www.digikey.com/catalog/en/partgroup/tcs3472/33049

The incoming colour data is 16 bits/channel; we wanted to scale this data from 0-255 (8 bits) -according to Matlab requirement- in order to display the colour as a single pixel. However, we faced a problem: the dynamic range of the data was a lot smaller than its bit width, meaning that we would only get a maximum value of approximately 23,000 on the unfiltered (clear) channel with a bright white LED shining on the sensor, whilst the maximum value of a 16 bit number is 65,535. Note: the other channels would go much lower than this at their peaks.

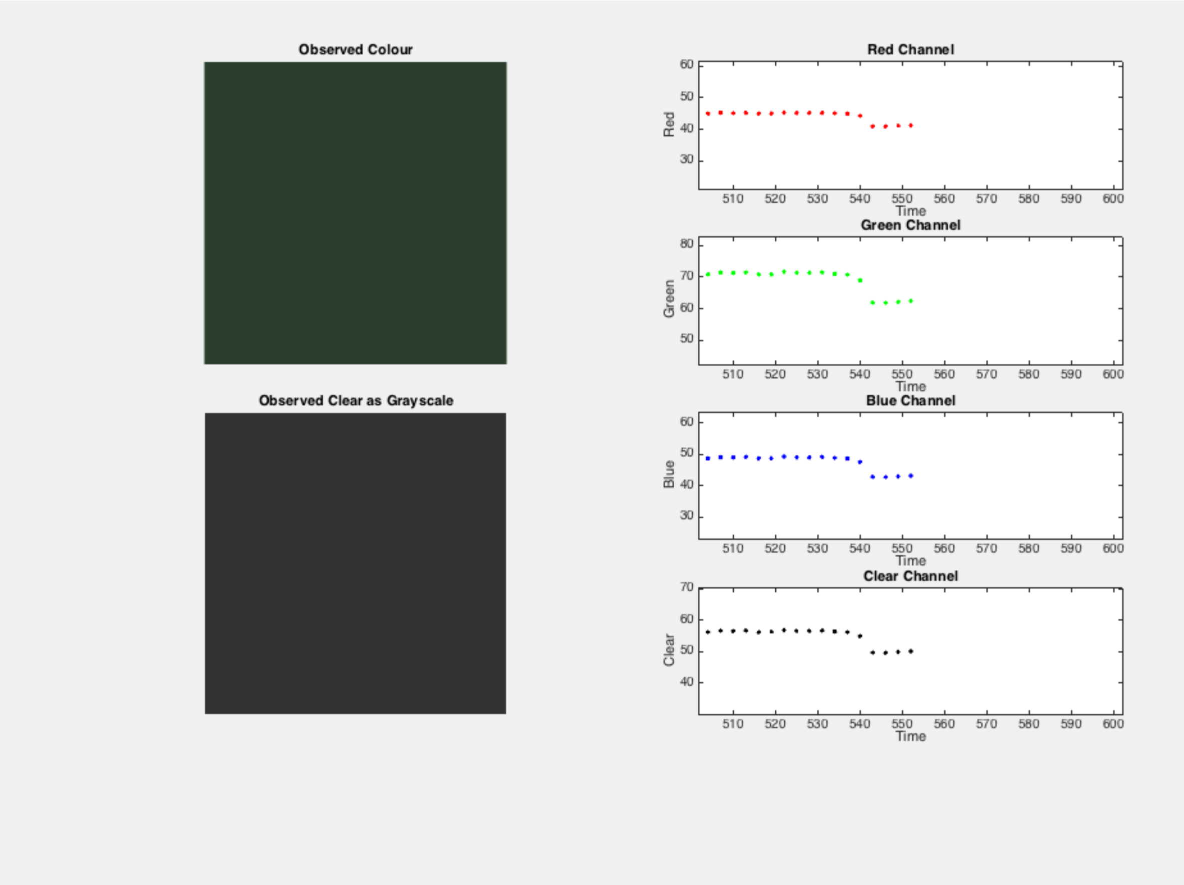

Figure 12: Showing tests of the TCS3472 colour sensor.

To overcome this issue, we implemented an algorithm in Matlab that constantly updates the maximum value received by each channel. We scaled the channels by their respective maxima and found that this gives us an appropriate dynamic range with calibration. To calibrate, one drags the sensor on a piece of paper with 4 separate areas (red, green, blue, white). Figure 12 shows the Matlab interface when scanning a surface and the graphs of the 4 colour components.

For mass production, ideally we would store the maximum values in the flash memory of the microcontroller. Furthermore, we would find these maximum values by shining coherent sources of light e.g. lasers, at known wavelengths corresponding to the different colours and then scale the received values by the ratio of the respective photodiode's response at the laser's wavelength to its peak response, found in the datasheet.[25]

---

[25] Digikey.com. TCS3472 - AMS-TAOS USA Inc - Specialized | Online Catalog | DigiKey Electronics [Internet]. 2015 [cited 15 March 2015]. Available from: http://www.digikey.com/catalog/en/partgroup/tcs3472/33049

Example: Assume that the red photodiode has a peak response at 620nm, yet only a 650nm laser is available. Also, assume that at 620nm, the response is 1.4x the response at 650nm. We would shine the laser, record the value and then multiply it by 1.4 to get our maximum calibration value.

6. Discussion

As a first step, we have decided to use the PDA as a colour light sensor type. We have decided to eliminate the idea of a lens because it is not feasible according to our time restriction, and the PDA is cheaper with a better spectral response.

