Exploring Colour Change Properties in 3D Print Photochromic PLA: towards Designing Central Cyanosis Actuator in a Baby Manikin

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Abstract. A high fidelity baby manikin with a colour changing mechanism is required for medical training, especially for cyanosis skin colouration assessment in a newborn baby. However, commercially available baby manikin simulators do not have the real colour-change of cyanosis skin. The efforts in increasing the fidelity of the manikin might improve the accuracy of cyanosis evaluation among the novices, thus enhances the quality of the medical training. This study contributes towards designing a colour change actuator for central cyanosis simulation in a baby manikin for medical training. The actuation method of the 3D print photochromic PLA using a low-voltage UV LED and the evaluation of its colour properties using a colour measurement device are described. The colorimetric properties of the photochromic PLA were evaluated in CIE\(u'v'\) colour space. Results are presented, showing a strong relationship between the colour intensity of the UV LED and the colour of the photochromic PLA. We reflect on the potential of the photochromic PLA as an actuator in imitating the cyanosis in a baby manikin. The specific PLA we used still cannot simulate the cyanosis well. However, the idea of using PLA photochromic is still considered promising.

1. Introduction

Photochromism is a reversible and repeatable colour changing mechanism, typically from colourless to a coloured state. It reacts to the stimuli of light, for instance to the UV light or the sunlight. When we remove the UV source, the colour state will revert to the original state. In medical simulation area, 3D printing (3DP) holds great promise because of its commercially accessible 3DP material and ease of manufacturing [1]. Thielen demonstrated a 3DP ribs cage for the realistic infant’s manikin for cardiopulmonary resuscitation (CPR) procedure training [2]. However, they focus on exploiting mechanical properties of the new material and their production methods (not colour). Another 3D printed models in medical training are the lung which realistically mimicking such organs that allows students and trainees to practice the lung related surgery [3]. Nevertheless, this promise has not been yet realized for a colour change 3DP thermoplastic for realistic colour changes in skin colour, especially for imitating the central cyanosis in a newborn baby. It reacts to the stimuli of light, for instance to the UV light or the sunlight. When we remove the UV source, the colour state will revert to the original state. The recent development of 3DP PLA chromic material enables digital printing models with the ability to change the colour reversibly with the UV light stimuli. The UV LEDs responsive 3DP photochromic actuator makes it an attractive platform for the application of designing a colour- changing artificial
skin. To the best of our knowledge, no work so far has presented a light-responsive baby manikin for medical training in imitating the colour change of central cyanosis.

The colour change of the baby’s skin is one of the immediate evaluation made after the baby was born. The assessment gives significant indication of the newborn’s condition [4][5]. For example, when the lips and mouth area of the baby remained blue after 10 minutes, it is recognized as central cyanosis [6], and urgent treatment from a medical team is needed. In various lighting condition in the baby’s delivery room as well as the colored objects around the babies makes central cyanosis assessment in a newborn quite challenging [7]. Hence, the cyanosis simulating baby manikin is needed for the training of cyanosis visual evaluation in a newborn among new medical trainees. The design parameters for a cyanosis actuator in baby manikin are; the colour change of an actuator should be controllable and reversible in a specific timing. As central cyanosis normally visualized in the thinnest epidermis area such as around the mouth and lips, hence, the sizing and dimensions of the actuator must be in the correct size and mimics the mouth and lips of the full term baby. Safety and power consumption are important e.g. 7.4W when the 3.7V lithium-ion battery pack is used [8].

