DEVELOPMENT OF SMART GLOVES

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Abstract. *Raynaud's phenomenon is a disorder which affects the blood vessels in the body's extremities. The disorder is characterized by episodic vasospastic attacks, usually in response to a change in temperature, that causes the blood vessels in the digits and elsewhere to contract. Raynaud's phenomenon can occur on its own, or it can be secondary to another condition such as systemic sclerosis or systemic lupus erythemotosus. A smart glove was proposed as a method to counter the effects of Raynaud's phenomenon. To be effective the gloves must be able to control the heat distribution in terms of temperature and location on the hand, as well as incorporating active feedback on surface skin temperature. This control structure is described and how it is to be integrated into the gloves. The method of providing power is also described.*

Keywords*: Raynaud's phenomenon, smart textiles, heated gloves, control.*

1. INTRODUCTION

Raynaud's phenomenon is a disorder which affects the blood vessels in the body's extremities. The disorder is characterized by episodic vasospastic attacks usually in response to a change in temperature, that causes blood vessels to contract. Raynaud's phenomenon can cause a drastic reduction of the blood supply to a particular body part which may result in numbness, intense pain and tissue damage. In the most severe cases, ulceration and gangrene can occur. An example of how severe the temperature differences can become in a Raynaud's patients hand during an attack, is shown in Fig.1, where the cold parts of the patients hand have become white due to the reduced blood flow.

One approach to treating Raynaud's phenomenon has been the use of artificially heated gloves. Although it has been shown that such devices offer some therapeutic benefit, their use is limited due to, for example, the bulky and heavy battery pack. Another problem is the fact that the gloves are heated uniformly across the whole of the glove causing those unaffected parts of the hand to overheat.

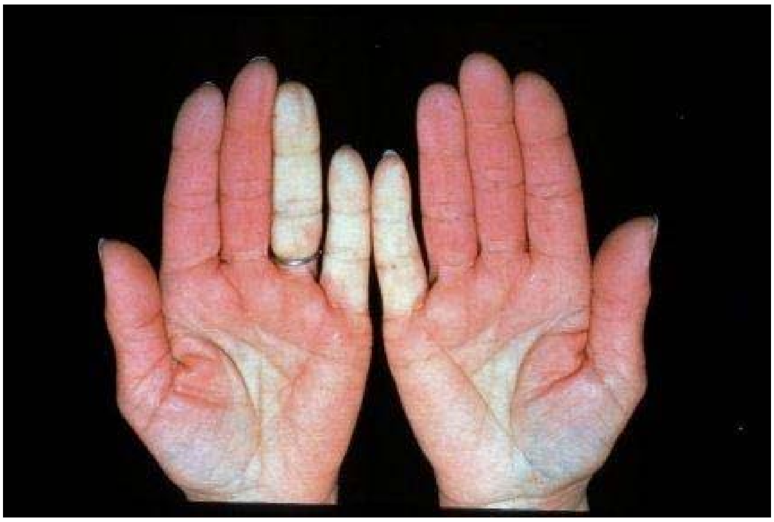


Figure 1. Raynaud's phenomenon: reflex vasoconstriction.

2. DEVELOPMENT & SPECIFICATIONS OF THE HEATED GLOVE

Ideally the gloves should be able to control the heat distribution in terms of temperature and location on the hand, as well as incorporating active feedback on surface skin temperature. This feedback would then be relayed back into the heating sources, ensuring a stable environment for the hand.

Perhaps one of the biggest challenges for this project is finding and developing a new way to power the gloves without using a large battery. There are several ways to go about this, the easiest and quickest is to use a slim lithium ion battery similar to those used in mobile phones. Other methods include Kinetic power induced by Pizo-electric ceramics, alternatively using a wind up clock method or a swinging pendulum capitalising on the bodies movements. Using these types of power supplies can only be viable when integrated with low current hence low power consumption heaters used in combination with a smart control system, saving power when the hands are already warm.

2.1. Problems with existing gloves

It was important to become familiar with the existing product in the market place in order to better understand the problems and inefficiencies affecting this type of product. Eight gloves were collected form several manufactures and distributors. The gloves were tested on the maximum temperature reached, heat distribution, heating element response time, power consumption and finally battery life. Through the investigation it became clear that there was no control within any of the gloves. Also there is no method of battery conservation resulting in the gloves using large power sources which are bulky and not liked by the users.

