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Colorimetric analysis of silicone cosmetic prostheses for upper-limb amputees

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Abstract—Every year the Italian National Insurance Institute of Accidents on Work (INAIL) Prosthesis Centre manufactures more than 300 silicone cosmetic upper-limb prostheses that are aesthetically similar to patients' missing limbs; however, the prostheses have the following drawbacks: subjectivity in color choice, high production costs, and long time frames for patient tests and prosthesis production. In an attempt to minimize these factors, we performed a study to test various systems that automatically detect the color of human skin. Such a system would allow us to reproduce a patient's exact skin color for silicone cosmetic prostheses. We analyzed the color identification systems available on the market and assessed the possibility of introducing such a system into the production cycle of the prostheses. We found that because of intrinsic factors of the materials, automatic color detection for prosthesis production is complex. Therefore, any of the systems we tested will require further development for full satisfaction of the needs of prostheses manufacturers.

Key words: chromatic coordinates, color, colorimetry, color space, digital camera, fiber-optic devices, Imaging Color Analyzer Module, silicone cosmetic prostheses, skin color, spectrophotometer.

INTRODUCTION

This study describes systems that perform color comparisons between human skin and colored silicone. Such a system would facilitate the work of prosthetists during the production of cosmetic prostheses for upper-limb amputees. The system must be easy to use and capable of acquiring the data that are to be processed and stored with the use of specially designed software within a limited time frame.

To better explain the question of chromatic detection, we included in this article a discussion of the production of silicone cosmetic prostheses and the concepts of color and colorimetry.

Production of Cosmetic Prostheses

The main goal of upper-limb prostheses is for amputees to gain a certain degree of autonomy. Traditional cosmetic prostheses reconstruct a missing body segment by focusing mainly on the cosmetic aspect (**Figure 1**). Cosmetic prostheses are provided as part of a personalized rehabilitation plan in which patients are assessed by a team of technical and medical professionals.

Abbreviations: 3-D = three-dimensional, CIE = Commission Internationale de l'Eclairage, ICAM = Imaging Color Analyzer Module, PC = personal computer, RGB = red, green, and blue.

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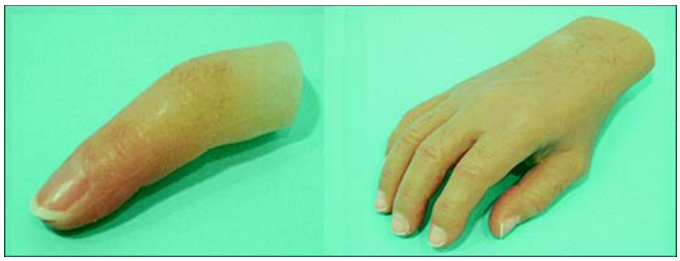

Figure 1.
Examples of traditional cosmetic prostheses.

Figure 2.
Otto Bock HealthCare color atlas for color detection of skin and nails. Each sample is certain hue in three thicknesses (thin, medium, thick). Different thicknesses of same bar give different chromatic coordinates. Each bar is univocally identified by code of a letter and two numbers.

The main steps in manufacturing silicone cosmetic prostheses are—

- Creation of the model of the residual and intact limbs.
- Detection of the skin color of the intact limb.
- Creation of the mold for the prosthesis.
- Introduction into the mold of appropriately colored silicone.
- Vulcanization of the silicone prosthesis.
- Completion of prosthesis finishing.

One of the most delicate phases of this process is the detection of the skin color. This phase is carried out in a room lit by either sunlight or fluorescent light (typical of indoor environments), depending on the patients' living habits; i.e., the place in which they will most frequently use their prosthesis, because the perception of skin color by the human eye varies according to the luminous radiation that strikes the body.

