Functional 3D Human Model Design: A Pilot Study Based on Surface Anthropometry and Infrared Thermography

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ABSTRACT

With the rapid development of functional product design, the digital human body applied to design and manufacturing need be improved with more information of the human body. Functional and smart clothing has been a popular trend among consumers. The human model or mannequin may not fully satisfied the increasing demands of anatomical and physiologic messages from the human body in a visual and accurate way. As one of the most important functions of clothing, thermal comfort plays a vital role in many functional clothing design. In this pilot study, a thermal model was introduced to lay a foundation for functional thermal clothing development. A step by step method was commentated to draw a map for functional model development. This model was constructed by geometric human model from 3D scanning data and 2D thermograms from IR camera. The skin temperature data of subject was transferred to exact 3D human body, the temperature distribution and features can be clarified easily for design and manufacturing process. With the further requirements on application on computer aided design and manufacturing, the thermal model can be utilized in patternmaking, pattern revision, virtual fitting and grading for functional clothing. This pilot research is the launch of functional model design for industrial application. Limitation of the research will be solved in the future work.

Keywords: human modeling, surface anthropometry, thermography, thermal model, functional clothing.

1. INTRODUCTION

The information of the human body is crucial to many areas such as product design, medical science, engineering and manufacturing. 3D human models are increasingly adopted to enhance the efficiency and sustainability in these human centered disciples [18]. In recent years, a growing trend on functional and smart products has increased the popularity among the consumers. The traditional geometry human model based on linear and non-linear anthropometry (e.g. 3D body scanning), which conveys size, shape, surface and volume properties of human being [13], may not fully satisfy the requirements for further research and rapid development on functional design and manufacturing [4, 12]. There is a necessity toward launching functional human model design.

Body temperature is a vital feature of human beings, which indicates the healthy status of human being. As a heat transfer system, the human body requires well-balanced thermoregulatory control loop [21,22]. Clothing is the second skin of the human body which can fulfill the functions to balance the heat and moisture conditions and keep thermal comfort [5, 17].

With the technological innovations, sufficient data related to internal human body can be reached from lots of iconography techniques, including computed tomography (CT), X-ray, positron emission tomography (PET), ultrasound imaging, magnetic resonance imaging (MRI) and infrared thermography (IRT). IRT has been used as an effective and non-invasive medical diagnosis tool, which helps to understand the human body in an ocular way [11, 15]. The thermogram can map the surface temperature distribution of the human body in two-dimensions. 3D body scanners, as instruments to capture the whole body and create a set of dimensionally accurate data, are widely used in many areas, such as human modeling [25] and human-centered product development [2, 10, 19] in fashion industry. The combination of 3D body scanning data and thermal imaging may construct a customized, intuitive and quantitative model to get in-depth comprehension on the human body, particularly for the control of accuracy on functional product design and manufacturing. The digital format on data processed will provide potential applications for computer aided design on progress of functional product development, such as functional design, virtual fitting and interactive patternmaking.

In this paper, a pilot study on a novel thermal human model is introduced. The flow chart for the thermal model construction process is shown in Fig. 1.

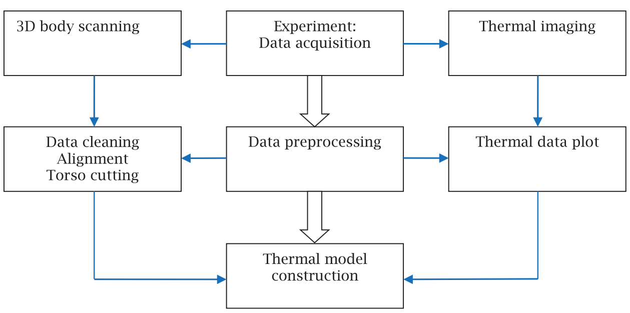

Fig. 1: The flow chart for thermal model construction process.

2. EXPERIMENT

In the experiment, the environment was under thermoneutral condition (temperature: 24 ± 0.5 °C, relative humidity: 60 ± 5%, air velocity: less than 0.1 m/s). A healthy male subject wearing only briefs was scanned by a 3D body scanner system in a naturally standing gesture. After scanning, in the same lab, an infrared camera was used to obtain thermal imaging from the front, back, right side and left side views of the torso of the subject (Tab. 1). The whole process was controlled and conducted in the same environment and completed within 15 minutes which potentially avoiding obvious surface temperature changes of the subject.