The idea of using photochromic material is attractive because we could avoid many weaknesses and side effects of traditional light sources. Comparing to conventional light sources such as visible-spectrum LEDs the strong point of the photochromic material is that the visual effect is independent of the external light source (the room’s illumination). If there would be purple LEDs inside the manikin, the purple LED light would have to go up when the light in the training room gets brighter. In addition, the purple LED must dim when the outside light goes down. Even the shadow of a doctor’s hand would reveal the LED nature of the colour. As a solution, the purple LED could be made adaptive, but that involves designing a sensor-based feedback loop. Of course, the photochromic PLA needs an LED too, but that is only for changing the PLA’s subtractive colour behavior. The latter is like the real baby skin behavior. When increasing the room’s illumination, pink lips stay pink, and purple lips remain purple. We can also compare to thermochromic materials, which are environment-independent too. However, working with temperature is difficult: we need to compensate for the environment’s temperature. Next, the thermochromic matter has a specific heat capacity: heat accumulates in the manikin’s head, and we need yet another feedback control loop to manage these effects. Even worse, the head gets hot, so the trainee could feel the heat, which is weird (it breaks the spell of suspended disbelief). The UV light, by contrast, does not accumulate by the heat and it is invisible. Of course, we have to see how the photochromic PLA can make these promises come true. That is why we undertake the design exploration of this chapter. Figure 1 illustrates the cyanosis colour change upon the UV LEDs stimuli in the baby manikin. This 3D printed photochromic baby’s head exhibits a purple colouration upon the exposure to UV LED (activation state) with an applied potential of a low voltage [9] and returns to the original colour when the UV LED is off (deactivation state).

![Figure 1. The colour change of the photochromic baby’s head during deactivation and activation](image)

Quantifying colour values in a photochromic material is a challenging task as the colour transition time of from colourless to coloured state very fast within seconds [10]. Moreover, the data of colour changing time upon the stimuli UV light is lacking from the manufacturer making such evaluation more difficult. Viková et al. investigated the colour measurement in photochromic for textiles application, using the solution spectrophotometer ACS ChromaSensor CS-5 with spherical measuring geometry [11]. In this study, we use the Spectroradiometer Specbos 1201 [12] to quantify the colouration of photochromic PLA. Here, we first examine the colouration of a 3DP PLA by modulating the light
intensity (in %) of the UV LEDs by the adjustment of the potentiometer. From this experiment, the colour change of during activation and deactivation state of photochromic PLA was obtained in the luminous, L [cd/m²] unit. The chromaticity data are also measured in the International Commission on Illumination (CIE) u’v’ 1976 colour space [13].

The main contributions of this work are 1) a controllable 3D printed colour change actuator using Pulse Frequency Modulation (PFM) for central cyanosis application, and 2) a quantifiable photochromic PLA colouration in CIE colour space. Although it does not resulted in the correct colour values of cyanosis in a real baby as reported in [8], we believe that the effort required to provide the colorimetry data of the photochromic PLA in CIE system is necessary and will provide a more direct path to the results we wished to present in the future. We adopt the working hypothesis that these four elements can be achieved by implementing the photochromic PLA in a cyanosis baby manikin. Thus, the findings provide new insight into the structure of research and offer a new platform for future research.

2. Creating a 3D printed baby’s head
We found two manufacturers Go-3D Print, based in San Francisco, California and RepRapWorld BV, Nootdorp, The Netherlands. The photochromic PLA we got from Go-3D Print, changes from white to blue and the photochromic PLA we got from RepRapWorld BV changes from white to purple. We noticed that the materials were rather pale for the baby’s face, so we considered spray- painted. Our initial experiment based on spray-painting from the outside was a failure because the UV induced colour change was hardly noticeable. Spray painting from the inside still considered to be options. Our design space includes at least four combinations because we can choose from two different materials and two different spray-paint options: spray-painted from the inside and not spray-painted. Rather than trying all combinations, we took two combinations, which are shown, in Table 1 and in Figure 2.

![Figure 2](image-url) To the left: Spray-painted from the inside. To the right: Original colour, not spray-painted.