Once these initial color choices have been made, the prosthetist patiently compares certain points of the intact limb with a selection of colored silicone bars. This measurement kit, manufactured by Otto Bock HealthCare (Duderstadt, Germany), has become the standard for measuring the color of skin and nails (**Figure 2**). For a single finger, the prosthetist usually selects 9 to 12 colors, while approximately 15 to 20 are required for a whole hand. Once the matching silicone samples have been identified, the respective codes are recorded on a patient record for later reference. To avoid changes in color caused by blood circulation (which can occur during the measurement phase), the prosthetist asks the patient to place his/her arm by his/her side every 20 to 30 s so that blood flow is as constant as possible during the color detection phase. One of the critical points of the process is the lengthy color identification; it raises costs considerably by prolonging the patients' stay at the Prosthesis Centre. Color identification is also strongly influenced by the experience of the prosthetist performing the measurements and, therefore, introduces a subjective component that is difficult to eliminate.

Color

Color is a subjective sensation that is derived from the stimulation of nerve centers, and the perception of it has three fundamental elements:

1. The light.
2. The eye.
3. The reflectance properties of the object.

All our attempts to measure this sensation and make it objective by translating it into numbers are impaired by the subjective response of each person.

Light is a type of electromagnetic wave [1], and the Commission Internationale de l'Eclairage (CIE) defines "visible light" as the wavelengths from 380 to 780 nm. These waves create vision by striking the eye and interacting with its photoreceptors [2].

The CIE experimentally defined two standard observers to reproduce the average observer in laboratory conditions. These observers are positioned at a distance of 46 cm, perpendicular to the sample they are to observe, and are classified according to the following—

- 2° standard observer (CIE 1931); areas observed have an amplitude of 2° of an arc.
- 10° standard observer (CIE 1964); areas observed have an amplitude of 10° of an arc.

The third element we consider in color definition is the object being observed because it provides the true chromatic sensation. Surfaces absorb or disperse part of the luminous wavelengths that strike them and only wavelengths that correspond to the perceived color are reflected.

Colorimetry

Colorimetry is the science that assigns various colors precise references and data and disregards an observer's physiological response. Color measurement is a complex issue as it combines physical values with physiological data. The possibility does not exist for us to accurately describe the color sensation caused by a certain light. To objectively define a color, one must know the spectrum of the light source, the spectrum of reflectance of the object, and the tristimuli curves of the standard observer, which represent the sensibility of the cones in the eyes of a standard observer. Once we know these three pieces of information, the possibility exists, through suitable mathematic calculations, to calculate the values of the *X*, *Y*, and *Z* coordinates of a suitable three-dimensional (3-D) space that contains the vast area of colors perceivable by the human eye. These coordinates are called tristimuli coordinates, and by considering the relative weight of each tristimuli coordinate in relation to the other, we can define the *x*, *y*, and *z* functions of a given set of tristimuli coordinates as follows $x = X/(X + Y + Z)$, $y = Y/(X + Y + Z)$, and $z = Z/(X + Y + Z)$ [2–6].

The Yxy space, which was introduced in 1931, was the fundamental reference instrument for all color measurements for years, and its three coordinates were known as chromaticity coordinates. However, this method has the drawback of not being uniform because equal perceptive distances do not correspond to equal geometric distances. To overcome this problem, the CIE proposed, in 1976, a color space with the variables *L*, *a*, and *b* (known as the Lab space) defined for a given set of tristimuli values *X*, *Y*, and *Z* as

$$L = 116 \times \sqrt[3]{Y/Y_n} \ ,$$

$$a = 500 \times \left(\sqrt[3]{X/X_n}^{16} - \sqrt[3]{Y/Y_n} \right) \ , \text{ and}$$

$$b = 200 \times \left(\sqrt[3]{Y/Y_n} - \sqrt[3]{Z/Z_n} \right) \ ,$$

where X_n, Y_n, and Z_n are the tristimuli values of ideal white under the same illumination and with the same observer and $Y_n = 100$ (by definition) (**Figure 3**). The tolerance of colorimetric measurements (δE), i.e., the distance between two 3-D points of the CIE Lab space, is equal to

$$\delta E_{\text{Lab}} = \sqrt{(\delta L)^2 + (\delta a)^2 + (\delta b)^2} \ ,$$

where

$$\delta L = L_g - L_f, \delta a = a_g - a_f, \text{ and } \delta b = b_g - b_f \ .$$

