# Synthetic Skins with Humanlike Warmth

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**Abstract.** Synthetic skins with humanlike characteristics, such as a warm touch, may be able to ease the social stigma associated with the use of prosthetic hands by enabling the user to conceal its usage during social touching situations. Similarly for social robotics, artificial hands with a warm touch have the potential to provide touch that can give comfort and care for humans. With the aim of replicating the warmth of human skin, this paper describes (i) the experiments on obtaining the human skin temperature at the forearm, palm and finger, (ii) embedding and testing a flexible heating element on two types of synthetic skins and (iii) implementing a power control scheme using the pulse-width modulation to overcome the limitations of operating at different voltage levels and sources. Results show that the surface temperature of the human skin can be replicated on the synthetic skins.

**Keywords:** Synthetic skin, social robotics, warm skin, rehabilitation robotics, prosthetics.

## 1 Introduction

Touch is a fundamental human need. The human touch promotes physical, emotional, social and spiritual comfort [1]. Through touch, distinct emotions such as anger, fear, disgust, love, gratitude and sympathy can be communicated [2]. However, these benefits are lost in the case of a loss of an upper limb that may be due to illness, accident or war. Likewise, it could also be possible to enable a social robot to be perceived as communicating emotions associated to comfort and care when equipped with capabilities for humanlike social touching.

This paper addresses the possibility of replicating the skin surface temperature of the human skin on synthetic skins. Toward this end, we conducted experiments to obtain the surface temperature of the human skin at the forearm, palm and fingertip. Then, we embedded a heating element on samples of synthetic skins and varied the voltage inputs to reach the typical range of human skin temperature. Lastly, we implemented a power control scheme to overcome the limitations of operating at different voltage levels and sources.

Previous works have been mainly focused on tactile sensing of surface temperatures for robotics applications [3-8] and the replication of temperatures through tactile displays for teleoperation purposes [9-12]. To the best of authors' knowledge, no

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research on replicating the human skin's warmth on synthetic skins has been reported. With the emergence of prosthetic hands that can be controlled with the user's thoughts [13-16], we surmise that synthetic skins with similarities to the softness and warmth of the human skin will be needed as it is human nature to touch and be touched, while being able to conceal the stigma from the loss of limbs. Our previous works on synthetic skins with humanlike skin compliance have been earlier presented in [17-20].

Traditionally, it was believed that the thermal sensitivity of the human skin consisted of isolated cold and warm spots with a single specific receptor beneath each spot which was assumed to have a one-to-one relationship with the quality of sensation by the spot of skin above it [21]. This view was first introduced by Blix [22], and Goldscheider [23]. In 1941, Jenkins [24, 25], provided psychological evidence that sensory fields are in the form of areas of highly sensitivity surrounded by areas of decreasing sensitivity. Later, Melzack et al [21], investigated the distributions of sensitivity by mapping large areas of skin using the stimulators, with their diameter and tip temperature controlled, to verify the evidence of overlapping receptive fields. Their studies showed that the distribution is in the form of large sensory fields with a variety of sizes and shapes. It was also observed that the spatial properties of stimuli play an important role in determining the quality of cutaneous experience [21].

It is known that the local temperature of the skin is dependent on a variety of factors, such as environmental and weather conditions, human internal metabolism, blood flow, and etc. According to Sakoi and co-workers [26], the air temperature, thermal radiation, air velocity, humidity, clothing and activity are six well known factors that influence the human thermal state in steady state and uniform thermal environments [26]. The skin temperature can also be different for people of different age, sex, and weight, as well as, different internal conditions. For example, when people are in a state of stress, the finger skin temperature decreases [27]. This is apparent when we shake hands with people who are nervous.