![Figure 3](image-url) The dimension of the 3D printed baby’s head.
Table 1. Commercial Photochromic PLAs.

| Head | Diameter | Spray-painted | Colour Change          | Trades Name          |
|------|----------|---------------|------------------------|----------------------|
| 1    | 1.75mm   | Not spray     | Original to purple     | RepRapWorld BV       |
| 2    | 1.75mm   | Spray from inside | Original to blue     | 3D PLA               |

One of the two models was spray-painted with MOTIP carat lacquer spray in ‘BABY’ colour to imitate the colour of a real human’s skin [14]. The ‘BABY’ colour was chosen as in Figure 3, based on the reference colour of the Pantone 108-8 C from the Humanae project which a collection of different human skin colours in a chromatic range [15]. The photochromic filaments were printed into the identical shapes of preterm babies in the dimension of 58.6 x 83 x 33.9 mm (See Figure 3). Both filaments were printed using a Craftbot-PLUS 3D printer, from CraftUnique in MakerPoint Eindhoven with the thickness: 1.0mm.

3. Material activation by UV LEDs
The plan is to illuminate the photochromic baby head from the inside using a particular type of LEDs, emitting UV light, which is by itself invisible to the human eye. First, we present how classical LEDs behave, then we move on to deploy UV LEDs. The concept of visible light’s brightness from LEDs is relatively straightforward. For instance, the brightness of LED perceived by the eyes usually measured in units of luminous intensity or candelas, I (cd). The total power output of an LED is a measurement of the number of Lumens, lm (Φ) [16]. These two measurements are the photometric quantities which relate to how human eyes perceived colours. All LEDs have the property that increased current leads to increase luminosity (brightness). An application notes of NICHIA white LED gives an example where relative luminosity goes from 1 to 1.7 if the current goes from 20mA to 40mA [17]. In the same application note, for a white LED NSCW215, we find the luminosity of 600mcd at 20mA and 1020mcd at 40mA, respectively. We assume UV LEDs work similarly. We acquired four UV LEDs of type PLCC-2 manufactured by Vishay Semiconductors, Malvern, Pennsylvania [18]. According the data sheet it should produce radiant power of 6.8mW at 20mA and the radiant intensity of 2.5mW/sr. The usage of mW/sr is common for UV and IR. For normal LEDs the unit mcd is used, a human-eye corrected measurement.

![Figure 4. Eight parallel-connected ring-shaped UV LEDs](image)

One single UV LED maybe not enough to generate the proper illumination, so we decided to put multiple LEDs in parallel. We tested several configurations, and we show one of the test results in Figure 5. The figure contains the measurement results where we used eight LEDs. We connected each LED in series with a resistor of 56 Ohm. Then eight of these LED-resistor pairs were put in parallel. In Figure 5, we see a knee Voltage of about 2.9V whereas at higher Voltages the behavior is mostly linear, which is the effect of the resistors. We thus also found that we could send high current through the LEDs, up to 230mA.
It is a requirement for the design of the baby manikin that the colour can be adjusted continuously. There are two ways of doing this; the first is to have a variable series-resistor connected to the LEDs (potentiometer or well-regulated transistor). The second way of doing this is by pulse modulation, which means that we switch the LEDs on and off regularly. The first solution has a severe disadvantage viz. the dissipation in the series resistor.

Figure 5. Forward Current vs. Forward Voltage

Figure 6. Slow colour changes observed in photochromic materials (Retrieved from [11]).

It would cause unnecessary heat development in the manikin and exhaust batteries. Now, we turn our attention to the second solution. We ask ourselves whether the pulses would appear in the colour of the PLA (the baby’s face). Fortunately, we found the result of Viková, which we learn that photochromic materials behave rather slowly, see Figure 6.

We decided to apply very short pulses of maximum intensity. We design a mouth-shaped configuration of four LEDs with no series-resistors. This allows us sending more than 250mA through the combined LEDs (put in parallel). The UV LEDs were arranged in the mouth-shape to illuminate the photochromic PLA, resulting in evenly spread colouration of central cyanosis area. The distance of LEDs to photochromic’s surface is approximately 31.6mm.