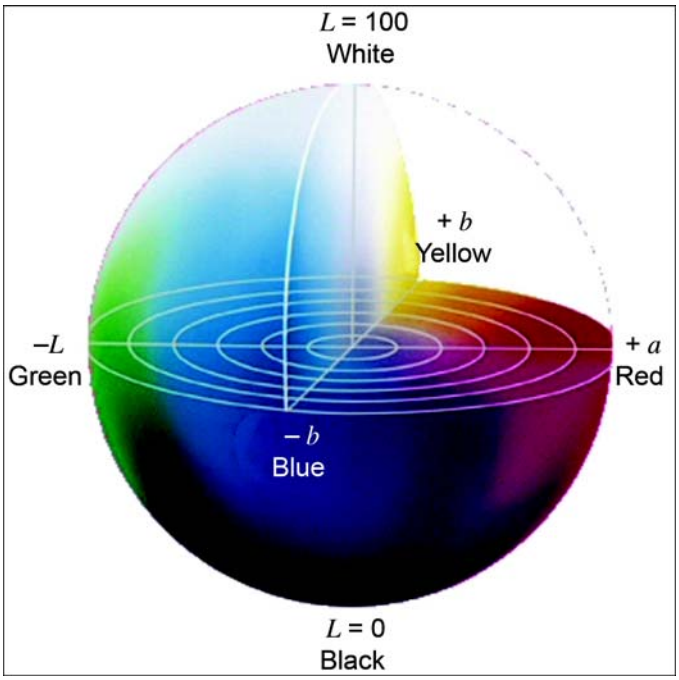

Figure 3.
CIE Lab color space: *L* is always positive and represents brightness; $a > 0$ represents red component, $a < 0$ green component, $b > 0$ represents yellow component, and $b < 0$ blue component.

Subscripts *g* and *f* indicate the coordinates that relate to two distinct points of the same space. Minimizing δE_{Lab} means reducing the difference between *g* and *f*. We simply use δE to indicate the distance, in the CIE Lab space, between the desired (or target) color and the color obtained by an instrument (http://www.poynton.com) [2–5].

Another important color space is the red, green, and blue (RGB). The RGB space has the capacity to represent a vast percentage of the visible spectrum with the use of the three primary colors: red, green, and blue. RGB space is used for all color representation in monitors, scanners, and televisions [2].

MATERIALS AND METHODS

In this study, we tested a number of automatic color detection systems; our main goal is optimization of the time and costs involved in producing silicone cosmetic prostheses. We attempted to identify a system that is capable of automatically detecting the color of human skin by comparing it with a database of silicone samples of different hues. Another element that must not be

underestimated is the cost of creation of the entire system. Having conducted thorough market research, we identified two categories of instruments:

- Devices that normally perform contact measurements; that is, exert pressure on the skin. This alters blood circulation and, therefore, color detection is not very accurate. This type of instrument has a large measurement area.
- Instruments that, in addition to not requiring contact with the skin, have the advantage of providing an image that can be stored on a personal computer (PC), where users can detect the chromatic coordinates of each individual pixel.

This study was performed with various devices and was aimed at identifying the system that offered the best value, as well as the most accurate color detection.

To evaluate the instruments, we created a database for each instrument that contained the color coordinates of all Otto Bock HealthCare silicone samples. Each silicone sample had three color coordinates for each thickness (thin, medium, thick). We then used each instrument to detect the color of the skin of the hands (particularly the dorsal surface, knuckles, fingertips, and nails) for three healthy subjects (males aged 28–40 yr) and obtain the corresponding chromatic coordinates. In this way, each subject's skin was defined by four sets of color coordinates (dorsal surface, knuckle, fingertip, and nail). Lastly, we developed software to identify the silicone samples in the database with chromatic coordinates closest to the skin in terms of δE. Subsequently, we visually compared the silicone samples selected by the instrument with the chosen points on the skin to qualitatively evaluate the choices. All subjects gave their consent to participate in the experiments.