Previously, some experiments were accomplished in order to investigate thermal comfort for the human body (both whole and local comfort) as well as the local skin temperature. Sakoi et al [26] carried out these experiments by setting up a booth in climate chambers with controlled environmental conditions. The experimental data were measured for different males and females with different clothing, while they were all requested to refrain from eating one hour prior to experiments [26]. It was shown that depending on the environmental thermal non-uniformity, the local skin temperature changes even if the mean skin temperature remains almost the same. Furthermore, the mean value of the skin temperature of the whole body was reported to be ranged from 32.6 to 35 ˚C and the peak of overall thermal comfort was located around 33.5˚C of the mean skin temperature [26]. It is also worth mentioning that one of the main results of this paper was the insufficiency of a mean skin temperature for describing the overall thermal comfort in non-uniform thermal conditions. Thus, in order to have a better picture of human thermal comfort, skin temperature distribution is reported to be essential [26].

With our stated objectives and leveraging on the existing knowledge on human skin warmth, this paper has been organized as follows. Section 2, describes the materials and the methods. Section 3 presents the results and discussions. Finally, Section 4 provides the conclusions and the future directions.

## 2 Materials and Methods

This section has been divided into two parts. In the first part, the experiments to measure the human skin temperature are described and then followed by the description of the heating element, synthetic skin materials and the procedures to replicate the measured human temperature data**.**

### 2.1 Human Skin Temperature

The local temperature of human skin is different in various parts of the body and varies according to different conditions; among them is the ambient temperature. When a person enters a room, the body starts to adapt its temperature until it reaches a steady state with time, which depends on individual's internal situation, age, sex, etc. In this regard, we measured the skin temperature on the forearm, palm and index finger to determine the typical values that will serve as target data for our synthetic skins.

**Experimental Setup.** Six subjects (4 males and 2 females) were selected for the experiments in two different conditions. In the first one, the subjects' hand temperatures were measured upon entering the room for different room temperatures (20, 25 and 32 ˚C) using a k-type thermocouple based precision thermometer (FLUKE 52-II). In the second one, the same experiment was repeated for the subjects after 30 minutes of entering the room which allowed the subjects' body temperature to stabilize. For each subject, in each room temperature, and on each active part of the hand, the measurement is repeated four times with intervals of two minutes. It should be mentioned that in this setup, it was assumed that the skin temperature does not vary due to sudden metabolic activities and blood flow.

**Human Skin Temperature Response.** The human skin temperature response with respect to the both skin materials was compared. Both of skin material and human were brought from a temperature of 32 ˚C suddenly into a room maintained at 20 ˚C and the rate at which the temperature decreased was recorded to check whether there is a need for a cooling element in addition to the heater.

### 2.2 Materials

**Heating Element.** A flexible polyimide heating element (HK5200R5. 2L12B, Minco, Singapore) was selected to duplicate the human skin temperature for synthetic skin. This heating element dimensions were chosen to be 50 mm × 6.5 mm. Then it was coupled to the skin material using a pressure sensitive adhesive (PSA-Acrylic, Minco, Singapore). The resulting resistance of the heating element was measured to be 5.1 ohms.

**Skin Material.** Samples of silicone (GLS 40, Prochima, s.n.c., Italy) and polyurethane (Poly 74-45, Polytek Devt Corp, USA) which were previously characterized for their mechanical behavior [19, 28] and used as skins of prosthetic and robotic fingers [29, 30] were selected for experiments. Each skin material was fabricated in a rectangular shape with the dimensions of 50 mm × 35 mm and thickness of 3 mm as shown in Fig. 1 (Left).

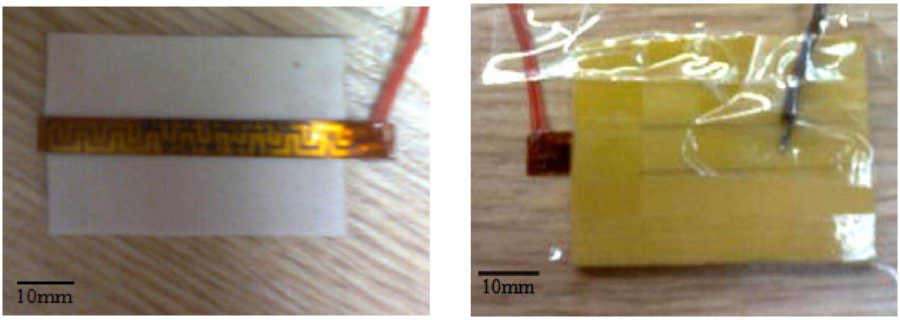


**Fig. 1.** (Left) The underside view of the silicone skin material with the flexible heating element. (Right) The polyurethane skin material with the heating element at the bottom and the thermocouple at the skin surface.