Descriptions	*Data*
Gender	Male
Age	26 years
Weight	62.4 kg
Height	169.2 cm
BMI	21.8
Core temperature (ear)	36.8 °C

Tab. 1: Basic information of the subject.

2.1. 3D Body Scanning

In this research, Human Solution 3D Body Scanning System was used to acquire true-to-scale 3D body model, which is mainly composed of scanning box, controlling computer and Scanworx software, see Fig. 2. The specializations of the scanning system are shown in Tab. 2. A set of cloud point data from the scanner includes large quantity of data points. The point cloud from the scanner is unstructured and includes hundreds of thousands of data points. The coordinates of the point p_i is (x_i, y_i, z_i).

Parameters	*Descriptions*
Scan area	2100 × 1000 × 1200 mm (height x width x length)
Scan time	approx. 10 seconds
Power	230 V/50 Hz, 115 V/60 Hz
Measurement principle	optical triangulation (laser technology, safe for the eyes)
Density of points	27 points/cm2
Tolerance	< 1 mm
Operation system	Window 7
Scan software	Scanworx
Export formats	ASCII, OBJ, STL, DXF

Tab. 2: The specializations of Human Solution 3D Body Scanning System.

2.2. Thermal Imaging

A commercial thermal imaging camera was used to capture the surface temperature of the subject. This IR camera is a non-contact device, which can detect infrared energy (heat) by IR sensors. The object above absolute zero (−273 °C) can radiate infrared radiation [1]. The higher temperature a source has, the more IR it sends out. The IR can be a measure to temperature [1]. The human body, as one of the IR emission source, can absorb IR simultaneously. When the environment temperature is lower than the skin temperature of the human body, the heat will be emitted out from the skin to the air [16]. The heat sensed by IR sensors can be converted to electronic signal and simulated to a thermal image by built-in processor [7, 14]. The working process of IR camera is demonstrated in Fig. 3. The output of a thermal camera is thermal image which can be transferred to a temperature list for further calculation and analysis. These kinds of thermal images can be used to monitor the temperature distribution and evaluate the heat performance of the object.

The specializations of IR camera used in the study are listed in Tab. 3. The experiment tools IR camera and the supporting adjustable tripod are shown in Fig. 4.