All visual comparisons were made inside a controlled light box; i.e., in a space that excluded the illumination present in the environment and provided various types of light. The light box normally reproduces sunlight, the fluorescent light typical of offices, and the incandescent light typical of homes.

1st System: Spectrophotometer

We worked with a leading colorimetry firm in the textile sector that provided a series of hardware and software, such as a light box, a direct light spectrophotometer, and a sophisticated software program for result management. The spectrophotometer measures the intensity of light at various wavelengths and is composed of four main elements: the white light emission source, the sample in the sample holder, the monochromator that separates the light reflected from the sample, and the detector or sensor that reads the signal and transforms it into electric impulses. The spectrophotometer is capable of detecting the color on surfaces and transferring it directly to a monitor with a preview of how it will be printed, as well as producing colorimetric and spectrophotometric values and some graphic representations.

The results obtained with this first system appeared unsuited to specific aspects of our goal, and we, therefore, decided to modify the system by replacing the spectrophotometer with a high-definition digital camera that was connected directly to the provided software. The camera was introduced, by means of a nut ring, into a hole in the top of the light box (**Figure 4**). We photographed the patient's healthy limb inside the light box. Once the image had been saved, it was processed with the software, and averages of the colors in the chosen areas were obtained. The RGB codes of the silicone and the skin were compared.

The use of a digital camera in the production cycle of silicone cosmetic prostheses has also been tested by the Institute of Rehabilitation in Ljubljana. Their study showed that the use of a digital camera in the construction of prostheses for partial hand amputation can be a valid technique for identifying the correct color for the silicone. It also provides interesting hints on the shaping of facial epitheses [6].

Figure 4.
Light box with high-definition digital camera in place of spectrophotometer.

2nd System: Portable Spectrophotometer

The second system we studied was a portable spectrophotometer with the following main characteristics: one or two areas of measurement available, direct and lit view of the sample through a spyhole, and limited weight and size. We used the larger measurement area (8 × 8 mm) to measure the silicone bars and the smaller one (3 × 3 mm) to measure patients' skin. The spyhole that lit the measurement areas allowed us to select the desired point exactly and eliminate inconvenient details (e.g., hairs, moles, veins). Its lightweight and compact design allowed us to use the instrument on each point of the upper limb. Dedicated software was designed to manage the instrument.

3rd System: Fiber-Optic Device

We performed this test to verify the performance of fiber-optic devices. These devices allow us to overcome the large measurement area required for contact instruments; this requirement makes detection of the chromatic coordinates of the fingernails impossible. The system we studied consisted of a very small spectrophotometer that allowed us to detect the color indicated by a fiber-optic cannula. The cannula was composed of one fiber optic for detection and six for transporting the illumination from the instrument to the sample (**Figure 5**). Tests were performed after calibration of the instrument with black and white samples.

4th System: Scanner and Spectrophotometer

The instruments previously discussed have drawbacks because color detection requires contact with the sample. We, therefore, focused on equipment that avoids this interaction. The instruments available include a scanner combined with a spectrometer that allowed us to acquire the color composition of each point of the sample measured. Once the instrument is focused, the image is acquired row by row, as with a normal scanner, through a slit. The optics of the spectrometer separate the radiation of every single point of the row into its spectrum components. The intensity is recorded by a camera that consists of a 2-D matrix of photosensitive elements. The spectrometer then captures a linear image and disperses the spectrum pixel by pixel onto a white/black matrix camera. This system offers the advantage of detecting color without contact. The system is self-lit and does not require light normalization systems.