**Experimental Setup.** The experiment consisted of the heating element, the skin materials (silicone and polyurethane), a k-type thermocouple based precision thermometer, split timer and a power supply. The heating element was coupled to the skin material as shown in Fig. 1 (Left) using a pressure sensitive adhesive. The other side of the heating element was insulated using wood which ensures the maximum heat transfer to the skin material. The heating element was powered from a DC source and the thermocouple was placed on the skin material directly above the heating element.

**Experimental Method.** The experiment was conducted in an isolated room which temperature was maintained at 20˚C. The skin material was allowed to settle down to a constant temperature and it was measured to be 23˚C.The heating element was turned on at time t = 0 second from a DC power supply. The temperature of the skin material exactly above the heating element was monitored as shown in Fig. 1 (Right). The time instant at which the temperature crosses integral temperature values (in ˚C) was recorded and tabulated. The experiment was repeated for different input voltage supplies to the heating element.

**Power Control Using PWM.** As the resistance of the heating element is constant, the square of the voltage applied across its terminals is directly proportional to the power dissipated as heat. Hence, we have,

$$P_{heat} = \frac{V^2}{R} \tag{1}$$

where $P_{heat}$ is the power dissipated as heat, $V$ shows the voltage applied across the heating element, and $R$ represents the resistance of the heating element.

In order to regulate the dissipated heat, the heating element needs a variable voltage supply. Practical implementation in a prosthetic device demands a compact power source such as a battery. Thus, a method needs to be devised to control the power delivered to the heating element from a fixed voltage source such as a battery. The pulse-width modulation (PWM) scheme facilitates such implementation by controlling the average power delivered from a fixed source. The average power delivered from the source can be varied by varying the PWM duty cycle ratio (D) of the modulator.

$$P_{heat} = \left( \frac{V^2}{R} \right) D \tag{2}$$

From (**1**) and (**2**) we can derive the relation between the duty cycle and the equivalent voltage ($V_{eq}$ ).

$$V_{eq} = V\sqrt{D} \tag{3}$$

The PWM heating system when operating from a fixed voltage V and duty cycle ratio D dissipates power equal to that dissipated by the heating element when driven from a DC Voltage supply of $V_{eq}$. To validate this, the experimental setup was driven using a 4V supply modulated with a duty cycle of 5/8 at a frequency of 0.02 Hz. The temperature of the skin element directly above the heating element was recorded. The same set up was then driven using its equivalent Voltage ($V_{eq}$ calculated using (**3**) to be 3.2 V) from a DC Power Supply and the time instants at which the temperature crosses integral values (in ˚C) were noted.

## 3 Results and Discussions

### 3.1 Human Skin Temperature

Fig. 2 shows the mean values of temperatures for the forearm, palm and index finger of six subjects at three different room temperatures. The top row shows the temperature data as the subjects enter the temperature-controlled room. The bottom row shows the data obtained after 30 minutes. The skin temperatures ranged from 21.3 to 36.5 ˚ C. The local skin temperature of various parts of the hand varies according to the room temperature. Among the selected locations, the lowest skin surface temperatures were recorded at the index finger. In accordance to earlier reports, our experimental data show that the temperature distribution is different for people of different weight, age, and sex.

### 3.2 Materials

Input voltages of 1V, 1.5V, 1.8V and 2V were set for the heaters embedded on the silicone material sample. For polyurethane, input voltages of 1V, 1.5V, 2V and 2.5V were applied. Figs. 3 and 4 depict the temperature rise that corresponds to the changes in the input voltages.