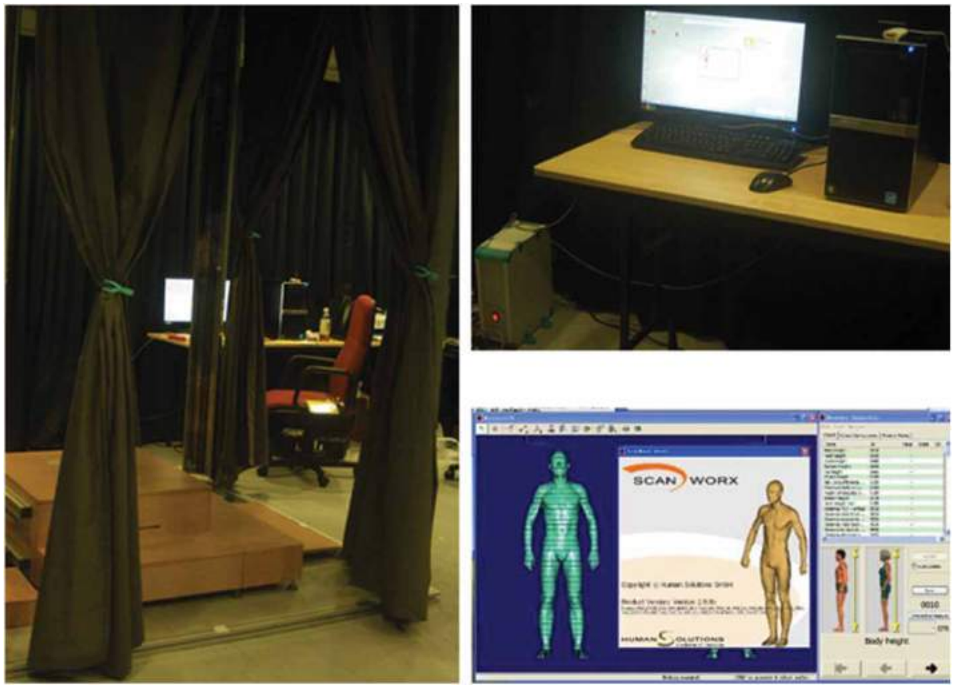

Fig. 2: Human Solution 3D Body Scanning System, right: scanning box, right upper: scanning control computer, right lower: Scanning software Scanworx interface.

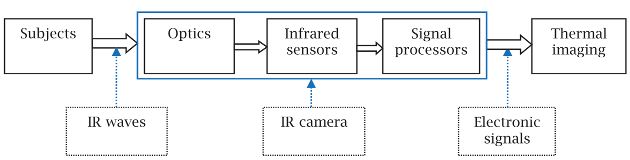

Fig. 3: The working process of IR camera.

3. DATA PROCESSING

The data gathered from 3D body scanner and IR camera were processed before modeling. For the cloud point data, alignment, data cleaning and component selection were done to prepare a compatible 3D model to match the 2D IR picture. The data plotting process helped to understand the format of IR data and visualize the temperature with images. The information conveyed by the thermal imaging is very important in the thermal model.

Parameters	*Descriptions*
IR resolution	160 × 120 pixels
Thermal sensitivity/NETD	< 0.07 °C @ +30 °C (+86°F) / 70 mK
Image frequency	60 Hz
Focus	Manual
Zoom	2 × and 4 × digital zoom, including panning
Display Touch screen	3.5 in. LCD, 320 × 240 pixels
Image modes	IR image, visual image, MSX, picture in picture, thumbnail gallery
Object temperature range	-20 °C to +120 °C (-4°F to +248°F) 0 °C to +650 °C (+32°F to +1202°F)
Accuracy	±2 °C (±3.6°F) or ±2% of reading, for ambient temperature 10 °C to 35 °C (+50°F to 95°F)

Tab. 3: The specializations of IR camera.

3.1. 3D Data Processing

3.1.1. Alignment

The alignment of the 3D data will recode the scanned part to the same reference axis, which will put them in a consistent axis. Anatomical and anthropometric landmarks can be used as a handle do alignment with mathematical and statistical methods, such as principle component methods [18]. In this research, the original alignment system, named VITUS coordinate system has been used to the entire 3D model, when scanning the body by the Human Solution system. The X-axis is vertical, Y-axis is frontal axis and Z-axis is transverse axis (see Fig. 5). When the human body was scanned in the fixed position and face front, all the scanned body was set in the same and consistent axis. The scanned data in this coordinate system was adopted for further processing.

Fig. 4: From left to right, (a) IR camera (b) adjustable tripod with IR camera.

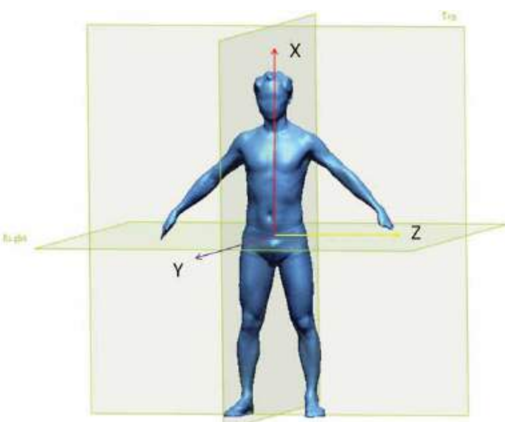

Fig. 5: Coordinate system.

3.1.2. 3D data cleaning

For data processing, 3D body scanner provided one set of cloud point raw data of whole body. Due to the general limitations on noises [6] arising from various sources, the 3D raw data was cleaned and smoothed by 3D software such as Rapidform (http://www.rapidform.com) and Meshlab (http://meshlab.sourceforge.net). The aligned and cleaned data represent the relatively exact body shape of the subject (see Fig. 6). The accuracy of the data is related to the technology of the scanning system. It is generally considered as a true-to-scale 3D body and keep the majority of shape characters of the human body.