From the datasheet of the LED, we learn that we can send high currents through the LED provided the pulses are short (less than 10µs). Therefore, we fixed our pulse width and varied the time between the pulses. This is called pulse frequency modulation (PFM). Looking back, we believe that PWM would also be a valid solution as well. In Figure 7, an Arduino compatible microcontroller, Teensy 3.2 board was used to generate the frequency signal of PFM. We mapped the Arduino linearly to read a potentiometer whose position to the between-pulses waiting time, ranging from 25µs (high intensity) to 1ms (low intensity). In our experiment, we refer to this highest intensity as 100%. The Arduino reads the percentage to the serial port, and from there it goes to a PC for inspection during the experiment.

In this experiment, we applied a DC voltage of 5V to the UV LED to activate the photochromic’s head. For each measurement, we allow the UV LEDs to be activated at least 20s to let the PLA change colour. We noticed that the colour change stabilized after few seconds (1 or 2s at high intensity and less than 10s at low intensity). At low intensity, we waited 20s.
4. Instrumental Methods

4.1. Instruments and Colour Measurement Setup

We considered using a handheld spectrophotometer. We have the Ci6x X-Rite handheld portable spectrophotometer in our lab. The initial measurement revealed that it is not possible because of the built-in lamp in the measuring device. The device’s integrated illuminant source is a gas-filled tungsten lamp and UV LEDs [9]. Because of that, the colour measurement using this spectrophotometer will activate the photochromic properties and itself already induced a colour change from normal colour to the purple colouration of the printed model. Even if we would add a UV filter or remove its UV LEDs, we cannot focus it on the cyanosis-mouth area, and it is not meant to measure curved surfaces. Therefore, we did not use the X-Rite spectrophotometer.

Another option would be to measure CIELAB values using an ordinary camera and our colour correction algorithm (we did those measurements, but we switched to our third option). Our third option has the advantage that we need no correction at all. The third option is to use the miniaturized and fast broadband Specbos 1201 spectroradiometer (with a wavelength of 380 to 780nm). This third option has its difficulties too, namely that the UV light will be measured by the spectroradiometer as well. Please note that the output of the UV LEDs is between 400 and 410nm with the typical value of 405nm as is specified by Vishay Semiconductors, which is in the range of the spectroradiometer. One solution would be to remove this part of this spectrum after the measurement. We show the problem in Figure 8.

Another solution is to take advantage of the fact that the PLA material does not react instantaneously. We can activate it for a number of seconds, then deactivate and measure immediately (< 1s). This is the solution we adopted. Figure 9 illustrates the position of the photochromic head in the experimental setup.

![Figure 7. Set up for controlling the colour change of head with the UV LEDs backlight actuation.](image1)

![Figure 8. Measured spectrum showing a strong peak at 402nm clearly, caused by the UV LEDs.](image2)
The cyanosis observation lamp, Philips Master LEDspot LED light (940 type lamp; Philips) [19] was set up as the source of the illuminant. We performed the colour measurement in a white box with the cyanosis observation light thus avoiding the unknown lighting conditions. The measurements took place in a dark room. In this way, we eliminated any influence from other types of light sources, which could affect the colour properties in the photochromic’s head (such as sunlight or other UV sources). We measured the light box with a white background which functioned as diffusers and helps to spread the light evenly and reduce unnecessary shadows [20]. A colour characterization of the PLA photochromic measurements was carried out with a distance of 30cm from the measured object as in Figure 9. At this distance, a target diameter of a spot laser is similar to cyanosis region’s size (approximately 10mm).

Figure 9. Colour measurement setup for measuring the colour value of the baby manikin head.