The standard lighting most researchers use is a blade-shaped halogen lamp that reproduces sunlight (**Figure 6**). The system is also fitted with its own basic software that allows the user to choose on which points of the photographs to detect the chromatic coordinates (Lab, Yxy, RGB) and to calculate averages and the δE between a point and the target.

5th System: Imaging Color Analyzer Module

The last system we studied was the Imaging Color Analyzer Module (ICAM), which is the first camera

Figure 5.
Spectrophotometer with fiber optics and instrument for calibration.

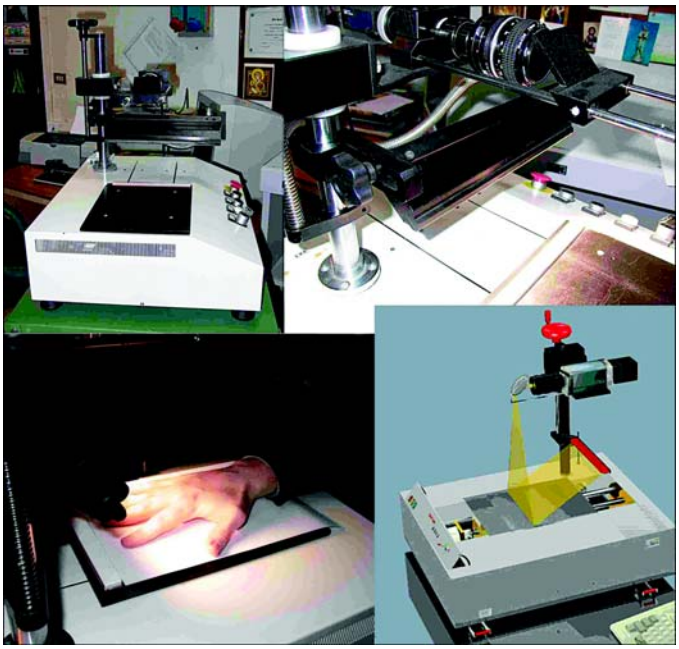

Figure 6.
Scanner fitted with spectrophotometer for spectrum acquisitions.

designed for color detection and approved by the CIE. It permits the user to store the acquired images on a hard disk and read them later with its own basic software. It allows the user to read a single pixel or average areas of varying sizes. It returns the Yxy coordinates and, with a white reference for calibration, the Lab coordinates of the sample. The instrument does not have standard illumination and is therefore equipped with a light box that contains four 18 W light bulbs that simulate sunlight.

We created the database with the ICAM, using all the silicone samples, by testing the samples on a black velvet background and recording the CIE Lab coordinates for each of the three thicknesses. We determined these coordinates by calculating the average of an area of 24 × 24 pixels (approximately 7 × 7 mm). Two series of photographs and chromatic detections were conducted on the Otto Bock sample range 3 days apart. The results demonstrated substantial repeatability of measurements. The average δE was 0.57 with a standard deviation of 0.4. The maximum δE value was 2.1. We searched for the right sample in the database by evaluating the minimum δE between the skin and silicone samples. This procedure is performed automatically by the software, provided that it had been suitably adapted for this purpose (**Figure 7**). The technical features of this device and the others we analyzed are summarized in **Table 1**.