All of the gloves tested used large power consuming resistive heaters wrapped in various patterns around the glove. These heaters are not only power hungry they have no limiters on them, so are capable of reaching dangerous temperatures, an extreme example of this was when one of the testes gloves reached and unloaded temperature of 103ºC. Another problem was the gloves tended to heat the whole hand regardless of temperature, resulting in discomfort and in some sever cases cause skin irritation.

All these factors make the gloves very uncomfortable and extremely unfashionable, a fact which contributes too many patients unwilling to wear the gloves leading to their condition worsening.

2.2. Design

Before the design details were finalised it was important to find the best way of heating the glove and also find the best methods of heating whether it be a gradual increases of temperature in regular intervals, or rapidly heated. To answer these and other questions a number of meetings took place with Dr Faisel Khan, an expert in the disorder as well as other vascular and blood related diseases. Through these consultations it was discovered that the following parameters had to be taken into consideration during design.

- Heating should be done gradually in steps.
- Max temperature 35ºC
- The heater to activate below 28ºC
- When heating the hand it was determined that point heating was relatively ineffective, thus it was decided to warm the whole finger irrespective of which sensing zone was triggered.

Taking these new factors into consideration, the design could move on and more research was undertaken into the various parts of the design. The first part of the design was to look at the heater design and setup; there are several methods of heating ranging from simple high resistive wire to complicated composites for example carbon fibre and PTC (Positive Temperature Coefficient) materials. The four heaters tested were:

- Heat by the yard is comprised of a woven ribbon of tungsten shown in Fig. 2
- Printed PTC heaters are printed on to a polyester sheet with Carbon ink and then capped to the users specified temperature by coating the heater in a substrate, see Fig. 3
- Carbon fibber heaters use a sold sheet of woven carbon fibber sealed in a plastic envelope, shown in Fig. 4
- Resistive wire heaters use two wires which have different resistances, when a current is applied across it the higher resistive wire will heat up, the heater and the join between the low and high resistive wires is shown in Fig. 5.

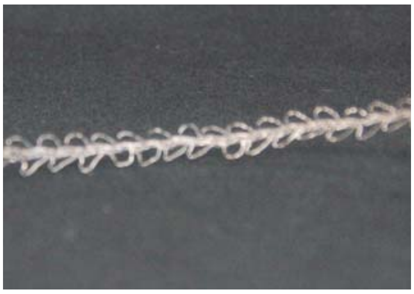


Figure 2. Heat by the Yard.

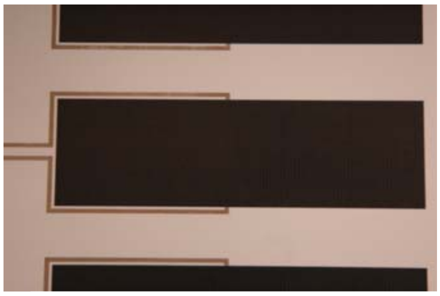


Figure 3. Printed PTC heaters.

Figure 4. Carbon Fibre.

Figure 5. Resistive Wire.

To determine the ideal heater for the glove, a series of tests were carried out. The tests measured current drain to reach and maintain a temperature of 40ºC, voltage, power, special features, size, durability and flexibility. To quantify the durability and flexibility a scale from 1 – 5 where 1 was poor and 5 was excellent. The results can be seen in Tables 1 and 2

Table 1. Experimental result's for the heaters.

	Current (A)	Voltage (V)	Flexibility	Durability	Sample Size (mm)
Heat By The Yard	1.5	9	4	1	850x5mm
High Resistance Wire	1	6	4	3	850x1mm
Carbon Fibre	1	5	3	5	75x50mm
PTC	0.2	7	5	4	110x35

Table 2. power and special features of the heaters.

	Power (W)	Special Features
Heat By The Yard	13.5	Very flexible and can be woven directly into the chosen fabric.
High Resistance Wire	6	Same as above
Carbon Fibre	5	Very durable can be manufactured to any dimensions or shape specified, very light weight
PTC	1.4	Very flexible and can be printed directly on to a fabric including all tracks and connections, can be temperature capped to and chosen temp, and they are very easy to implement into a design.