4.2. Colour Measurement of 3D Print PLA Photochromic

There is a notion of luminance, \( L \) [cd/m\(^2\)] in the radiometric quantities which would be used when testing light source, but this is not what we need because our baby head is not a light source (unlike baby heads whose colour change would be implemented by visible-light LEDs). We need to apply the external light sources to see and measure the manikin heads like a real baby. We need to work in one of the CIE colour spaces. We found that the CIELAB implementation of our spectroradiometer was not functioning properly, and therefore we use the option of the spectroradiometer to measure the \( u' \) and \( v' \) according to CIE \( u'v'1976 \) (2-degree observer) [13] [21]. There are conversion formulas between CIE \( u'v' \) and CIELAB, which later can be used to compare the PLA heads to the colour of the real babies (with and without cyanosis). Figure 10 and 12 shows the cyanosis observation light illuminating the photochromic’s head, which is then, observed by the human eye. The photochromic head transmitted the illumination spectrum and weighted with its spectral reflection behaviour. If the human eye receives this signal, and the pectral convolution with its own three sensitivity curves, \( \bar{x}, \bar{y}, \) and \( \bar{z} \) will took place here. The result shows how the colour is perceived in the photochromic head, expressed by the tristimulus values \( X, Y \) and \( Z \) (See Equation 2) [22]. The CIE XYZ (1931) colour system is the root of all colorimetry. Here, the \( Y \) is refers to luminance, and all visible colours can be defined using only positive values, and, the \( Y \) value is luminance. The chromaticity diagram is highly non-linear and \( X, Y \) and \( Z \) tristimulus values do not contribute any information about lightness, hue and saturation. Therefore, a transformation into other colour systems which is quantifiable is needed.

The chromaticity values of CIE \( L'u'v' \) are calculated according to the equations below [23]:

\[
L' = 116(Y/Y_n)^{1/3} - 16, \text{ when } Y/Y_n > 0.008856 \\
L' = 903.3(Y/Y_n)^{1/3} - 16, \text{ when } Y/Y_n \leq 0.008856 \\
u' = 13L'(u'/u'_n) \text{ and } v' = 13L'(v'/v'_n) 
\]

where \( Y \) is the tristimulus value, \( u' \) and \( v' \) are chromaticity coordinates from the CIE \( u'v'1976 \) diagram. \( Y_n, u'_n \) and \( v'_n \) are tristimulus values of \( Y_n \) and the chromaticity coordinates of \( u'_n \) and \( v'_n \) of the perfect reflecting diffuser, respectively. The transformation from CIE \( u' \) and \( v' \) from CIE L’u’v’ is:
\[ u' = \frac{u^*}{13L^*} + u' n v', \quad v' = \frac{u^*}{13L^*} + v' \]

5. Results and Discussion

5.1. Photographs of the effect

Figure 10 and Figure 11 show the colour change of Head 1 and 2, respectively when the UV LEDs intensity output was changed by adjusting the duty cycle to 2%, 20%, 40%, 60%, 80%, and 100%. Upon increasing the intensity from 2% to 100% brightness range, we measure the colour values of the head during activation and deactivation state. The photographs were taken immediately after the activation of UV LEDs. The purple colouration can be seen for both heads very clearly. Head 1 is not very realistic, mostly because of the white colour when the UV LEDs are off. Head 2 appears more promising. The reversible colour change from non-cyanosis to cyanosis colouration based on the UV LED actuation allows users to control the colour based on the intensity. 2 to 100% is corresponding to the relative position of the potentiometer and it’s corresponding to the specific frequency in PFM.

5.2. Measuring Luminance

The basic idea of this measurement is to illuminate the baby head by the Cyanosis Light described before (two lamps), and measure how much light comes back and meets the observer’s eye. Here, we focus on luminance, L, not yet a colour. As before, during activation, we allowed the material to become stabilized before taking the measurement. The deactivation values are measured immediately after switching off.

The luminance output, L during both states was recorded in Table 2 and Table 3 for Head 1 and Head 2, respectively. Referring to Table 2, during the activation state of Head 1, the luminance change was decreasing when the intensity was increased from 2% to 100%, indicating that the activation state already started at the lowest frequency of the PFM. The maximum L was visible during 2% with 148[cd/m²] and the minimum L was visible at 100% with 123[cd/m²]. The luminance changes started from 2% with 148[cd/m²] to the maximum intensity of 100% with 141[cd/m²].

To get an impression of the time constant involved, we measured the luminance immediately after switching off the LEDs (after full activation, which is 100%). The results can be seen in Table 2. Photochromic PLA’s colour stabilization happened in about 20s.