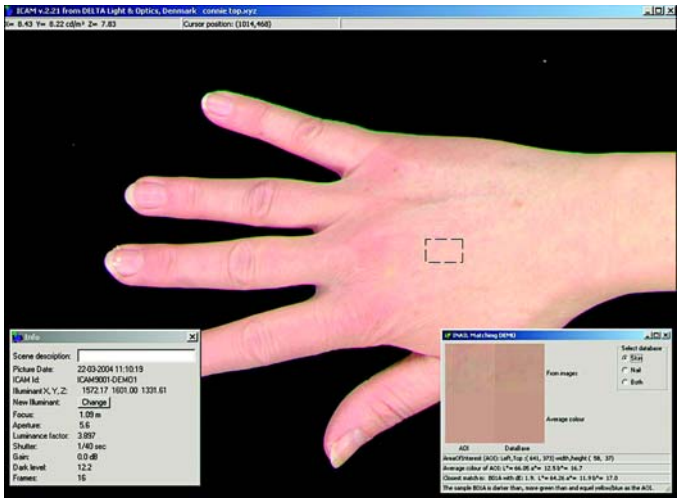

Figure 7.
Image of hand acquired with Imaging Color Analyzer Module system. Software allows selection of area or single pixel of image. Window shows silicone sample code with chromatic coordinates closest to those of area selected, and indications are given as to which primary colors should be added or removed to reach target (skin) color.

RESULTS AND DISCUSSION

Results are given for each system tested, and the advantages and disadvantages of each system are listed in **Table 2**.

1st System: Spectrophotometer

In all tests of the first system, the silicone samples identified by the system were visibly darker than the corresponding points on the limb ($\delta E > 15$). Furthermore, the geometry and operation of the spectrophotometer were unsuited for the specific requirements of the task. **Table 2** contains the advantages and disadvantages of this first system.

Integrating the camera into the light box initially appeared to us to be very valid. Contact with the skin was not required, and we obtained an image of the patient's limb that could be quickly saved in a database (**Table 2**). However, the detection and comparison of the RGB codes of the silicone and the skin brought to light a number of problems: the chromatic coordinates of the silicone samples varied with the background (**Table 3**) and the silicone samples that were visually identical to the skin had substantially different RGB coordinates (**Table 4**). We found this system inadequate for the prosthesis production.

2nd System: Portable Spectrophotometer

The tests of the second system produced good results (**Table 5)**. **Table 5** has four columns: the first represents the number of the test, the second the subject and the point of the hand tested with the system, the third the code of the silicone bar (selected by a prosthetist) perceptively most similar to the area of interest, and the last the codes of the silicone bars the instrument detected. The table shows six experiments: the first, second, third, and fifth experiments show that the system produced the same code (or that immediately before or after it) as the bar that the prosthetist detected subjectively. In the fourth experiment, the objective result did not coincide with that obtained subjectively. However, comparing the sample identified by the system with the fingertip of subject 3, we found that the color identified by the system was more similar to the color of the skin than that identified by the prosthetist. Our observation that, visually, the chromatic distance between these two samples was minimal proved the efficiency of the objective method over the subjective one. The same applies to the sixth test where the difference between the objective and subjective choices was minimal.

Table 1.
Technical features of all systems analyzed.

System	Properties	Specifications
1st System: Spectrophotometer	Optical geometry	45°/0°
	Receiver	Array with 16 elements
	Spectral range	400 to 700 nm
	Light source	3 xenon lamps
	Time of measurements	<2 s
	Dimension of area measured	5 mm
	Dimension of device	69 × 76 × 137 mm; weight 340 g
2nd System: Portable Spectrophotometer	Optical geometry	d/8°
	Dimension of sphere	52 mm
	Receiver	Double array with 40 elements
	Spectral range	360 to 740 nm
	Spectral resolution	10 nm
	Light source	3 xenon lamps
	Time of measurements	1.2 to 2.0 s
	Dimension of area measured	3 or 8 mm
	Dimension of device	69 × 96 × 193 mm; weight 670 g
3rd System: Fiber-Optic Device	Receiver	Linear array with 2,048 CCD
	Spectral range	350 to 1,000 nm
	Spectral resolution	0.3 to 10.0 nm
	Interface	USB + Basic Software
	Integration times	3 ms to 65 s
	Optical fibers	7 optical fibers (200 μm d; 6 illuminant and 1 receiver)
	Calibration	Halogen tungsten light source
	Dimension of device	89 × 64 × 34 mm; weight 200 g
4th System: Scanner and Spectrophotometer	Spectral range	380 to 1,000 nm
	Spectral resolution	5 to 7 nm
	Receiver	2/3 in. CCD
	Spatial resolution	15 coupled lines per mm
	Total efficiency	>50%; independent from polarization
	Missing light	<0.5%
5th System: Imaging Color Analyzer Module	Time of measurements	2–3 s
	Camera	1/2 in. CCD, 1024 × 768 pixels, 8 bits
	Exposure time	10 μs to 1/15 s
	Focus	115 mm
	Dimension of device	285 × 125 × 155 mm

CCD = charge-coupled device, USB = universal serial bus.