Having collated all the data, it was apparent that PTC heaters were far superior to the other types. The main factor was the low power consumption the other advantages include their superior flexibility and the ability to cap the temperature, ensuring an in-built safety mechanism.

Perhaps the most important part of the design is the implementation of control; this is completely unique within the clothing industry. The control will enable power conservation, temperature monitoring and control. Temperature sensors will constantly monitor the skin surface temperature, feeding the sensory data back into the control system. This control will in turn activate the corresponding heaters creating a zone, these zones allow for precise control, only heating the cold digit of the hand thus increasing power efficiency and eliminating over heating. There are several methods of control that could be used ranging from PIC micro controllers to surface mount electrical circuits. It was found to be easier to arrange a simple control circuit controlling each zone individually, and by using surface mount components it is possible to miniaturise the control. Fig. 6 shows the circuit layout for one heating zone.

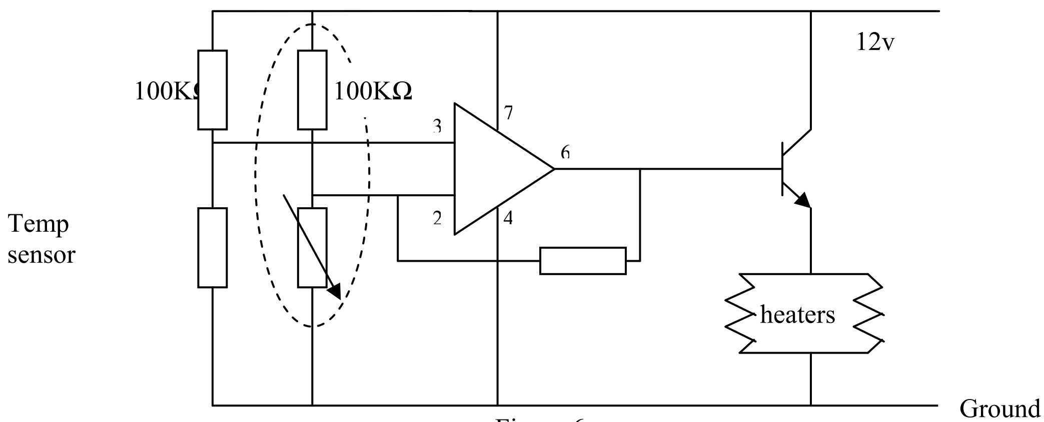


Figure 6.

The control design was later adapted for multiple sensors to trigger the heaters irrespective of which part of the finger is cold. This was achieved by connecting 3 temperature sensors in parallel as shown in Fig. 7.

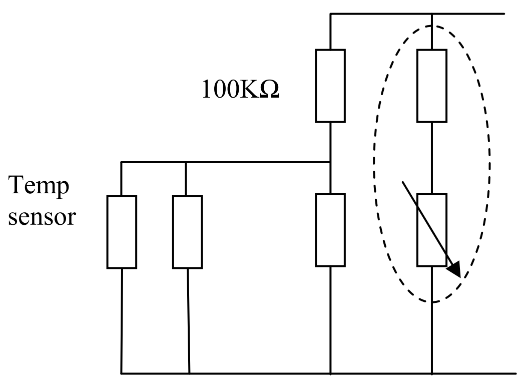
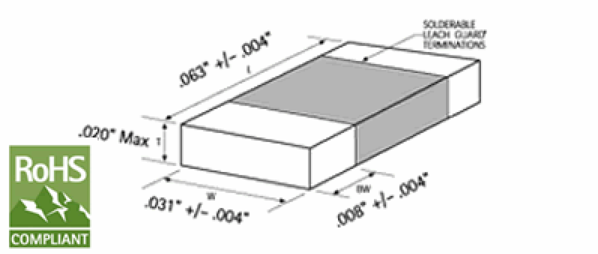


Figure 7.

By having the temperature sensors in parallel, the control can monitor more then one section on a finger but activate the heater on the whole digit. Five of these circuits are needed to control the whole glove.