3.1.3. Torso cutting

In this study, the thermal modeling was based on the torso of the subject according to the body position captured by IR camera. The torso of the subject was cut from 3D model of the whole body (see Fig. 7). A 3D torso model, called geometric model (G-model) was selected and cut for thermal mapping from 2D thermal imaging to 3D human body.

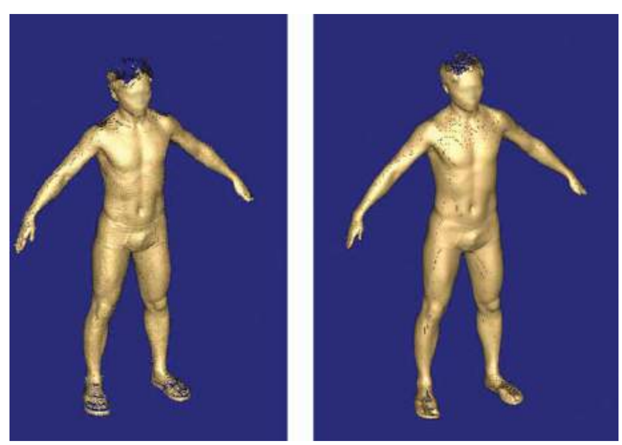

Fig. 6: From left to right, (a) before data cleaning, and (b) after data cleaning.

3.2. Thermal Imaging Processing

The resolution of a thermal camera is a significant parameters, which reveals the quantity of the pixels capturing radiations, or the numbers of sensors [20]. Each pixel presents a unit of sensor, like a thermometer. In other word, a thermal imaging taken in

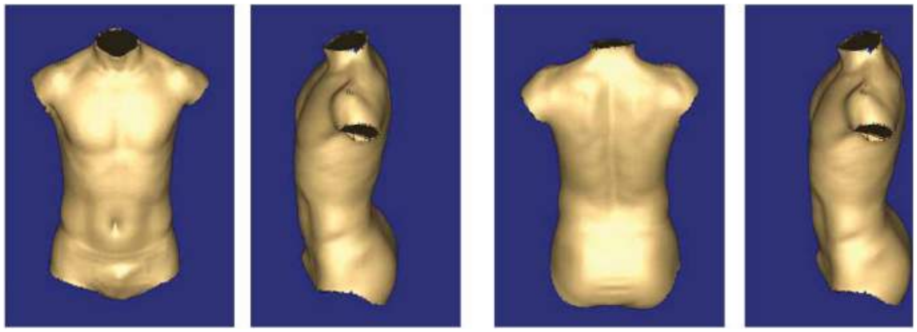

Fig. 7: From left to right, G-model (a) front side, (b) right side, (c) back side, and (d) left side.