We have decided to use the ISL29125 model as our light sensor, which is a low power, high sensitivity, Red-Green-Blue (RGB) light sensor with an I2C interface.[26]

We chose the TCS3472[27] model instead of ISL29125[28] because of its low-power, high sensitivity, wide dynamic range (3,800,000:1) and Infra-Red (IR) blocking filter. The TCS3472 consumes more than ISL29125 in active state (235µA compared to 56µA) on an output voltage of 0.5V.[29] Since the skin colour detector will only scan once in every use, we decided that it is worth trading a relatively higher power dissipation of 118µW with higher accuracy. However, when inactive it goes into a very low power state of 2.5µA, decreasing average power consumption. It can have a high degree of precision according to the integration time that it is adjusted to. It also rejects artificial light flicker (50Hz and 60Hz frequencies), due to the integrated Analogue-to-Digital Converter (ADC). Although it costs 7.25GBP, while the ISL29125 costs 4.66GBP, it has a high spectral responsivity for the desired wavelengths (600±100nm) and will simplify testing with the algorithm. The I2C supply ranges from 1.7V to 3.63V, and operating temperature from -40°C to +85°C, which are consistent with our design specifications.

In order to obtain measurements for the UV radiation of an area, we have chosen to use an integrated UV sensor. Initially, we faced the problem of having to convert the voltage values obtained by the sensors into UV intensity units. Using their linear relationship (refer to appendix 5) this problem was tackled. However, converting UV intensity to UV index proved to be very complicated. We would need to discretise the pdf function and integrate it over all the contributing wavelengths, as discussed in the development of concept 2. To avoid going through this procedure, making our design more feasible, we decided to use an integrated UV sensor that performs these operations internally. While choosing the appropriate model, we faced an elastic trade-off between cost and accuracy. The SI1132 model is a good compromise of sufficient accuracy and comparatively low-cost, given that the sensor is the main component of our design.

The SI1132 model integrates multiple photodiodes, an analogue to digital converter, a signal processor, and a digital I2C control interface. Figures 13 and 14 show two of the manufacturing procedures in order to use the SI1132 UV index model. The necessary actions were to etch the tiny UV sensor on a copper board, solder and then test it with an Arduino board.

---

[26] Intersil.com. ISL29125 [Internet]. 2015 [cited 13 March 2015]. Available from: http://www.intersil.com/en/products/optoelectronics/ambient-light-sensors/light-to-digital-sensors/ISL29125.html
[27] Digikey.com. TCS3472 – AMS-TAOS US
[28] Intersil.com. ISL29125
[29] Digikey.com. TCS3472 – AMS-TAOS US

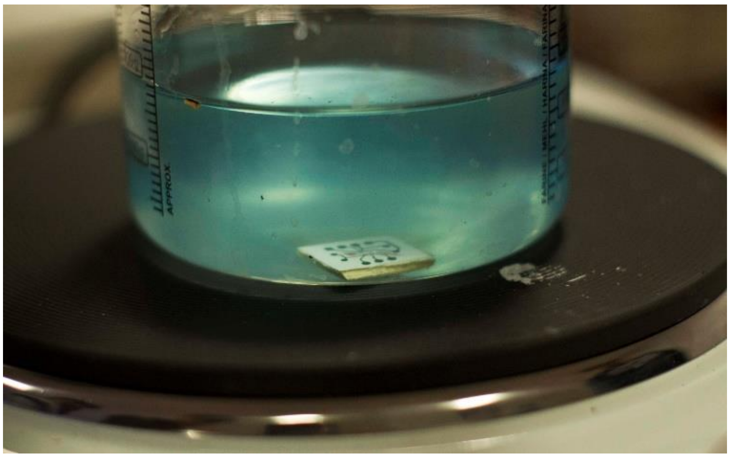

Figure 13: Etching the UV sensor copper board, heated in ammonium persulfate.

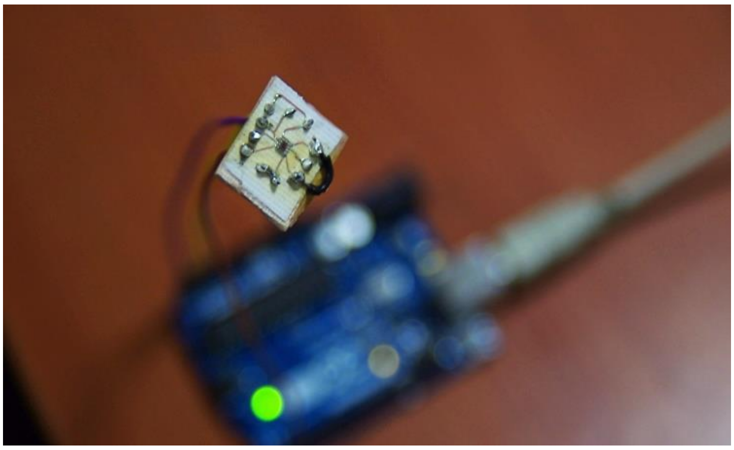

Figure 14: Testing UV sensor with Arduino board

We selected to use the Si1132 instead of the ML8511 because it is much more feasible as a design. Although it is cheaper as a component (2.00GBP compared to 9.60GBP), it needs to be soldered and glued onto a board. Lack of design simplicity is overcompensated by its moderate accuracy and great user and modelling simplicity (gives UV index value from 1-11 with increasing risk). According to the customer survey (Appendix 3), 83% of consumers would pay more than 20GBP to buy the product. Therefore, it is sensible to invest 2GBP to our main sensor that scans UV radiation. It should be pointed out that in case the skin colour sensor fails, the UV sensor will still work with its default value[30], which is not true vice versa. The model used for the design (SI1132) has an average current of 1.2 μA average current and (less than) 500 nA on standby, compared to 300μA and low standby current 0.1μA for the ML8511. In the UV sensor's case, low-power is very important, as the sensor will be continuously scanning for a change in the UV index. The SI1132 would dissipate 250 times less than the ML8511, resulting in longer battery life. Also, it is half the size of the ML8511 model (2 mm x 2 mm compared to 4.0mm x 3.7 mm), which aids the integration to a single compact device.

