Colored Prosthetic Skins

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Abstract

Currently, artists color prosthetic skin by hand to match each patient's natural skin color and texture. However, this is an expensive and time-consuming process. Therefore, the goal of our project is to design a faster, systematic method to color prosthetic skin. The device must be able to quantify skin color, precisely reproduce prosthetic skin color, and be operated by one person. After analysis of four proposed solutions – pad printing, lithographic printing, laser printing, and inkjet printing – it is shown that the inkjet printer design is the most feasible and will therefore become part of the final prototype.

Background

Current Method

Currently, medical artists, such as our client, Mr. Greg Gion from Medical Art Prosthetics, must use his or her eyesight and intuition to match the prosthetic skin color to the patient's natural complexion. The first step of coloring prosthetic skin is to apply as much color and detail as possible into the inside of the mold of the prosthetic by using a paintbrush. The pigment that is currently used to color these prosthetic skins is a mixture of a catalyst and un-catalyzed silicone-based ink. After the artist finishes coloring the inside of the mold, it is filled with room temperature vulcanizing (RTV) silicone. This mold-silicone complex is then cured in the oven, at which point the ink from the inside of the mold is transferred to the prosthetic limb itself. The second stage of prosthetic skin coloration takes place during installation. At this point, Mr. Gion paints additional detail onto the prosthetic to ensure that it blends perfectly to the surrounding natural skin.

The biggest challenge of this coloration method is the enormous reliance on eyesight and intuition. The lack of systematic methodology contributes greatly to excessive need for time, effort, and money. As a result, natural-looking prosthetic skin becomes expensive and inaccessible to many patients.

Problem Statement

Currently, the procedure for prosthetic skin coloration is done manually, which requires a lot of time, money, and energy. Although there are many different skin tones and color, resemblances exist among individuals from similar regions of the world. Our client proposes a systematic method to mass-produce skin colors to create realistic prostheses. He would like to create a process that can color prosthetic skin with consistent characteristics and qualities.

Design Requirements

As stated in the Problem Statement, our client is looking for a systematic method to reproduce skin colors for prosthetic skins. As a starting point, he suggested a printing process that can mass-produce a certain pattern, such as wood grain. Specifically, he wants to focus on a printing process that can mass-produce a certain pattern- for example, sheets of wood grain. Several criteria were considered while researching different methods:

1) Pigment: adheres well to the substrate and consists of the primary colors – red, yellow, blue
2) Substrate: silicone, polyurethane, or thermoplastic elastomer (TPE)
3) Materials: must be non-toxic and hypoallergenic. The materials cannot cause any allergic reaction to the patient who uses the completed prosthetic, since it will be fixed to his or her skin.
4) Process: operable by one person
5) Cost: less than $500

Problem Motivation

The final design would reduce the time, labor, and cost, from the current manual method. An automatic printing process would allow a rapid and accurate prosthetic skin production. Each customer's skin color and texture will be mimicked, quantified, and recorded by computer software such as Adobe Photoshop. Increasing printing efficiency will help reduce the time and cost of producing prosthetic skin. Moreover, skin quantification records allow production for replacement prosthetic skin without the presence of patients (since reproduction generally happens every 5 years for adults and 6 months for children – data given by client)

Competition

In industry, most skin prosthetics are colored manually. A possibility that was recently proposed is to modify a rapid prototyping machine to facilitate three-dimensional printing of prosthetic limbs. Rapid prototyping, or stereo-lithography, starts with a three-dimensional Computer-Aided Design (CAD) generated image, which is then sliced into layers of 0.1 mm thickness. Next, the computer instructs the rapid prototyping machine to discharge liquid photopolymer to form these thin layers one by one. Once all layers are formed, the prototype is then cured inside an ultraviolet oven (www.howstuffworks.com).