A list of criteria was written up to determine the optimal temperature sensor for the design. The first criteria was that the sensor must be small and not impair movement in any way, the sensor must be easily integrated into the design, the accuracy should be around ±1ºC for an operating temperature of 0º to 100 ºC, it is important to have such accurate sensors because of the relatively small temperatures being measured. There are two main types of sensors RDT or thermocouple. Due to the small range of temperature the glove will be operating at it was decided to go for the RDT's.

The next task was to incorporate the right type of RDT, the three RDT's tested were, negative temperature coefficient (NTC) Thermistor, these sensors are used to measure very low temperatures in the region of 10K, as a result have poor accuracy making undesirable in this application. WWT weldable sensor are made of a high-purity nickel foil grid encapsulated in fibreglass-reinforced epoxy-phenolic, and equipped with integral three-tab terminal, commonly used as strain gauges, in order to use the WWT as a temperature sensor they are normally installed on a flat surface and should always be oriented with the gridlines in the direction to minimum strain to avoid strain-induced errors. It is for this reason that the sensor was deemed unsuitable due to the extremely high stress environment it would be near impossible to achieve a stable reading. Finally surface mount thermistors which are ideal for temperature sensing within a constrained area, as well as being very durable and can be integrated easily into the design using conventional surface mount techniques, Fig. 8 shows the surface dimensions (n inched) and specifications of the heaters.



- Thermal Time Constant: 5 seconds max in still air
- Dissipation Constant: 2 mW/°C min in still air
- Power Rating: .0625 W at 25°C, derate to 0 W at 125°C
- Resistance @25°C: 20K ohm and 100K ohm
- Operating temperature range: -55°C to 125°C
- Storage temperature range: -65°C to 150°C

Figure 8. The PTC heaters.

It was also important to find the optimal positions for the sensors and to prove that they would accurately measure skin temperature. To test this, an existing heated glove was modified with the surface mount sensors coated in resin for protections. Figures 9 & 10 show the sensor placement and control board layout.

Figure 9.

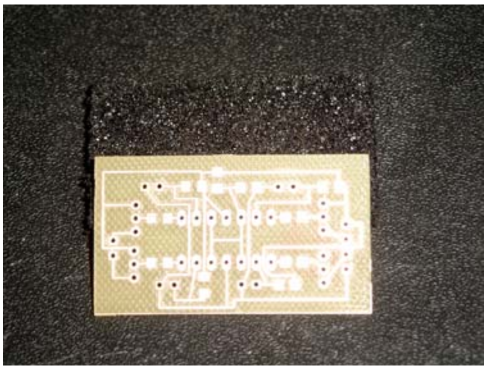


Figure 10.

Now that all the different components have been finalised and tested, it remains for them to be integrated into a single system. The design of the glove has to place all the connecting tracks, heaters, sensors and control all onto the one hand shaped piece of Tyvec material which can then be stitched into a glove or to create an insert to be used with other gloves of the users choosing.

3. THERMAL TEST

Thermal tests were carried out on 3 subjects, subject one is a 58 year old female, suffering from Raynaud's syndrome. The second subject is a 59 year old male, not suffering from any circulatory conditions. The third subject is a 22 year old male, again with no circulatory problems. The test started with all the subjects taking a brisk 5 min walk outdoor with an air temperature of 5°C, after the walk the subjects were all tested in indoor at and ambient temperature of 22°C, images were taken of the front and back of the hand directly after the walk and again 20 minuets after the first for subject 1.