[30] As mentioned in the PDS in Appendix 1.

7. Conclusion

Due to the deteriorating condition of the ozone layer[31], average temperatures will increase throughout the globe. Skin diseases and general symptoms from UV radiation will be expected to rise if the situation remains unchanged, raising health concerns regarding UV radiation. In this effect, people will fear UV exposure and will end up on the other side of the UV exposure curve of Figure 2, lacking sufficient vitamin D. Since our product will provide a personalised UV exposure optimisation device, we expect demand for our product to increase due to higher risk of skin cancers.

After having tested both the colour and UV sensors, we look forward to writing the algorithm that takes the data from the sensors and warns the user. The user will notice the main LED shining at a higher frequency, when the UV index increases. We aim to add a timer function in the algorithm, so that the device tells the user exactly how much exposure time is healthy, according to his skin colour. A LED light would shine with a red colour when the user has reached the exposure threshold, and is in-risk of getting burned. If we had more time, we would integrate our device with the current smartphone technology. This would enable monitoring of data, in the case of doctors keeping track of their patients or parents looking after their children.

Additionally, we would add more degrees of freedom as variables, including location (closer to the equator, UV levels are higher so even shorter periods of exposure suffice[32]), medical history, medication taken and type of user (mother, elder, children etc.) to maximise the effectiveness of the sensor. For instance, UV thresholds would be decreased (allow less UV exposure) for pregnant women.

Finally, we would add data collection features, such as date/time, weather and location, which would enable users to make more informative conclusions about their sun exposure. For example, an elder realised that he received a warning within 20 minutes of exposure at 1 p.m., showing him that exposure at early day times is dangerous.

[31] International Business Times UK. Climate Change: 'Unexpected Increase' in Ozone Destroying Substance HCI [Internet]. 2014 [cited 15 March 2015]. Available from: http://www.ibtimes.co.uk/climate-change-unexpected-increase-ozone-destroying-substance-hci-1473357

[32] Who.int. WHO | The known health effects of UV [Internet]. 2015 [cited 15 March 2015]. Available from: http://www.who.int/uv/faq/uvhealtfac/en/index1.html

8. References

Websites

1. Nasa.gov. NASA - An Improving Ozone Layer, Something to Sing About [Internet]. 2015 [cited 12 March 2015]. Available from: http://www.nasa.gov/centers/langley/news/researchernews/rn_ozone.html
2. Epa.gov. The Process of Ozone Depletion | Ozone Layer Protection | US EPA [Internet]. 2015 [cited 12 March 2015]. Available from: http://www.epa.gov/ozone/science/process.html
3. Ucar.edu. Stratospheric Ozone: Background Material [Internet]. 2015 [cited 12 March 2015]. Available from: https://www.ucar.edu/learn/1_6_1.htm
4. Who.int. WHO | Ultraviolet radiation [Internet]. 2015 [cited 12 March 2015]. Available from: http://www.who.int/uv/en/
5. Healthycanadians.gc.ca. Health effects of ultraviolet radiation [Internet]. 2012 [cited 12 March 2015]. Available from: http://healthycanadians.gc.ca/healthy-living-vie-saine/environment-environnement/sun-soleil/effects-uv-effets-eng.php
6. Who.int. WHO | The known health effects of UV [Internet]. 2015 [cited 12 March 2015]. Available from: http://www.who.int/uv/faq/uvhealtfac/en/index1.html
7. Macmillan.org.uk. Melanoma overview - Cancer Information - Macmillan Cancer Support [Internet]. 2015 [cited 12 March 2015]. Available from: http://www.macmillan.org.uk/Cancerinformation/Cancertypes/Melanoma/AboutMelanoma/Melanoma overview.aspx
8. Coxworth B. UV-measuring wrist band lets you know when to reapply sunscreen [Internet]. Gizmag.com. 2013 [cited 12 March 2015]. Available from: http://www.gizmag.com/uveband-uv-measuring-wrist-band/26559/
9. Sciencedirect.com. Color constancy [Internet]. 2015 [cited 13 March 2015]. Available from: http://www.sciencedirect.com/science/article/pii/S0042698910004402
10. Silabs.com. Si1132 Ulta Violet Index and Ambient Light Sensor IC | Silicon Labs [Internet]. 2015 [cited 12 March 2015]. Available from: http://www.silabs.com/products/sensors/infraredsensors/Pages/si1132.aspx
11. Cancerresearchuk.org. Skin cancer mortality statistics : Cancer Research UK [Internet]. 2015 [cited 12 March 2015]. Available from: http://www.cancerresearchuk.org/cancer-info/cancerstats/types/skin/mortality/uk-skin-cancer-mortality-statistics
12. Causes S. Skin cancer risks and causes | Cancer Research UK [Internet]. Cancerresearchuk.org. 2015 [cited 12 March 2015]. Available from: http://www.cancerresearchuk.org/about-cancer/type/skin-cancer/about/skin-cancer-risks-and-causes
13. Sciencedirect.com. Color constancy [Internet]. 2015 [cited 13 March 2015]. Available from: http://www.sciencedirect.com/science/article/pii/S0042698910004402
14. Intersil.com. ISL29125 [Internet]. 2015 [cited 13 March 2015]. Available from: http://www.intersil.com/en/products/optoelectronics/ambient-light-sensors/light-to-digital-sensors/ISL29125.html
15. Semiconductor R. ML8511-00FCZ05B Rohm Semiconductor [Internet]. Digikey.co.uk. 2015 [cited 12