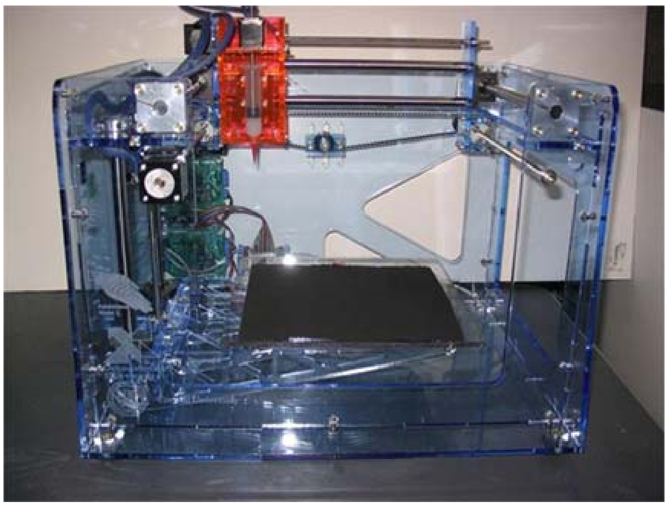

Figure 1: *Rapid prototyping machine.* The Rapid prototyping machine used for testing at UK National Center for Product Design and Development Research. Source: www.newscientist.com

Domenic Eggbeer and the United

Kingdom National Center for Product Design and Development Research are currently performing a laboratory study. As of January 16, 2006, trials are being conducted on wax. These prototypes cannot yet match skin texture accurately, and the methodology for prosthetic skin coloration has not been explored (Copying wrinkles, 2007). The apparatus this group is using is a rapid prototyping machine, shown in Figure 1.

Although this method presents the exciting possibility of producing prosthetic limbs and coloring prosthetic skins in one step, the technology is still at its infancy. A typical printing of a medium sized object ranges anywhere between six to twelve hours. Larger objects have been known to take days to produce. Since the study of three-dimensional printing has only been started recently, we believe that a less innovative but highly productive method of coloring skin prosthetic would be more beneficial to the field of prosthetic skin.

Design Proposals

The following will describe each proposed printing process: pad printing, offset lithographic printing, laser printing, and inkjet printing.

Pad Printing

Pad printing is a printing process that utilizes three main components, excluding the substrate: a cliché, ink, and a silicone pad. A cliché is a plate made of either steel or plastic with an etched design on the top where the ink is applied. The process usually uses a solvent-based ink; however, there are some companies that use a silicone-based ink. The silicone pad is used to transfer the ink from the cliché to the substrate, and is the most important part of the process.

The silicone pad has some important factors to take into consideration for use: the hardness of the pad, the shape of the pad, and the surface energy of the pad. The hardness determines how much deformation occurs with the pad. Deformation of the silicone pad will affect ink transfer between the pad and the substrate. The shape of the pad is usually one of three types: conical, rectangular, or roof-shaped. Each shape works best with different substrates. Lastly, the surface energy of the silicone pad has to be lower than that of the substrate in order for ink to transfer.

Applying this process to printing colors on prosthetic skin is fairly easy. The basic materials needed – ink, silicone pad, substrate (silicone or polyurethane), and cliché – are available at many different companies. The challenge is to make sure that the ink will transfer from silicone to silicone, if that is chosen as the substrate. In order to make this process work, the substrate will need to be surface-treated to alter its surface energy, by using plasma treatment for example to achieve this.