Referring to Table 3, during the activation state of Head 2, the luminance of a colour change also was decreasing when the intensity was increased from 2% to 100%. The maximum L was also visible during 2% with 110[cd/m²], and the minimum L was visible at 100% with 80.2[cd/m²]. Moreover, in the deactivation state of Head 2, when the UV LEDs is switched off, the colour change also decreased from 119[cd/m²] to 74.6[cd/m²]. The colour of the photochromic heads change in parallel with the change of the LEDs intensity, starting from 2% to 100%.
Figure 10. Central Cyanosis in a manikin (Head 1: Original to purple colour change).

Figure 11. The spray-painted 3D PLA photochromic (Head 2: Original to blue colour change)

Table 2. Head 1: Not spray-painted. Original to purple colour change.

| Luminance, L[cd/m²] | Activation | Deactivation |
|---------------------|------------|--------------|
| 2%                  | 148        | 148          |
| 20%                 | 145        | 148          |
| 40%                 | 144        | 147          |
| 60%                 | 141        | 146          |
| 80%                 | 137        | 146          |
| 100%                | 123        | 141          |
| LED OFF             |            | 156          |
To get an impression of the time constant involved, we measured the luminance immediately after switching off the LEDs (after full activation, which is 100%). The results can be seen in Figure 12. Stabilization happened in about 50s.

![Figure 12. Luminance change of the Head 1 (White) after switching off the LEDs.](image)

Table 3. Head 2: Original to blue colour change.

| Luminance, $L[cd/m^2]$ | Activation | Deactivation |
|-------------------------|------------|--------------|
| 2%                      | 110        | 119          |
| 20%                     | 105        | 119          |
| 40%                     | 105        | 111          |
| 60%                     | 103        | 106          |
| 80%                     | 102        | 96.4         |
| 100%                    | 80.2       | 74.6         |

![Figure 13. Luminance change of the Head 2 (Spray-printed) after switching off the LEDs.](image)

5.2.1. Discussion If we try to interpret this result, we see that the luminance goes down when the UV LED is more active. This is what we expected, the PLA goes from white to purple, subtracting certain part of the visible spectrum. The PLA photochromic Head 2 reflects more light than Head 1. We also see that there is a difference between the activated and deactivated state, despite our protocol of fast measuring immediately after going from activation to deactivation. There appears to be a fast reaction by the material. We note that at high LED activation percentages, there is an opposite effect (illumination goes down from 80.2 to 74.0 when the LED is switched off). We conjecture that this is UV light shining through and picked by the spectroradiometer (which is more sensitive to UV than our human eyes). However, we want to focus on the objective colour change, more than on the luminance. In the next stage, we will focus on the CIE $u'v'$ colour space.
5.3. Colorimetric Measurement

To illustrate the colouration of photochromic PLA as perceived by human eyes, the colour change was plotted in CIE $u'v'$ space. We decided to work in the CIE $u'v'$ space rather than in CIELAB because we found that the $L^*$ values given by the Spectroradiometer are sometimes above 100, so we believed that possibly the $a^*$ and $b^*$ also could be unreliable. Both CIE $u'v'$ and CIELAB are designed to respect the perceptibility of colour differences by the human eye [24].

Before zooming in, we give the big picture of the entire CIE $u'v'$ colour space. First, we present the colour change of Head 1 in Figure 14 (left). We see all the measurement points are not too far from the “white point”. Please note the lowest point, measured during 100% of activation. It is clear that the UV light itself is dominant here. We consider the left-most peak, which we observed in Figure 8 as evidence that indeed the UV light itself shines through the PLA material. In the same way, we present Head 2 in Figure 14 (right). We notice that there is no deep blue outlier anymore. It can also be observed that the changes are smaller. We conjuncture that the spray-painted partially inhibits the penetration of the UV lights.