The system produced good results in detecting color of the skin and of silicone samples with a thickness greater than 3 mm. However, it was less successful at chromatic measurement of the nails, veins, and thin layers of silicone. These limitations led us to seek a new, more complete solution. For reliable color detection, the pressure exerted by the prosthetist when bringing the spectrophotometer in contact with the skin was also very important. This drawback imposed a further term of subjectivity to the measurements, a factor that we had aimed

Table 2.
Advantages and disadvantages of all systems analyzed.

System	Advantages	Disadvantages
1st System: Spectrophotometer (1st version)	Costs < $15,000 Easy to use Good repeatability Portability and practicality	Large measurement area Impossible to measure nails Contact measurements $\delta E > 15$
1st System: Digital Camera (2nd version)	Costs < $15,000 Easy to use No contact measurements Short acquisition time	Bad repeatability Impossible to measure nails Chromatic changes due to transparency of silicone
2nd System: Portable Spectrophotometer	Costs < $15,000 Two measurement areas Good quality:price ratio $\delta E < 4$	Contact measurements Impossible to measure nails and veins
3rd System: Fiber-Optic Device	Costs < $15,000 Small measurement area	Poor functionality Poor repeatability Contact measurements $\delta E > 10$
4th System: Scanner and Spectrophotometer	No contact measurements Total image of limb	Poor repeatability Problems with device calibration Costs > $15,000 $\delta E > 7$ Unsuitable acquisition protocol
5th System: Imaging Color Analyzer Module	No contact measurements Total image of limb Good repeatability $\delta E < 5$ Easy to use	Costs > $15,000

δE = tolerance of colorimetric measurements.

to minimize. As a whole, the system had good quality versus price characteristics and, with suitable limitations, could prove to be a good solution (**Table 2**).

3rd System: Fiber-Optic Device

The third system we studied allowed us to detect the Lab coordinates of skin and silicone at a low initial cost. However, from the very first measurements, the instrument clearly had functional limitations and poor flexibility that made it unsuitable for our application. For example, the instrument software was too difficult for the user to learn and use for sample measurement. Moreover, by varying the slope of the fiber-optic cannula, we found that the color coordinates of the skin changed during the acquisition. This, combined with the poor results obtained in terms of δE, led us to abandon the instrument (**Table 2**).

4th System: Scanner and Spectrophotometer

We conducted a systematic series of tests with the fourth system that highlighted considerable intrinsic problems in the system. The acquisition process required positioning the object (in this case the patient's limb) on a mobile platform that, despite moving very slowly, proved to be uncomfortable for subjects. The focusing procedure also proved to be somewhat awkward. These considerations led us to abandon the experiments on the instrument. **Table 2** gives the final considerations.

Table 3.
Variation in RGB of silicone sample on basis of background. Results obtained with spectrophotometer (1st system; 2nd version).

Sample Thickness	Gray Background			White Background			Black Background		
	R	G	B	R	G	B	R	G	B
Thin	92	88	80	112	112	112	100	92	88
Medium	96	88	80	120	120	112	92	80	76
Thick	96	88	80	128	124	116	92	80	76

R = red, G = green, B = blue.

Table 4.
Comparison of skin and corresponding silicone. Results obtained with spectrophotometer (1st system; 2nd version).