3.1 Results

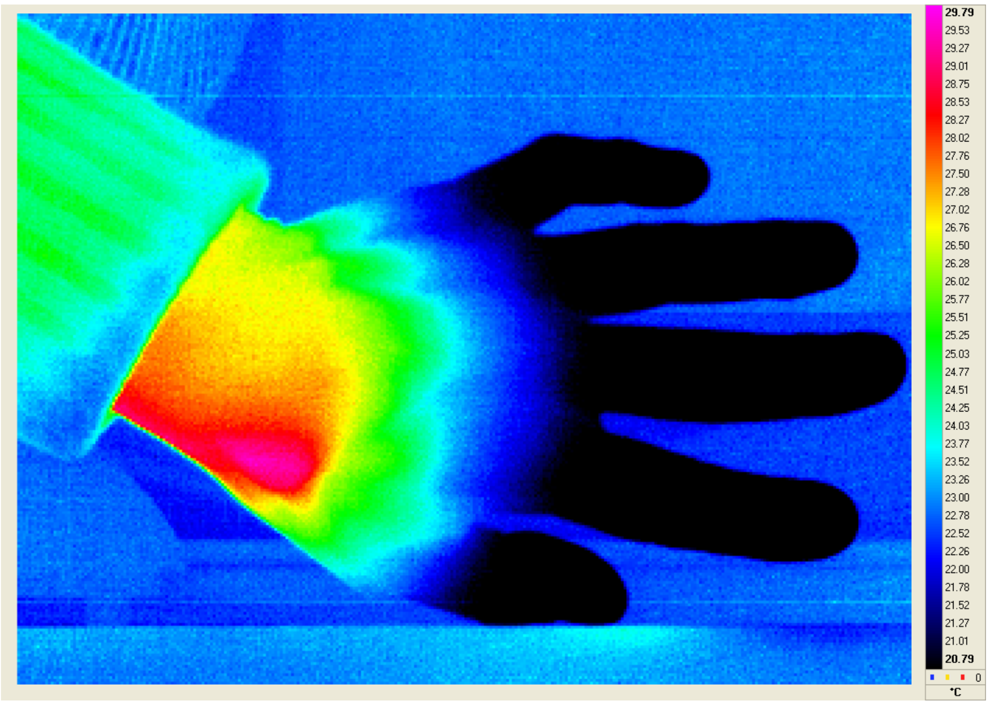


Figure 11. Subject 1, thermal image of the back, right hand.

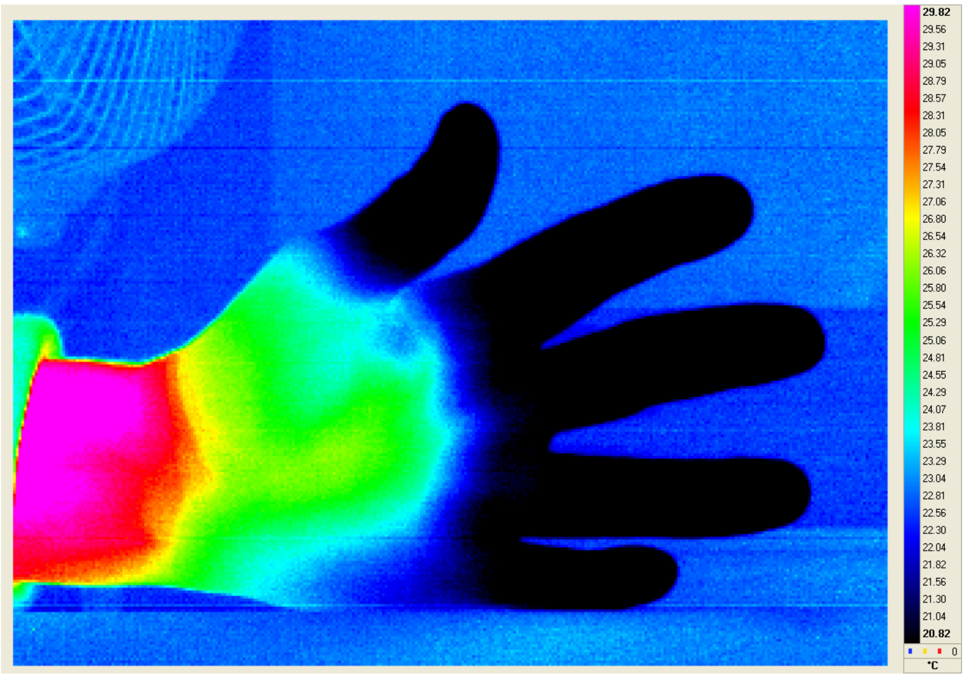


Figure 12 subject 1, thermal image of the palm, right hand

The images show the back and front of the hand respectively, it is immediately apparent that there is a large temperature difference between the fingers and the wrist. It is clear that after the short walk, subject 1 is suffering a Raynaud’s attack, the digits are even colder then the ambient room temperature indicating that the blood vessels are in complete spasm becoming vasio constricted. Another observation is that counter to popular belief there is no variation in temperature in the digits at these low temperatures, this is an important discovery, because it allows for a more flexible design in placing the heaters and temperature sensor. The images shown here are of the subject’s right hand but the left hand was also tested and was found to conform to a similar thermal pattern.