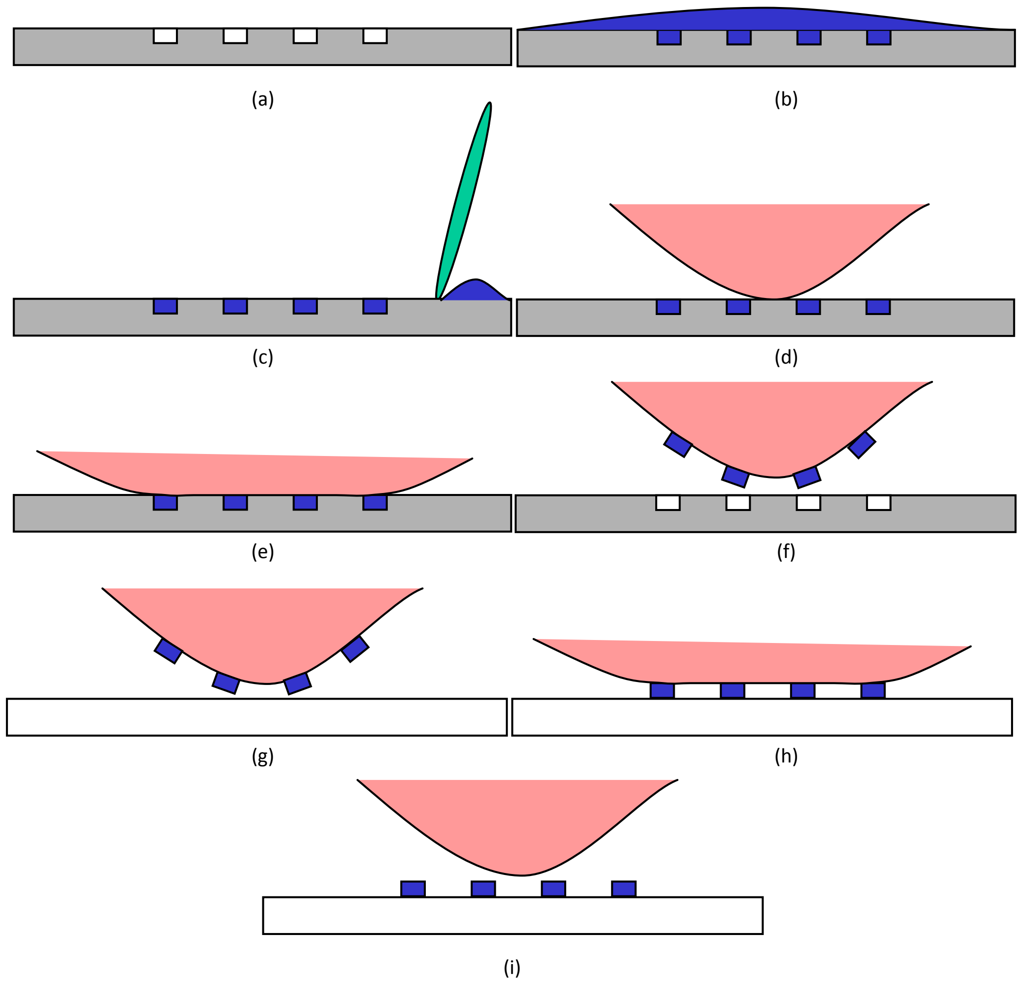

Figure 2: Diagrams showing the basic process of pad printing. (a) Basic cliché ready for use. (b) Ink flooded onto cliché. (c) Top layer of ink scraped off cliché. (d) Silicone pad lowered to cliché. (e) Pad applied with force onto cliché; deformation of pad contacting cliché. (f) Pad lifted off cliché; returned to normal shape. (g) Pad lowered over substrate. (h) Pad applied with force onto substrate; deformation of pad. (i) Pad lifted off substrate; ink transferred.

The basic process is detailed as follows, also shown in Figure 2. First, the cliché is flooded with ink. Then the top of the cliché is scraped clean until the only ink that remains is that which resides in the etched design. Next, the silicone pad is pressed with force onto the cliché, with slight deformation of the pad, ensuring that all the ink is picked up. The pad is then lifted off the cliché, pad returning to its original shape. Then the pad is pressed with force onto the substrate, slightly deforming the pad again. The ink transfers completely from the silicone pad to the substrate. Lastly, the pad is lifted from the substrate, and the process can be repeated.

The benefits of this process are that it is easily operable by one person, the components used are versatile, a variety of ink colors can be used, and the process is easy to modify. There are not many components needed to operate this process, so each operator should not have difficulty with learning the steps to pad printing. Also, pad printing allows the user to print colors on many different substrates, including metal, plastic, wood, and fabric. The variety of ink colors available for pad printing includes the primary colors is an advantage for creating natural skin color. The limitations, however, are that the process mainly uses solvent-based ink, the substrate needs a higher surface energy than the silicone pad, as mentioned before, and the ink is thin (Pad Print Process).