March 2015]. Available from: http://www.digikey.co.uk/product-detail/en/ML8511-00FCZ05B/ML8511-00FCZ05BCT-ND/4259547

16. NOAA-EPA Brewer Network. Instantaneous UV Index and Daily UV Dose Calculations [Internet]. 2015 [cited 13 March 2015]. Available from: http://www.esrl.noaa.gov/gmd/grad/neubrew/docs/UVindex.pdf
17. Digikey.com. TCS3472 - AMS-TAOS USA Inc - Specialized | Online Catalog | DigiKey Electronics [Internet]. 2015 [cited 15 March 2015]. Available from: http://www.digikey.com/catalog/en/partgroup/tcs3472/33049
18. International Business Times UK. Climate Change: 'Unexpected Increase' in Ozone Destroying Substance HCI [Internet]. 2014 [cited 15 March 2015]. Available from: http://www.ibtimes.co.uk/climate-change-unexpected-increase-ozone-destroying-substance-hci-1473357
19. Who.int. WHO | The known health effects of UV [Internet]. 2015 [cited 15 March 2015]. Available from: http://www.who.int/uv/faq/uvhealtfac/en/index1.html
20. Iac.ethz.ch. Solar erythemal ultraviolet radiation [Internet]. 2015 [cited 15 March 2015]. Available from: http://www.iac.ethz.ch/en/research/chemie/tpeter/www_uv.html
21. Mail Online. Pregnant women 'should avoid the sun' [Internet]. 2015 [cited 15 March 2015]. Available from: http://www.dailymail.co.uk/femail/article-461377/Pregnant-women-avoid-sun.html

Books

1. Lantz, K. O. P. Disterhoft, J. J. DeLuisi, E. Early, A. Thompson, D. Bigelow, and J. Slusser, "Methodology for Deriving Clear-Sky Erythemal Calibration Factors for UV Broadband Radiometers of the U.S. Central UV Calibration Facility," J . Atmos. and Ocean. Tech. 16, 1736- 1752, 1999.
2. Bernhard, G., C.R. Booth, and J.C. Ehramjian, "Supplement to Version 2 data of the National Science Foundation`s Ultraviolet Radiation Monitoring Network: South Pole," J. Geophys. Res. 109, D21207, doi:10.1029/2004JD004937, 2004.

9. Appendices

9.1 Appendix 1 – Design Criteria

1. Performance: Product should be able to detect the colour of the skin it is exposed to using a sensor. For best results, the user should pull up the band to his forearm, while scanning. Figure 3 illustrates the size and functionality of the device. If the user keeps the band in the wearing position while scanning, he might scan a part of the skin being blocked from sunlight, giving a small error. This is not essential for functionality, yet it significantly improves performance. According to the customer survey (refer to Appendix) the scanning time should not be more than 5 seconds. The Red-Green-Blue (RGB) sensor used is a low-cost, moderate performance sensor and gives accuracy of 3 digits. It could attain a scanning time of 3 ± 1s without compromising neither power nor accuracy. The RGB sensor should give the colour in 3 digits accuracy. Issues related to colour constancy (colour to appear identical under different illumination conditions[33]) will be addressed through the microprocessor's algorithms. It is speculated that 6 different skin colour thresholds will give the required accuracy. If testing shows otherwise, extend to 12 thresholds. The UV sensor and microprocessor are estimated to take 1 ± 0.5s each. The product's functionality is purely electrical and is estimated to dissipate low power (<Watt).

2. Environment: In order to determine the product's operating temperature, the temperature range of all the components were combined to find the mutual operating range. It was found to be –40 to +85 °C. However, due to the exponential relationship of temperature with current, the ideal operating temperature was reduced to –20 to +60 °C. All the components of the product should function properly throughout this range. The product is not expected to provide accurate readings if the sensing area is covered by dirt or dust. Other variables such as humidity and pressured should not affect the performance, as long as they are not extreme. Although water-resistant, the product would not be waterproof, as the sensors would be damaged (short-circuited). As a whole, the product will be resistant to environment changes in the manufacturing, shipping and storage as long as the environment temperature is between –40 to +85 °C.

3. Life in Service: The product should be durable and long-lasting. It is estimated to last eight months to a year, assuming non-abusive use. This is because it will always be used in high temperatures (id est when people are exposed to sunlight).

4. Maintenance: In case the sensor surface is blocked by dust or dirt, the user should use a cloth to clean the product's surface before use. In particular, the user manual would recommend softly wiping the scanning surface before every use, to ensure accurate measurements. Users will not need regular maintenance as components should not experience wear and tear. The components used, such as the LEDs or sensors, have long lifespan, therefore the maintenance of the elements should not be an element of concern for the customers. The product will be robust and sensitive components will be protected in our design. Although water-resistant, it is suggested that the user wipes the product from any liquid, before it gets absorbed, as indicated in the user manual.