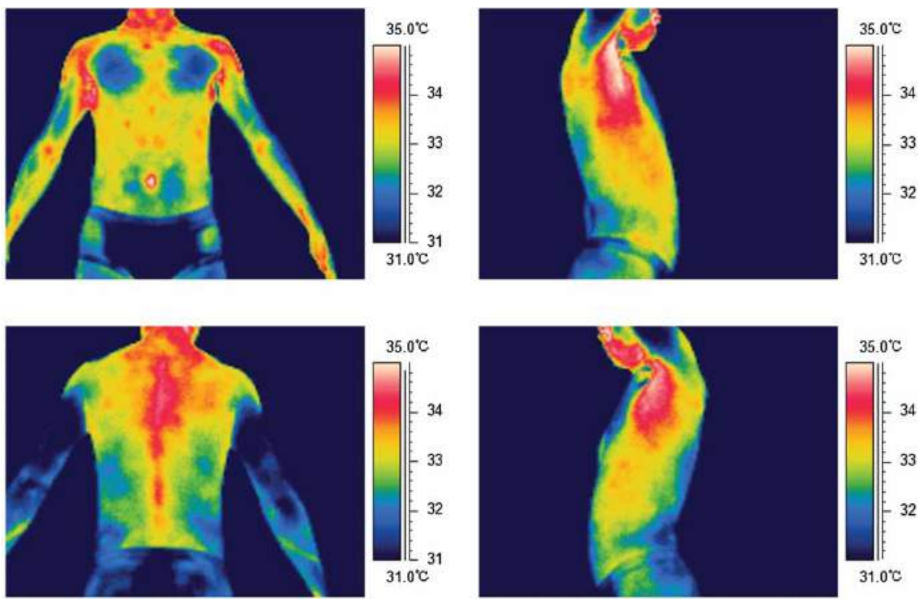

Fig. 8: From left to right, thermal imaging of torso: (a) front side, (b) right side, (c) back side , and (d) left side.

a resulotion of 160 × 120 pixels, can be considered a temperature map based on the data collected from 19,200 thermometers. The color shown in thermal image is not true color in photos taken by normal pictures, but false color which just presents the temperature range by data plotting with color palettes. The palette containing a range of color frequently adopted for thermal imaging with defined corresponding relationship between colors and temperature.

3.2.1. *Thermal data plot*

Matlab or the IR camera self-contained software can be used to do the data plotting based on the temperature data output by the IR camera. In Fig. 8, a set of thermal imaging in 4 sides of the subject are displayed in the color palette named rainbow. White and red pixels represent the higher temperatures close to 35 ℃ and the temperatures near or below 31 ℃ are shown in dark blue. The temperature features of the human body conveyed by this kind of pictures can be directly perceived through the senses.

Various color palettes can be used for the temperature data plotting, such as the examples in Fig. 9, which can be selected to show the image type of the thermogram according to characterization of temperature distribution and the target modeling requirements.

Besides, according to different display objective, the temperature range can be changed to demonstrate the thermal image of the subject in diverse way. In Fig. 10, the gradually changed temperature range can reveal the high temperature distribution by reducing the lowest temperature from 26 ℃, 28 ℃,30 ℃ to 32 ℃, with a fixed highest temperature. By means of thermal data plotting, the thermal image can be transformed to meaningful types which can indicate more information of the human body from the thermal aspects. Thermal data plotting lays a good foundation for the 3D thermal modeling.

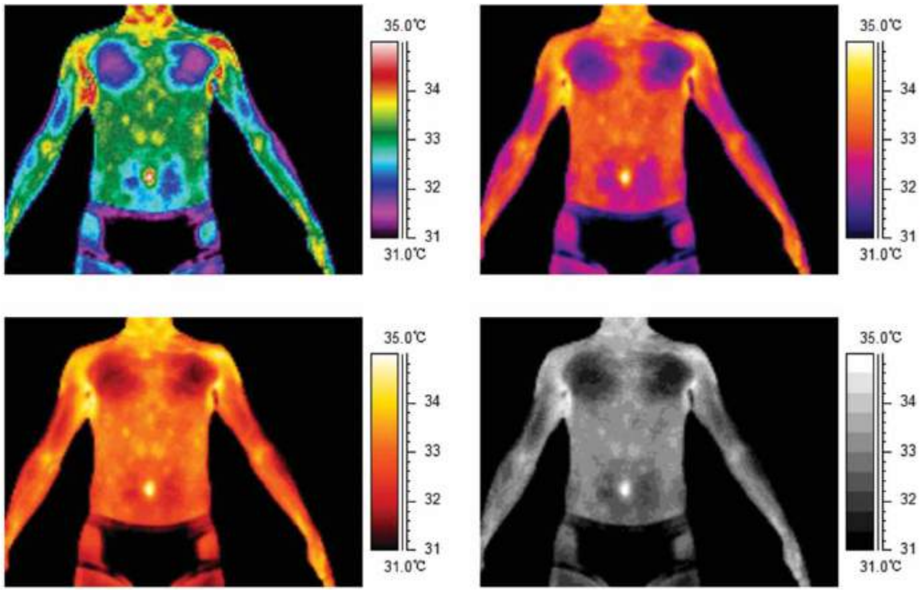

Fig. 9: From left to right, thermal imaging with various color palettes: (a) Rain, (b) Iron, (c) Glowbow, and (d) Gray.