Figure 13. Subject 1, 20 minuets after primary test.

After 20 minutes of being in a gently warmed by the subject a second test was taken. From this test we can see that all the digits are back up to 30°C, which is considered a normal temperature. Again there is very little fluctuation of temperature with in the fingers.

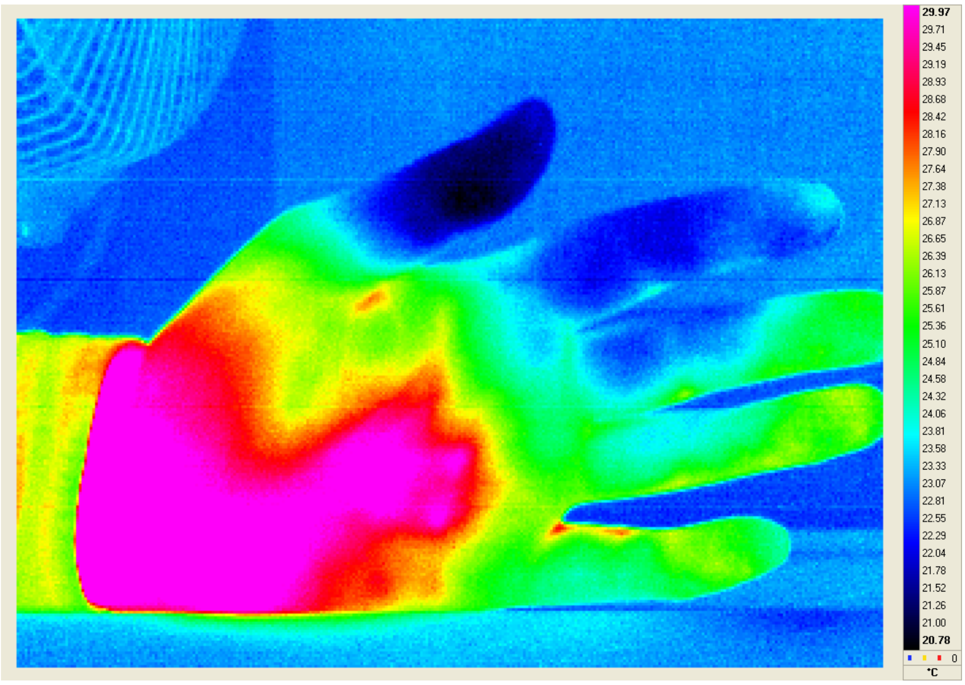


Figure 14. Subject 2, thermal image of the palm, right hand.