Background	Photo of Skin			Corresponding Silicone		
	R	G	B	R	G	B
Gray	108	92	88	74	68	60
White	72	60	60	60	54	60
Black	172	160	156	144	132	124

R = red, G = green, B = blue.

Table 5.
Silicone bar color codes obtained with portable spectrophotometer (2nd system).

Test	Subject/Surface	Subjective Measurements	Objective Measurements
1	1/Dorsal Surface	B87	B87
2	2/Dorsal Surface	B31	B32, B31
3	2/Fingertip	R42	R41, R42
4	3/Fingertip	R41	R32, R33
5	1/Knuckle	B64	R43, B65
6	3/Knuckle	B44	R34, R35, R45

5th System: Imaging Color Analyzer Module

In tests of the ICAM, the silicone samples identified by the system appeared to have an average δE of 4. However, comparing these samples with the skin examined, we found that the visual differences were considerable. This result confirmed the well-known problem of nonuniformity of color spaces: small geometric distances do not always correspond to small perceptive distances. However, the system does allow the operator to select even just a single pixel of the image, which allows the user to eliminate any "disturbances" that could affect the detection of skin color (hairs, veins, moles, etc).

As mentioned previously, we created the silicone sample database by measuring the samples on a black velvet background. The presence of this background inside the light box creates problems in calculating the chromatic coordinates of the samples because the semitransparency of the material allows the ICAM to detect not only the chromatic hue of the silicone, but also that of the background. To eliminate this problem, we would require a perfect knowledge of the coefficients of transmittance and reflectance of all the materials in question; therefore, it is practically impossible. In an attempt to reduce the influence of this variable on calculations of the CIE Lab coordinates of the samples, we measured a silicone bar, chosen by a prosthetist and visually most similar to the color of the skin, by placing it on the hand of the subject under examination. Subsequently, the chromatic coordinates of the sample and the skin as determined by the ICAM were compared; contrary to expectations, the δE between skin and sample was still rather high (equal to about 5) despite the two elements being perceptively of the same color. Once again this demonstrates the imperfect uniformity of the color space and the difficulty in making colorimetric comparisons on the basis of chromatic coordinates alone.

During the testing phase, the problem of microfibrils came to light. The Otto Bock silicone samples contain pigmented microfibrils that influence determination of the Lab coordinates for the database. The color of the bars measured by the ICAM may therefore not be that perceived by the human eye because the naked eye has difficulty recognizing the fibrils. However, this system has the advantage of detecting color without contact being required, and therefore, changes in blood circulation do not occur. One element to be considered is the particularly high purchase price. The ICAM demonstrates its high technological potential, although for us to completely resolve the problems of prostheses production, the system requires further development. **Table 2** contains some final considerations on this system.

CONCLUSION

The problem of automatic detection of human skin color requires a very complex technological and methodological solution, and as we have seen, depending on the budget assigned and the potential return on initial investment, a number of different approaches are possible.

The best chromatic results were obtained with the ICAM. Within 2 to 3 s, this instrument provides a complete image of the patient's limb and allows us to save it on a PC. From this image, we can then determine the tristimuli variable Yxy and/or Lab coordinates of a single pixel or area of size and identify in a database the silicone sample with the most similar chromatic coordinates. This kind of instrument could be used in the production of silicone cosmetic prostheses, which would allow us to considerably reduce detection and, therefore, production times. Patients would only need to be present for the acquisition of a first image and not for the entire duration of the production cycle as is currently the case. Furthermore, the use of the instrument would allow us to establish an objective color measurement procedure. Our results also include the final software implementation for managing the instrument, measurements, and data.

This study helped us to identify and resolve certain problems, such as standard illumination and color detection without contact. It also highlighted the difficulty in completing the silicone sample database because of the semitransparency of the material and the presence of pigmented microfibrils inside the samples.

For the future, we foresee automatic detection of the percentages of dye needed for reproduction of the color on the prosthesis, despite the fact that the complexity of the problem would increase considerably.

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