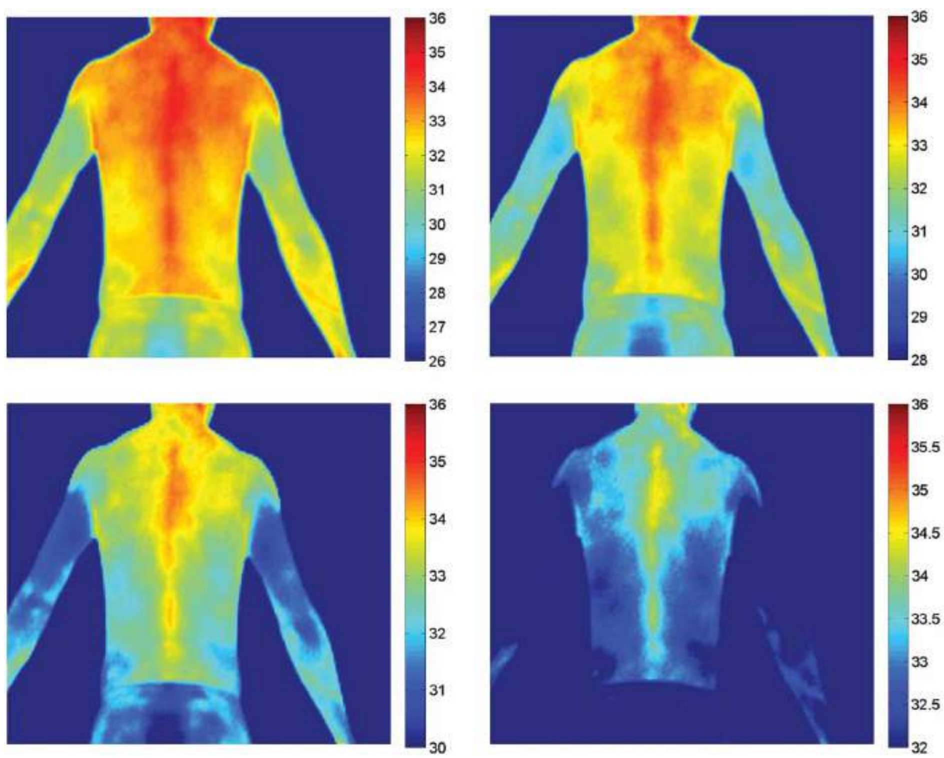

Fig. 10: Thermal imaging with different temperature ranges.

4. THERMAL MODELING

The thermal modeling process is to map the 2D IR image to 3D human model, which means the 2D picture is projected to the 3D object. These kinds of projection, as one of the most successful techniques in computer graphics, is commonly used in design and modeling areas [8,9]. As 2D texture mapping is a frequently used technique and a lot of commercial 3D design software provides these user-friendly functions, the projecting from 2D IR image to 3D model was conducted by Rapidform.

In this study, Rapidform version XOR3 was adapted to do the thermal mapping. The flowchart in Fig. 11 shows the commands and steps to realize thermal mapping by means of Rapidform software. As the landmarks and texture mapping are most important steps that are highlighted in 4.1 and 4.2 for details.

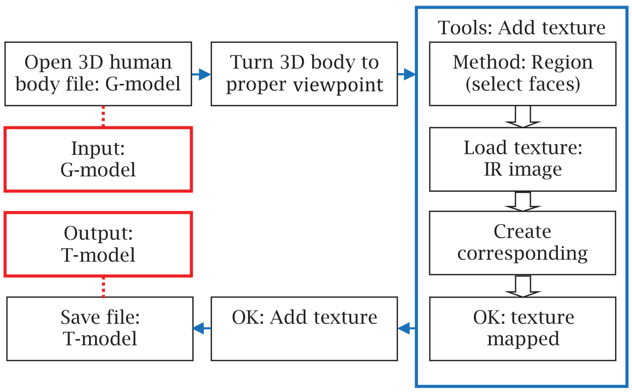

Fig. 11: Flowchart of thermal mapping by means of Rapidform version XOR3.

4.1. Landmarks

In order to set up the correspondence between 2D IR images and 3D geometry model, a series of landmarks were located (see Tab. 4 and Fig. 12). The selection of corresponding points complied with the distinguishing features of the human body.