Offset Lithographic Printing

The offset lithographic printing design applies the technique that is widely used to print newspapers and magazines. It works based on the principle that water and oil-based ink do not mix. The ink will adhere to the image areas, while the water will adhere to the non-image area. First of all, the desired image is created on a negative film, and then transferred to a plate or cylinder using the same technique used in photography to develop photographs. A certain amount of light is allowed to pass through the negative film to expose the plate. The light will activate the ink-receptor on the plate, which will then pick up ink released from the ink rollers (Printing Process Descriptions). Ink will be washed off from the non-image area by water since the oil based ink does not mix with water. Then, the image from the plate will be “offset”, or transferred, to a rubber “blanket”, and the image will be printed onto the substrate. We would like to modify this system so that we will be able to use silicone-based ink instead of oil-based ink, as well as use the silicone substrate instead of paper.

This design has two separate inputs of ink and water. We can apply this when using silicone-based ink because it is necessary to keep the ink and its catalyst separated. Areas where silicone ink and catalyst interact will form images, which will be transferred to the offset drum. The drum must be made of materials that can hold silicone ink, and the image will be printed on silicone substrate. This technique is very useful for mass production (web-fed printing). Moreover, it allows precise reproduction once the image is created. However, it is very expensive and extremely difficult to re-modify. The image shown in Figure 3 illustrates a one-color ink unit lithographic printer. In order to create natural skin colors, multiple units must be installed to accommodate three primary colors. This will increase the cost and difficulty of building the prototype.

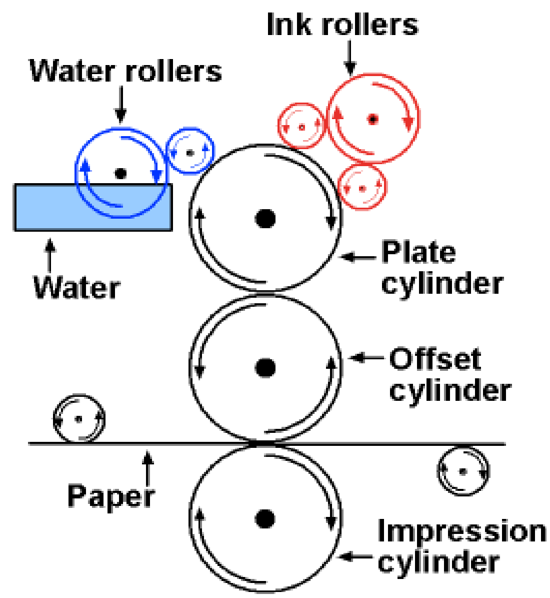

Figure 3: Diagram shows one color unit in offset printing. Ink rollers release ink to plate cylinder for ink-receptors to pick up and form image. Water rollers dampen water to plate cylinder to wash off ink from non-image area. Image on plate will be transferred to offset cylinder, and printed on substrate.

Source: www.howstuffworks.com

Laser Printing

Static electricity is the basic principle behind laser printing. There are five main components of laser printers: corona wire, laser scanning unit, photoreceptor drum assembly, toner, and fuser. Figure 4 depicts the basic components of the laser printer. As soon as the printer

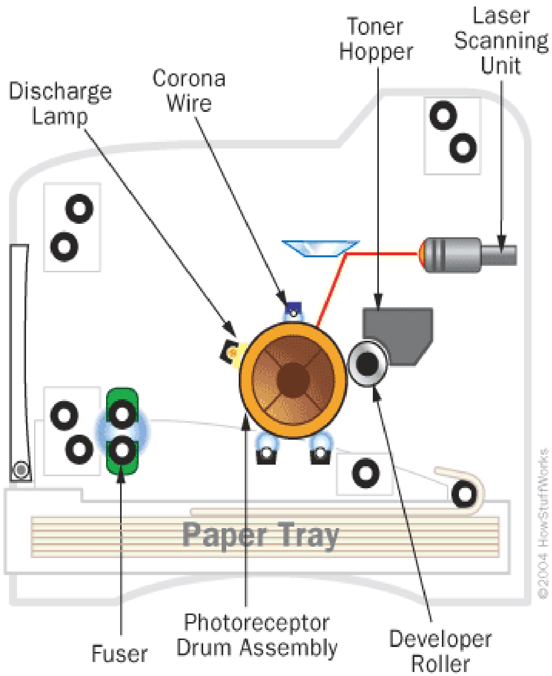

Figure 4: *Basic laser printer components.* This figure shows the main components of laser printer and their relative positioning inside a typical laser printer.
Source: www.howstuffworks.com

receives the command to print, the corona wire gives the photoreceptor assembly a positive charge. The laser inside the printer then draws the document to be printed according to the electrostatic image on the photoreceptor drum assembly.