5. Target Product Cost: We would like the manufacturing cost to be low. However, given that we have not finished our product's business and marketing plan, the exact cost cannot be determined. For the moment, other design specifications are prioritised, such as performance and safety.

6. Competition: Currently there are no competitors who are producing such a product or design.

---

[33] Sciencedirect.com. Color constancy [Internet]. 2015 [cited 13 March 2015]. Available from: http://www.sciencedirect.com/science/article/pii/S0042698910004402

7. Shipping: Product can be shipped by any means. Not an element of importance.

8. Packing: Product should be shipped at the simplest way possible to minimise transport costs. The necessary conditions are that it is placed horizontally, wrapped with foam cushioning and bubble wrap. During shipping, it should at least have two box layers, to protect from salt water and liquids.

9. Quantity: For the demo phase, the desired quantity would be 50 pieces. After the product's place in the market has been established through tests and illustrations, a greater quantity would be requested, according to the business plan.

10. Manufacturing Facility: It will be challenging and expensive to build electrical facilities to build, solder, program and test the product.

11. Size: Both sensors and programmable chip should be contained in one compound unit. However we are willing to compromise on products size in order to attain colour accuracy. The wristband should have a diameter of 15-18 cm for women and 18-21 cm for men. In the future, it is planned to be released in 5 different sizes. Its width should not be more than 0.4 cm. Its depth is constrained by the component size, which will take at least 1.5cm. If the creation of a single integrated arm band is not feasible, our alternative design would be to create a separate unit for the sensor and microcontroller. They should both be reasonably sized in order to be light to carry and comfortable to use.

12. Weight: Product should be relatively light so that users can use it with ease and comfort. However, again we are willing to compromise on weight up to 200 grams to obtain the expected performance and low-power.

13. Aesthetics, Appearance and Finish: Product should be a cool, fashionable bracelet. This element is important as most people do not comprehend the importance of sun protection and sufficient vitamin D. Therefore, the wristband should be pleasant to wear. The colour of the prototype would be dark blue (an easy to match colour) and larger than the intended product. After the optimisation of the technology and appearance (according to customer survey Appendix 3), it will be released in numerous colours and of minimal size. In addition, it will have a modern, smooth and curved shape and a lean texture. Given that the device is not a necessity, it should be seen as a fashionable, revolutionary and aesthetically pleasing.

14. Materials: The wristband should not overheat or burn at high temperatures and cause burn to the user. The material of the armband's circumference should be a light lean rubber. The external circumference should be consisting of a thick layer of plastic to protect the sensors from collision damage from everyday use and pressure. The interior includes the colour-detecting sensor, on the same line as the UV sensor. Therefore, the band will mainly be made of elastic, resilient rubber. This will make the product fun to use, as it will be loose and light.

15. Product Life Span: Product should remain in production as long as the batch orders are being updated. The product is going to be manufactured in batches. As mentioned, the first one will be 50 items. The life of the product's production will depend on the demand for the product. This tactic minimises the cost in case of not breaking-even.

16. Standards and Specifications: We are not currently aware of any international standards or specifications that apply to our product. In any case this is not an element of great importance.

17. Ergonomics: Ergonomics is one of the most important design specifications. The product would be marketed as a wristband, which nowadays is a common wearable. Therefore, it should also be light, firm and comfortable. It should at the same time fit the wrist and not be noticeably firm (refer to size

specification). The back side should be thinner, given it does not include any electronic components. The band's rubber and plastic should have good elasticity, so that it comfortably embraces the forearm. The band's main ergonomic characteristic is symmetry. From one edge to the other, it has a parabolic pattern, creating a wrap-around effect. The sensor triggering button should have a large contact area of about 50mm, making it visible, easy to trigger and reliable.

18. Customers: For all our decisions, we have consulted our customers' opinions. The customer survey in Appendix 3 illustrates some opinion that were considered. Consumers were considered on the features they would like included in our product as well as the functionality (response time, dimensions). It was concluded that elder people would be more willing to use it, as they are more aware of the UV radiation risks. However, a majority commented on their inability to use new technology. Consequently, the product will be released in many modes and variations. Having been consulted about the elders' inconvenience with the internet, it was decided that upon purchasing the wristband in store, an employee would configure it for them (scan skin colour and deactivate "advanced mode"). Then, elder users would simply need to click the on button when exposed to the sun. In addition, 'pregnant are more sensitive to high temperatures' and should avoid the sun.[34] Similarly, the product will be configured in that mode upon purchase in store. In fact, changing from mode to mode would simply involve downloading the computer application, connecting the band with a USB cable and changing the "Mode" field accordingly. Sun exposure in childhood develops to deadly skin cancer.[35] Therefore, mother should purchase the specific wristband to protect their children. Depending on the child's age, they may put-on the band to their own or to their child's wrist.

19. Quality and Reliability: Feedback will be available after comprehensive testing of first batch.

20. Storage: Product uses electrical components which might be prone to rusting or corrosion in the long term. General decay could be combatted by minimising shelf life through ordering small batches each time and immediately deliver in stores.