Several observations can be made from the results of Figs. 3 and 4. First, it can be seen that the temperature curves have a steep initial climb, which stabilizes with time. This indicates that most of the heat is absorbed initially by the skin material to raise its temperature and as time passes, the skin element attains a steady state temperature and the heat supplied to the heating element is radiated into the surroundings.

Second, we can observe that the voltage range of 1V to 2V is sufficient to replicate the range of human skin temperatures as shown in Fig. 3.

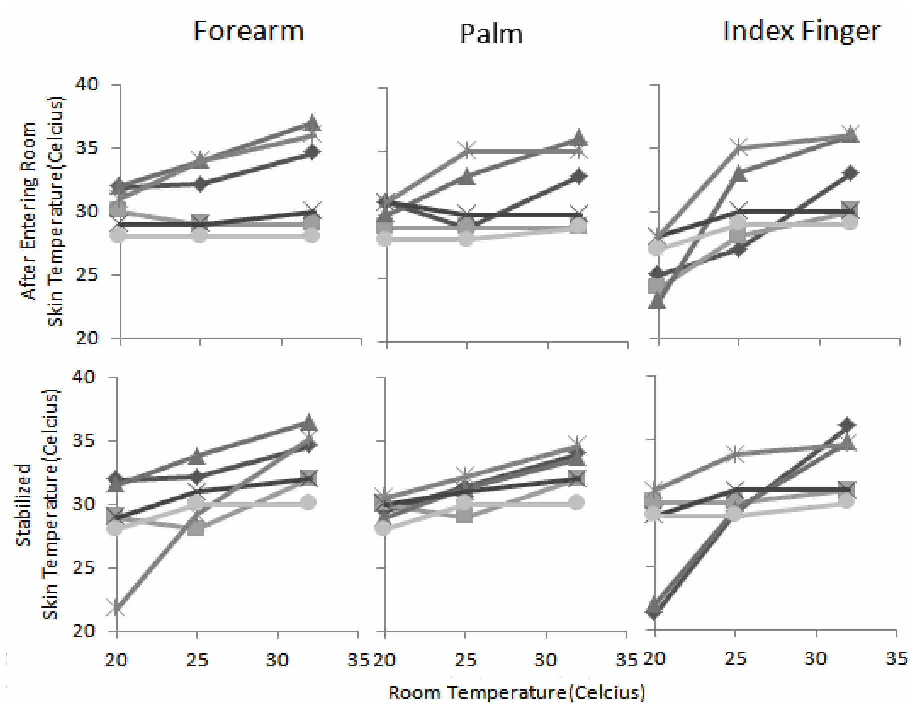


**Fig. 2.** Forearm, palm, and index finger skin temperature vs. room temperature for six subjects in two conditions (top row: temperature taken upon entry to the room and bottom row: after the subject has stayed in the room for 30 minutes)