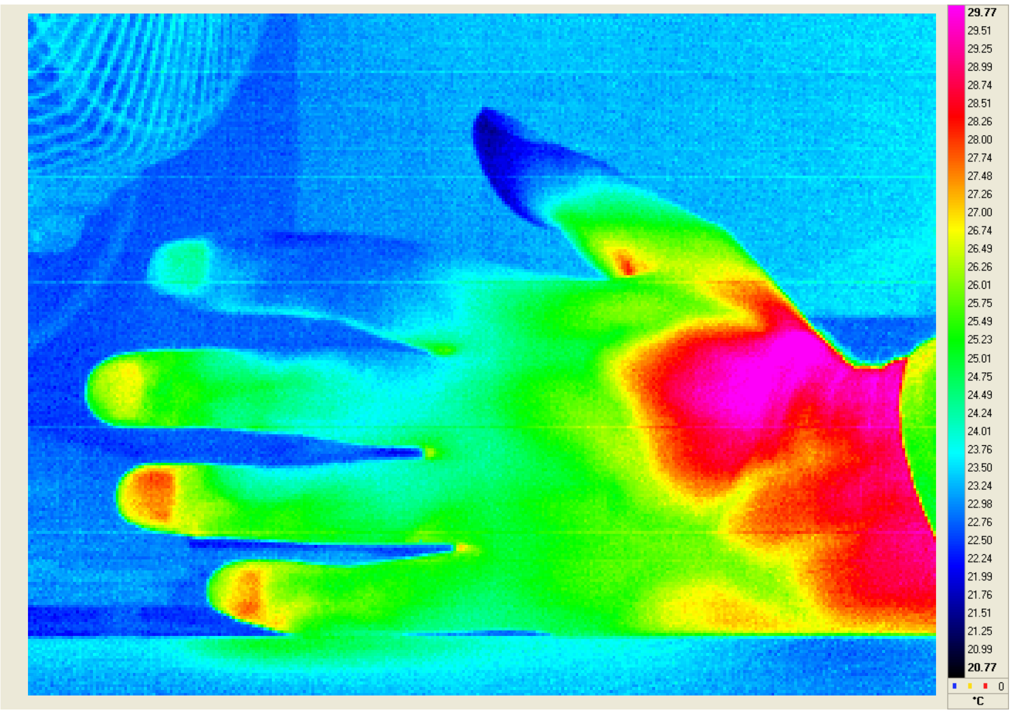


Figure 15. Subject 2, thermal image of the back, right hand.

Subject 2 may not be a sufferer of Raynaud’s, but there are clear areas of the hand which have poor circulation, primarily the thumb, index and parts of the middle digits. In terms of heat distribution the thumb and index digits are as expected giving a uniform and even temperate around the circumference, but in the middle finger we see something very different where the region of cold concentrated along the edge. This is down to the way the blood vessels and arteries are arranged within the fingers meaning the transfer of heat flows from the top edge to the bottom. The transfer time is yet to be determined, it can be less then a few minutes, and if this is the case then the sensor placement will not be effected.

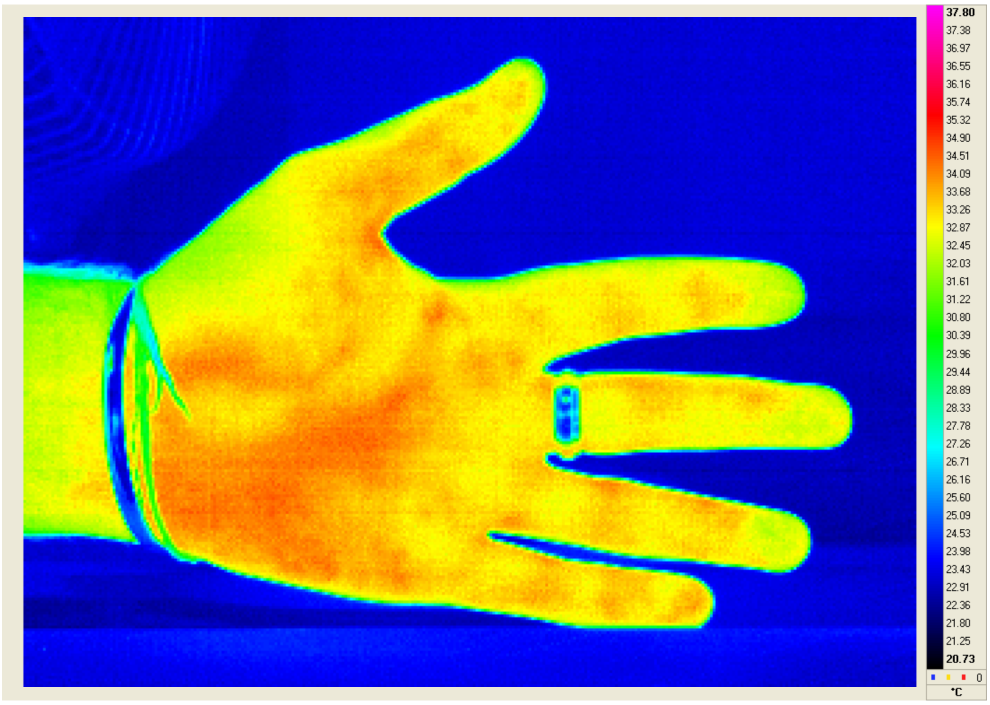


Figure 16. Subject 3, thermal image of the palm, left hand.

Figure 17. Subject 3, thermal image of the back, right hand.

Subject 3 has very good circulation, despite the cold. You can see an even distribution of temperature through out the hand and is at all points higher then 30ºC.