21. Processes: Standard wiring and PCB design procedures should be applied. Not an element of great significance.

22. Time-scale: Fixed deadline for completion on the 26th of March.

23. Testing: Product will be tested to determine ways in which design can be improved upon completion of first proto-type. This is very important for minimising the size of the wristband. More efficient wiring, sensors or on-band chip configurations might be possible, which require appropriate testing. The voltage levels of the sensor must be tested in response to different surfaces and shades, to determine the appropriate driving current for the components. The colour sensor must be tested on multiple skin colours to estimate its accuracy. If propagating error leads to error of more than 10%, improve the colour-constancy algorithm by increasing number of iterations. This means that the data from the sensor will be a better average of the incident colour, which minimises the random error. In case the same error persists, repeat the procedure for a low-power RGB sensor of double the pixel resolution.

24. Safety: There is no risk relevant to the wristband itself. The electrical components are operating on very low voltage, and are fully insulated due to the plastic.

[34] http://www.dailymail.co.uk/femail/article-461377/Pregnant-women-avoid-sun.html
[35] Causes S. Skin cancer risks and causes | Cancer Research UK [Internet]. Cancerresearchuk.org. 2015 [cited 12 March 2015]. Available from: http://www.cancerresearchuk.org/about-cancer/type/skin-cancer/about/skin-cancer-risks-and-causes

25. Company Constraints: We are constrained to a fixed budget of 50£.

26. Market Constraints: Feedback from potential customers (survey in Appendix 3) limited the design concept according to the particular audience. For instance, due to the increased interest of elders, it should be more easy to use than fashionable as a design.

27. Patents: We are not aware of any patents that conceptually conflict our product's design. There exists a patent for UV-sensors but our product does not rely on this particular configuration, nor sensor type. Not an element of importance.

28. Political and Social Implications: Product will not have any undesired political nor social effects. Not an element of importance.

29. Legal: Legislation needs to be adopted for the Terms of Use statement that removes any responsibility due to reliance on the product's sunlight exposure time suggestions.

30. Documentation: Manual and product description would be available in package for user's disclosure. It should refer to the product's maintenance (drying it from any water or other liquid, wiping dirt and dust off the sensors). The manual information would also be available online.

31. Disposal: Product would be disposed similar to other electronic devices. Product is also recyclable (in the electronic devices section). Does not include hazardous or toxic parts.

32. Installation: Product is handheld and requires no physical installation. As mentioned, the sensor can be configured through a USB connection in the store or at home. USB cable provided in product package.

9.2 Appendix 2 - Component List and Costs

Type	Name	Unit Price(£)	Quant.	Total Price(£)	Supplier	Website
Colour Sensor Module	ISL29125	4.66	1	4,66	Cool Components	https://www.coolcomponents.co.uk/sensors/visible-light/isl29125-rgb-light-sensor.html
Colour Sensor Module	TCS34725 - Adafruit	7.25 (incl. VAT)	1	7,25	Digital Means	https://digitalmeans.co.uk/shop/rgb_color_sensor_with_ir_filter_and_white_led-tcs34725
UV Sensor Breakout	ML8511	9.60 (incl. VAT)	1	9,60	Hobbytronics	http://www.hobbytronics.co.uk/ml8511-uv-sensor
UV Sensor Digital Index	SI1132-A10-GMR	1.99	2	3,98	Digi-Key	http://www.digikey.co.uk/product-detail/en/0/336-2621-1-ND

9.3 Appendix 3 – Customer survey

This survey was conducted from 5-8 March. The sample size was 100 people, from which 50 were Imperial College students and 50 were pedestrians on Exhibition Road. This kind of sample was chosen for two reasons. The first reason was to determine if our speculated audience are actually interested in using the product, and change it accordingly. Secondly, responses from a variety of ethnic groups, ages and nationalities would function as a good critique on our product, from very many different perspectives.

A short description of the product was given, followed by the questions below.

a. How likely would you use the product?

   a) Very likely b) Likely c) Not likely

   10%, 75%, 15% answered a, b, c respectively.

b. What is your maximum allowable operation time of this product?

   a) 1 second b) 2-3 seconds c) 5-7 seconds d) 10+seconds

   8%, 83%, 7%, 2% answered a, b, c, d respectively.

c. How big would you like the product to be?

   a) 15-17 cm b) 17-19 cm c) 19-21 cm d)21-23 cm

   33%, 55%, 10%, 2% answered a, b, c, d respectively.

d. Do you have any skin-related diseases in your medical history?

   a) Yes b)No

   9%, 91% answered a, b respectively.

e. What is the maximum price you would be willing to pay?

   a) 10 gbp b) 20 gbp c) 30 gbp d) 40 gbp e) 50+ gbp

   17%, 40%, 13%, 12%, 18% answered a, b, c, d, e respectively.

9.4 Appendix 4 – SI1132 UV Sensor

This sensor integrates multiple photodiodes, an analogue to digital converter, a signal processor, and a digital I2C control interface. This model will enable us to set thresholds and relevant warning when they are passed. Also, it allows determining the cumulative UV exposure during a period of time.

<u>Si1132's important features:</u>

- Digital UV Index sensor
    - Determine real-time UV sun exposure and cumulative UV sun exposure
- Low-power sensor, signal processer, and ADC enable long battery life
    - As little as 1.2 µA average current with once per second UV Index measurements
    - 1.7 to 3.6 V supply voltage
    - < 500 nA standby current
- I^{2}C interface for ease of communication with host MCU
- Tiny 2 mm x 2 mm clear QFN package.
- Operating temperature: – 40 to 85 °.
- Excellent performance under a wide dynamic range and a variety of light sources including direct sunlight.
- Can also work under dark glass covers.
- The photodiode response and associated digital conversion circuitry provide excellent immunity to artificial light flicker noise and natural light flutter noise.