Figure 15 shows the colour value shift in CIE $u'v'$ during the activation and deactivation states of Head 1. During activation and deactivation states, there is a slight increase in CIE $u'$ from 0.2440 to 0.2478 and from 0.2428 to 0.2584, respectively. Meanwhile, as for CIE $v'$ during activation state, there is a decrementation from 0.4759 to 0.2399 when going from 2 to 100%. A slight decrementation in the deactivation state was observed in CIE $v'$ from 0.5045 to 0.4878.

Figure 17 shows the colour change of Head 2. During activation and deactivation states, there is a decrementation in CIE $u'$ from 0.2536 to 0.2363 and from 0.2550 to 0.2511, respectively. Meanwhile, as for CIE $v'$ during activation state, there is a decrementation from 0.4972 to 0.4218 from 2 to 100% of dimming brightness. A slight decrementation in the deactivation state was observed in CIE $v'$ from 0.5015 to 0.5000.

![Figure 14](image1.png)

**Figure 14.** Colour change of the Head 1 (Left) and Head 2 (Right) : White photochromic PLA, change colour from original to purple in CIE $u'v'$. The black series show the measurement points of the activation state. The blue series show the measurement points of the deactivation state.

![Figure 15](image2.png)

**Figure 15.** Activation and deactivation state of Head 1 (Not spray-painted) Colour change from white to purple in CIE $u'v'$ colour space.
Figure 16. Colour change of the Head 1 (Not spray-painted): the colour change from original to purple photochromic PLA in CIE $u'v'$.

Figure 17. Activation and deactivation state of Head 2 (Spray-painted): Colour change from white to blue in CIE $u'v'$ colour space.
Figure 18. Colour change of the Head 2: Spray-painted photochromic PLA, change colour from original to blue in CIE $u'v'$.

5.4. Comparing Baby Data
The colour change recorded in the experiment of the previous section shows a clear colour difference between activation and deactivation state of the photochromic material and we can shift by changing the UV LED’s intensity. Nevertheless, it is not obvious whether the colouration achieved in this experiment approximates real cyanosis colour values as reported in [8]. In this section we compare them.

In Figure 19, we show the data from real babies, as obtained in the earlier study. We then convert the CIE $a^*b^*$ values to the CIE $u'v'$ space. The calculation of the colour space conversion from CIELAB to CIE $u'v'$ as discussed in Section 4.2.

Figure 19. Colour change of cyanosis to non cyanosis colouration from the data of five real baby images

Figure 20 depicts the colour change of cyanosis to non-cyanosis colouration from the data of five real baby images in CIE $u'v'$. The colour values of cyanosis will be minimum at approximately CIE $u'v'$ of (0.2380, 0.4856) and the non-cyanosis colour value will be maximum at 0.2896 and 0.5130. The arrows in the figure illustrate the measurement points from cyanosis to non-cyanosis. If we compare the colour change show in Figure 17 and Figure 19, we can see that colour changes in the deactivation state of Head 2 (by changing the intensity from 2 to 100%) could mimic the changes from cyanosis to non-cyanosis lips colour as in the database of Baby 4 in Figure 19. As for Baby 4, the cyanosis starts at (0.2639, 0.4953) in comparison with the (0.2536, 0.4972) at the maximum activation of the LEDs.

6. Conclusion
In this study, we examine the effects of the colour change and the UV LED’s intensity on the 3D print photochromic PLA filaments. The evaluation of the PLA photochromic was done by calculating the colour value for each of the colouration from 2% to 100% intensity of the colour change upon applying UV LEDs. Large colour differences were found in chromaticity values during the activation mode but smaller in the deactivation mode. The specific PLA we used still cannot simulate the cyanosis well enough for training the precise colour observation skill, but the combined effect of the reduced lightens and the colour shift gives a remarkable impression of cyanosis. Hence, the idea of using PLA
photochromic is consider promising. The main contributions of this work are 1) a 3D printed controllable colour change actuator for central cyanosis application and 2) a quantifiable colouration of the PLA photochromic in CIE $u'v'$colour space.

Figure 20. Colour change of cyanosis to non-cyanosis colouration from the data of five real baby images in CIE $u'v'$.

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