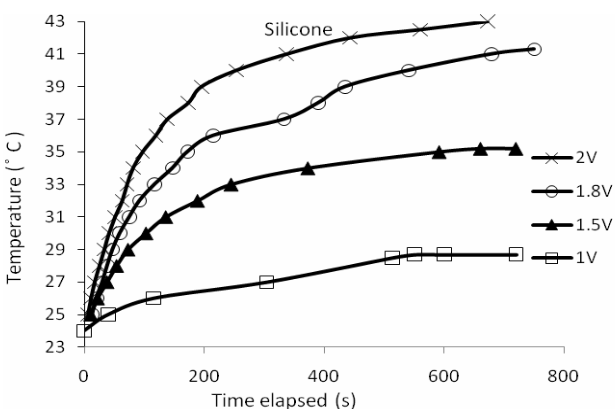


**Fig. 3.** Silicone surface Temperature vs. time at various input voltages

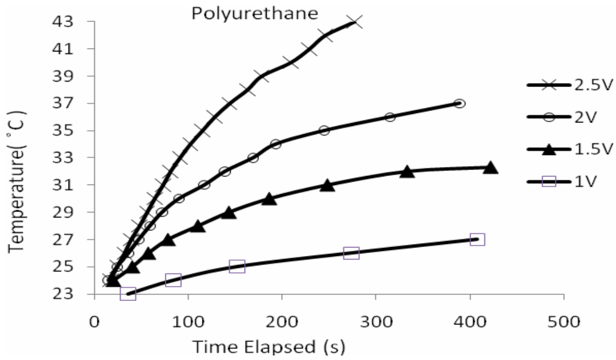


**Fig. 4.** Polyurethane surface temperature vs. time at various input voltages

Third, we can infer that when the power output from the heating element is higher, it takes a longer time to reach steady state temperatures on the skin material. Hence the time taken for establishing a given temperature (response time) varies with the target temperature. To achieve specific response times for a given temperature, constant voltages cannot be used. This calls for a different powering scheme to power the heating element so as to mimic the human temperature response.

From the Fig. 5, we see that the PWM controlled heating element and the DC powered heating element ($V_{eq}$) have similar temperature variations. The PWM frequency was purposely set to a very low value (0.02Hz) in order to get a better understanding of the power averaging that it delivers. A closer look at the graph shows the temperature of the skin material tries to reach the temperature of the skin material heated using a fixed $V_{eq}$ at the instances of time that differ by the time period (1/frequency) of PWM, thereby creating an averaging effect on the power delivered.

Since the heating elements are made using closely laid pattern of conducting material, a large sheet of heating element (as ones that can be used to heat a forearm) can have large parasitic capacitance. This limits the maximum frequency at which the

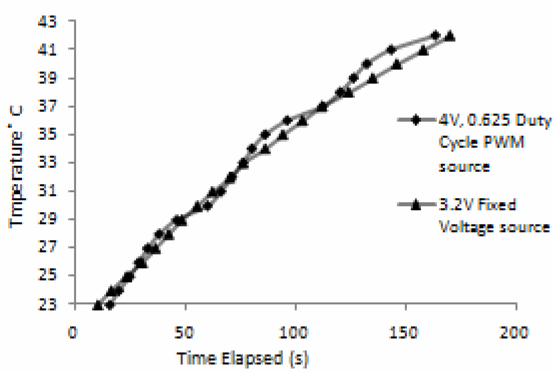


**Fig. 5.** Comparison of PWM controlled source and a fixed DC source for a heating element

PWM scheme can be operated. But since the human temperature response times are slow, the PWM frequency only needs to be less than a few KHz in most cases and thus allowing large sheet heating elements to be implemented.

In summary, the PWM controlled heating element provides control over the power delivered to the heating element and thus provides us the ability to adjust the response time for achieving a target temperature, which would not be possible as mentioned before using a fixed voltage scheme.

## 4 Conclusions and Future Work

Intelligent prosthetic and robotic limbs are emerging. It is conceivable that the next technological step is to make these devices look and feel more humanlike in order to achieve more natural contact interactions with humans.

In this paper, the skin temperatures at the forearm, palm and the finger were obtained as these locations are possible areas where contact interactions could occur. The temperatures were obtained at different room temperatures. The suitable temperature range within which the human skin temperature gets regulated was found to be 21.3 to 36.5 ˚C. Flexible heating element was embedded on two different synthetic skin materials. The results show that it was possible to replicate the surface temperature of the human skin on these synthetic materials. Lastly, a power control scheme was developed for possible implementation of the heating system design to an actual prosthetic or robotic device.

From these preliminary results, a possible direction to undertake is to model the input power required for the heating element based on the room temperature and thermal properties of the skin material. The model can be used along with a modulation scheme to establish a controller based heating system that can automatically regulate the skin temperature of various parts of the prosthetic hand as an attempt to fully mimic the human skin temperature.

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