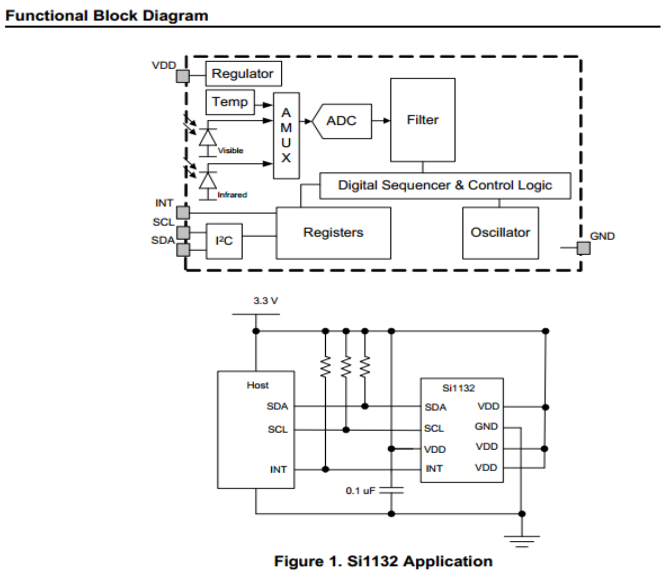

Figure 15: Inner structure of sensor (top) and the default connection configuration

We can control the operational state of the sensor through registers accessible through the I^2C interface. The operational state of the sensor can be “sleep” or “wake up”. The host can command the sensor to start sensing the UV index on-demand. In this case the operational state of the sensor changes with the command sent. It is also possible to place Si1132 in an autonomous operational where it takes measurements at set intervals and interrupts the host after each measurement is completed. In this case however, the operational state of the sensor changes, at several intervals, not demanding any command from the host. This provides overall system power saving allowing the host controller to operate longer in its sleep state instead of polling the sensor continuously. [36]

The wavelengths of concern are that of 295 to 325 nm, because they are the most damaging to the skin. The UV power spectrum is weighted according to a weighting curve called CIE Erythemal Action Spectrum[37], which is a standardized curve illustrating how skin responds to different wavelengths. Figure 16 illustrates the CIE standardised curve, which adds greater weighting to UV-B wavelengths (harmful to the body) and less to UV-A radiation wavelengths. Figure 17 shows how the sensor’s effective spectrum (blue curve) can be obtained by multiplying the sunlight spectrum (red curve) by the standardised erythemal action spectrum (green). UV index is found by integrating the weighted power spectrum along the whole spectrum.

$$UVI = \frac{1}{\frac{25mW}{m^2}} \int_{286nm}^{400nm} I(\lambda)w(\lambda)d\lambda \quad ^{38}$$

Where $I(\lambda)$ is the irradiance and $w(\lambda)$ is the weighting function.

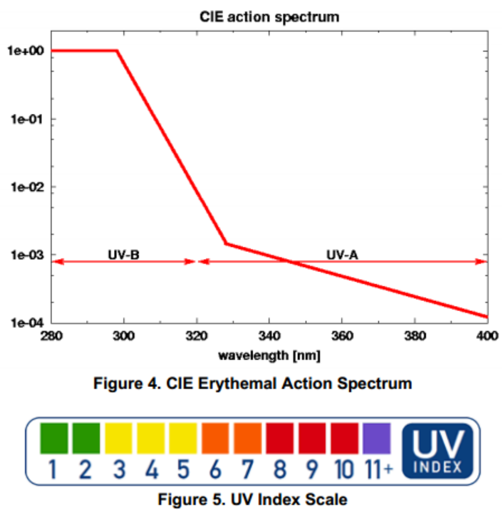

Figure 16: CIE EA spectrum showing standardiser graph (top) and UV index scale with increasing risk (bottom)

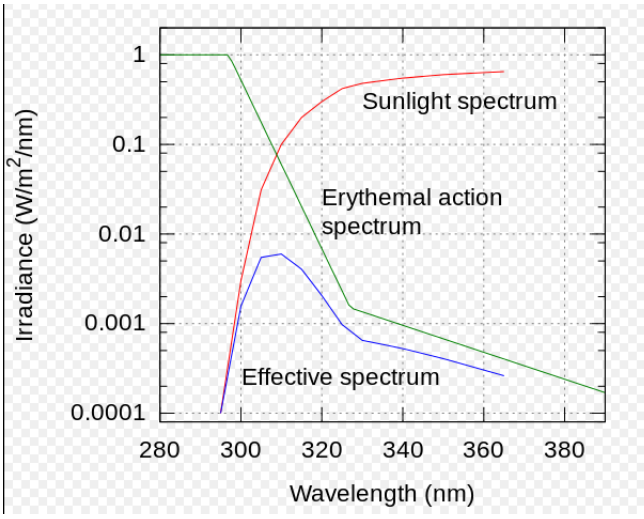

Figure 17: Irradiance versus wavelength

[36] Silabs.com. Si1132 Ulta Violet Index and Ambient Light Sensor IC | Silicon Labs [Internet]. 2015 [cited 12 March 2015]. Available from: http://www.silabs.com/products/sensors/infraredsensors/Pages/si1132.aspx

[37] Iac.ethz.ch. Solar erythemal ultraviolet radiation [Internet]. 2015 [cited 15 March 2015]. Available from: http://www.iac.ethz.ch/en/research/chemie/tpeter/www_uv.html

[38] NOAA-EPA Brewer Network. Instantaneous UV Index and Daily UV Dose Calculations [Internet]. 2015 [cited 13 March 2015]. Available from: http://www.esrl.noaa.gov/gmd/grad/neubrew/docs/UVindex.pdf

9.5 Appendix 5 – ML8511 Sensor

General description: [39]

It has an internal amplifier, which is used to convert photo-current to voltage depending on UV intensity. This offers an easy peripheral interface with the external circuits such as ADC. Its standby current in the power down mode is very small (0.1μA), providing longer battery life.