4. SENSOR AND HEATER PLACEMENT

The first prototypes will use a separate control board which will be interchangeable between the different designs using a simple pin connector method. The gloves have been designed with the data taken from the thermal tests as well as information gathered from Dr Faisel Khan; three designs have been short listed for further development and can be seen below

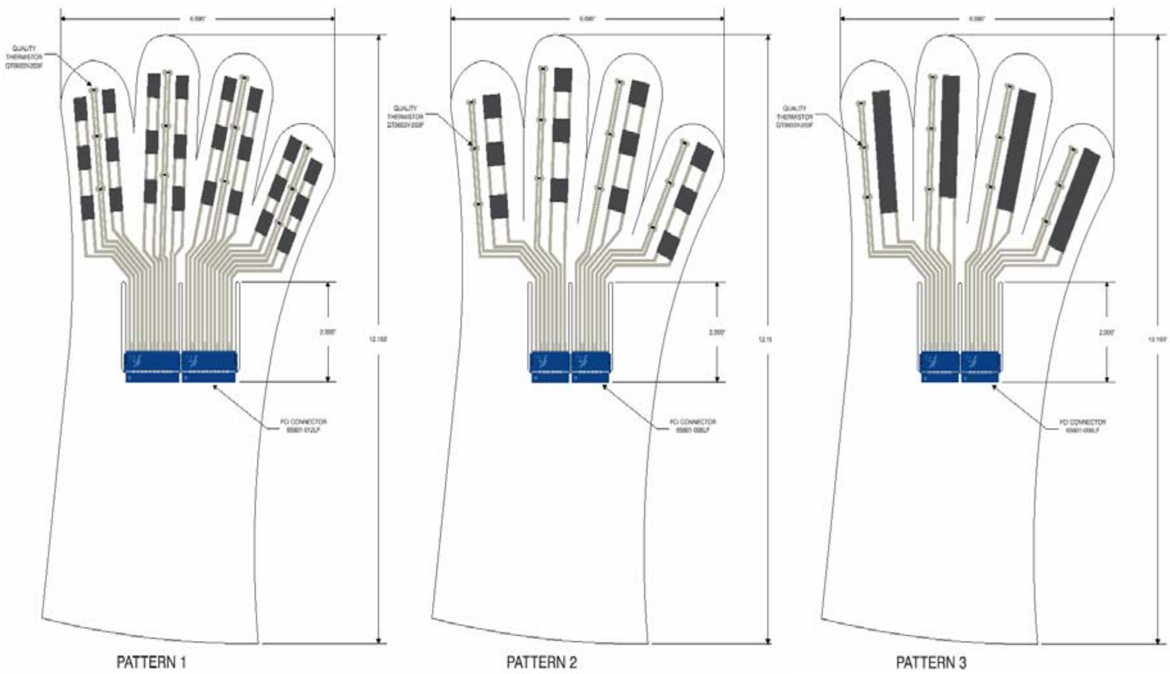


Figure 18. Final heater and sensor placement.

Pattern 1 has the temperature sensors along the middle of the digits with segmented heaters along the sides. Both the heater banks and temperature sensors are linked in parallel to enable uniform control for the heaters and multiple sensing for the temperature.

In pattern 2 the sensors have been moved to the edge of the digit, this is taking into account the temperature response time of the flow of blood. The heaters are again segmented for dexterity but as there is only one bank it will not have as quick a response time as Pattern 1.

Pattern 3 has a similar sensor set up as pattern 2 but instead of using segmented heaters, one solid heater will be used for ease of manufacture and also to reduce the heating time.

A series of test will be carried out with each of the designs, helping to refine the design even further until the optimum setup has been established.

5. CONCLUSION

The development of this glove is to ease the pain induced by Raynaud's syndrome but concentrating heat in the effected digits reducing over heating in turn increasing the users comfort and battery life. Using low power consuming heaters integrated into a precise temperature control circuit it has been able to reduce the battery size to a small 3.5v mobile phone battery, a vast improvement from existing power supplies. Another important development has been to introduce the idea of segmenting the heats and using surface mount sensors, improving dexterity and minimising skin irritation.

Further development into an innovative method to power the gloves has yet to be done; this will eliminate the need to charge the gloves from a mains supply. There are many different possibilities of supplying power to the gloves; each of these will be analyzed in order to find the most optimal supply method.

6. ACKNOWLEDGEMENTS

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