At this point, the corona wire gives the paper a negative charge. As the paper passes under the photoreceptor drum assembly, the positively charged toner (a powder containing pigment and plastic particles) becomes attracted to the negatively charged paper. Gravity is the only force keeping the toner on the paper until the electrostatic image is fully drawn, at which point the positively charged toner is discharged from the toner hopper.

The toner-covered paper then passes through the fuser, which functions as a heater that melts the toner powder. The melted toner powder binds into the fibers of the paper; hence, laser printer images have high tolerance to smudging. As the paper continues to travel to outside tray, the electrostatic image on the drum assembly is erased by a discharge lamp. This completes the process of laser printing (www.howstuffworks.com).

Advantages to this design come from speed, precision, and accuracy. A typical color laser printer can print up to 6000 pages per hour. The incorporation of the laser in the formation of the electrostatic image gives rise to this design's precision and accuracy. Compared to other designs that we have explored so far, the laser printer should have the longest lasting prosthetic skin color. This comes from the fact that the toner actually binds into the substrate instead of adhering only to the substrate's surface.

Laser printers, however, have several great disadvantages. The biggest disadvantage to a laser printer is the extremely high fuser temperature, usually above 200^{o}C. The high temperature of the fuser is required for the toner powder to melt and bind into the substrate. Currently, many companies are still trying to develop an effective fuser temperature control apparatus. The melting point of the silicone substrate is anywhere between 200 to 260^{o}C (How a laser printer operates, 2001; Butts, et al., 2000). Unless we are able to find a toner that melts at a lower temperature and a corresponding fuser, this design is very likely to cause the silicone substrate to melt inside the laser printer, a problem that would cost the client time, money, and possibly the printer itself.

Another disadvantage to this design is the current high cost of a laser printer. One of the reasons that laser printers are commonly used only in professional settings is due to their current unaffordable price. The price of a laser printer and its modification is very likely to exceed our given budget of $500.

Inkjet Printing

In an inkjet printer, a nozzle holds ink and contains either a resistor (in thermal printers) or a piezoelectric heater. In the thermal printer design, the resistor warms the ink, causing it to expand until the surface tension can no longer counteract gravitational force. The piezoelectric design utilizes a vibrating piezoelectric heater that pushes the ink out of the nozzle. For the purpose of this project, a plate-feed inkjet printer is ideal in that it can print a variety of surfaces rather than only sheets.

There are several advantages to modifying a regular inkjet printer. First, it is inexpensive. On amazon.com, for example, a new Epson Stylus Photo 260 Inkjet Printer costs $79.99, and a new Epson Stylus Photo R380 Inkjet Printer costs $99.99. Both are less than 20% of the $500 budget the client suggested. Second, the materials are easy to obtain in that most retail stores that carry printers sell inkjet printers. Third, this is a simple design, since it merely requires tweaking of an existing inkjet printer. Finally, the design should be easy to operate by one person in the same way that most people can easily print a document on paper without assistance. These attributes make this design a feasible prototype.

Unfortunately, there are a couple of problems with this design. It is the least innovative of all the suggested designs, since Professor Justin Williams of the Biomedical Engineering department has already modified some inkjet printers for biological applications. He has not modified inkjet printers to print on silicone, though. Also, the ink may adhere only to the surface of the substrate, decreasing the durability of the color. However, a toner (such as in the laser printer design) may be applied to the ink to counteract this potential problem.

Design Evaluation

In order to select a final design, we created a matrix with eight features weighted based on their importance to our design constraints. For example, one of the largest goals is to build a prototype and test it within the allotted time, so feasibility is weighed most heavily. On the other hand, safety has less weight. The matrix is a tool to help aid choosing a design, and each design is almost equal in safety, meaning that safety is not a helpful criterion in terms of the matrix. Therefore, it held less weight on the overall score. Each alternative design was evaluated on a scale out of 10 for each criterion, with a grand total of 80 possible points. Each team member evaluated these criteria individually, and then our team discussed and averaged the points. Finally, the average points were multiplied by the weight percent assigned as shown in Table 1.