Features:

- Photodiode sensitive to UV-A (tanning rays) and UV-B (burning rays)
- Embedded operational amplifier
- Analogue voltage output
- Low supply current (300μA typ.) and low standby current (0.1μA typ.)
- Small and thin surface (4.0mm x 3.7mm x 0.73mm)

Output Voltage-UV Characteristics

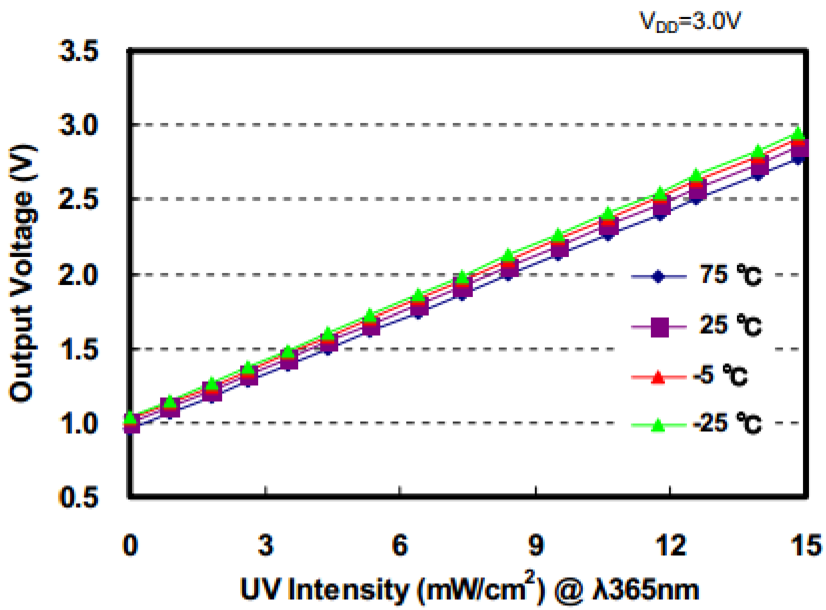

Figure18: Output Voltage vs. UV intensity linear relationship

The ML8511 sensor is easy to use. It outputs an analogue voltage that is linearly related to the measured UV intensity (mW/cm^2). Figure 18 illustrates the linear relationship of output voltage to UV intensity, for different operating temperatures. Provided that the microcontroller that we will use has an analogue to digital converter, we can use the graph above read off the UV intensity, from the output voltage given

[39] Information obtained from datasheet: Semiconductor R. ML8511-00FCZ05B Rohm Semiconductor [Internet]. Digikey.co.uk. 2015 [cited 12 March 2015]. Available from: http://www.digikey.co.uk/product-detail/en/ML8511-00FCZ05B/ML8511-00FCZ05BCT-ND/4259547

by the sensor.

Spectral Responsivity Characteristics

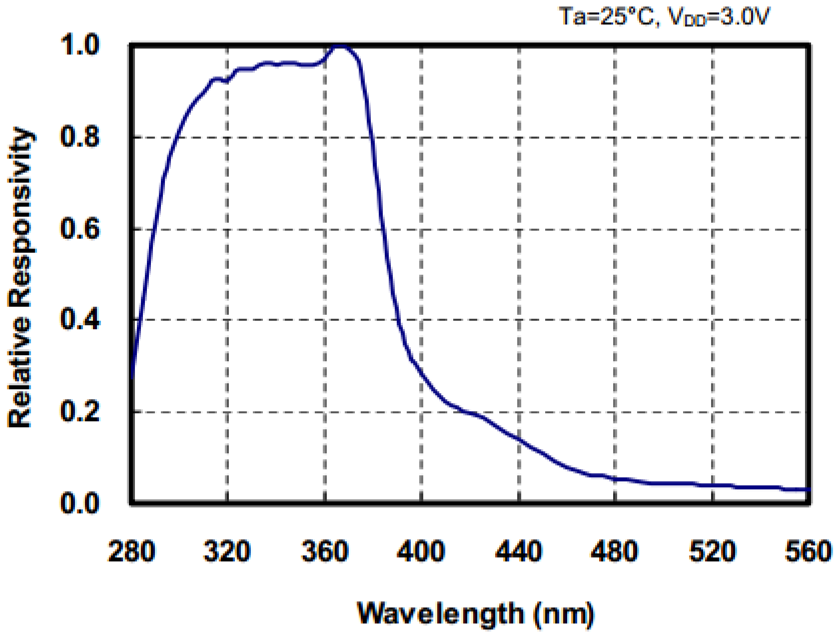

Figure 199: Spectral responsiveness of the ML8511

Figure 19 shows the spectral responsiveness of the ML8511 UV sensor. This sensor detects 280-390nm light most effectively. This is categorized as part of the UVB (burning rays) spectrum and most of the UVA (tanning rays) spectrum.