Table 1: Summary of criteria used to evaluate the four designs.

Criteria	Weight	Laser	Pad Print	Litho	Inkjet
Feasability	0.35	5.3	9.0	8.3	10.0
Accuracy	0.15	9.5	7.5	7.5	9.0
Durability of Process	0.15	3.8	7.3	7.8	10.0
Efficiency (Mass Production)	0.1	7.0	5.8	9.3	7.0
Usability	0.1	6.0	8.5	8.5	9.0
Cost	0.05	3.5	8.3	4.0	7.0
Safety	0.05	6.5	8.8	8.5	8.0
Durability of Color	0.05	9.0	7.0	7.0	7.0
Total	1	50.5	62.0	60.8	67.0
Total with Weight		6.1	8.0	7.9	9.1

After rating all of our designs, it was found that the inkjet design scored the highest based on its high feasibility and durability. Therefore, we have chosen to pursue it as our final design.

Materials

The final design requires a plate feed inkjet printer and the substrate, silicone. The printer components will also require a coating to prevent the substrate from sticking to them. In addition, the design will require pigments to color the substrate. The pigments may be the same paint currently used by the client or some other type of ink. Lastly, a plasma treatment set-up is necessary to attach hydroxy groups to the silicone, which is naturally hydrophobic, so that the pigment will adhere to it.

Future Work

The goal for the remainder of the semester is to build and test the prototype. First, we will obtain the materials necessary to build the prototype. Then, the prototype will be assembled by modifying inkjet printer so that it can print on silicone. We will test various inks and pigments with the design to determine the most appropriate way to color the silicone via the printer. Additionally, testing may be conducted to ensure that the printer works optimally, and computer software Adobe Photoshop will be applied to digitally design skin color and texture. In a possible subsequent semester, the design may be modified for mass production of prosthetic skin color.

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Project Design Specification

October 24, 2007

Team Members: Anika Lohrentz, Alice Tang, Rexxi Prasasya, Chou Mai

Problem Statement:
Currently, artists perform the procedure for skin coloration of facial prosthetics manually, which requires a lot of time, energy, and money. However, there are numerous similarities among individuals from similar regions of the world. Therefore, our client proposes a systematic method to mass-produce the different layers of skin for skin prostheses.

Client Requirements:
- Design a systematic procedure for mass production
- Find a suitable substrate for production

Design Requirements:
1. Physical and Operational Characteristics
a. Performance Requirements- The design must be low-cost, safe to use and produce natural looking skin tones.

b. Safety- Materials must be non-toxic and hypoallergenic. Process must not cause harm to the operator and may require FDA approval.

c. Accuracy and Reliability- Produce prosthetic skin that precisely matches the natural skin color of the patient.

d. Shelf Life- The prototype of the process must last at least 5 years and withstand frequent use. The color applied by the process must last so that it will not need touch-ups for 6 months.

e. Operating Environment- The prototype of the process will operate at room temperature.

f. Ergonomics- The prototype of the process will be operated on a table for presentation purposes. It must also be easy to operate by one person.

g. Size and Shape- The prototype of the process will be no more than 3 cubic feet.

h. Weight- Not applicable to design.

i. Materials- Prefer materials to be silicone-based, but any substrate will work.

j. Aesthetics - It should be streamlined in appearance.

2. Product Characteristics:
a. Quantity- Only one prototype is needed.

b. Target Product Cost- The device should stay within the client budget, ideally under $500.

3. Miscellaneous:
a. Standards and Specifications- Obtain FDA approval.

b. Customer- The substrate that will be used should preferably be silicone, but polyurethane and thermoplastic elastomer (TPE) are also options. Silicone-based paint will be used.

c. Patient-related concerns- The color must match the natural skin color of the patient.

d. Competition- Similar prosthetic devices exist which are mainly created manually. Currently mass-produced prosthetic skins are unnatural looking. This team will combine merits of the two processes, therefore creating mass-produced natural looking skin.