Corresponding point No.	*Corresponding point (IR picture &3D-model)*
1	Right neck point
2	Left neck point
3	Right shoulder point
4	Left shoulder point
5	Right armhole point
6	Left armhole point
7	Right waistband point
8	Left waistband point
9	Belly hole

Tab. 4: The corresponding points of IR picture and 3D-model.

4.2. Texture Mapping

After the previous original data collecting and processing, the surface temperature conveyed by thermal imaging was mapped to 3D torso by using 3D software or programming on Matlab software, see Fig. 13 and Fig. 14. The T-model have been created, from which accurate size, surface and volume data can be read together with real body's skin temperature distribution. This T model enables visualization of the thermal features in a 3D way and quantifies the surface temperature distribution by point-to-point corresponding match.

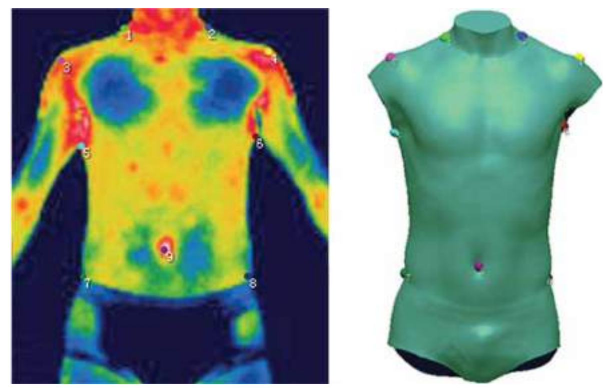

Fig. 12: From left to right, (a) IR picture with corresponding points, (b) 3D model with corresponding points.

5. DISCUSSION

Depending on the interpretation of IR data, numerous of IR images can be plotted to find out the individual differences of the human body, the positions, ranges and spreading directions. In fact, thermography has been a noninvasive medical tool to diagnose tools to diagnose disease for years [3, 23, 24]. In Fig. 15, a set of thermal imaging of torso with different temperature range were plotted to show the high temperature range of the back. When the IR images were mapped to the 3D torso, see Fig. 16, it would be easier to clarify the thermal status of the subject, which would be a visual and quantified tool for functional product design applied to different areas.

To compare with other subjects, further experiments was carried out on more subjects. In Fig. 17, the thermal images of another healthy male subject for comparison are shown, with the same viewpoint and temperature range setting as Fig. 15. The T-model of the comparison subject can be watched in Fig. 18. It is observed that, even though the thermal status of the normal human body must be unique, their skin temperature distribution still has some features in common. For the back viewpoint, the shoulder and spine have higher temperatures and differences between subjects can be used to compare the potential abnormal parts of the human body. If a T-model database is set up, the practical and statistic meaning will be more significant for many human-centered areas, such as medicine, design and ergonomics.

Fig. 13: From left to right, T-model (a) front side, (b) right side, (c) back side, and (d) left side.

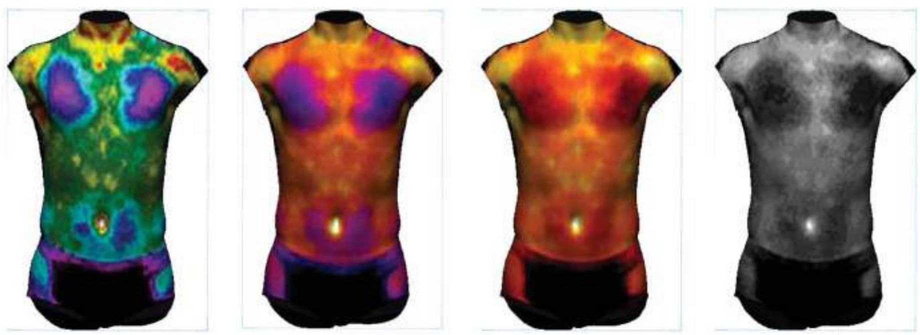

Fig. 14: From left to right, T-model with various color palettes: (a) Rain, (b) Iron, (c) Glowbow, and (d) Gray.

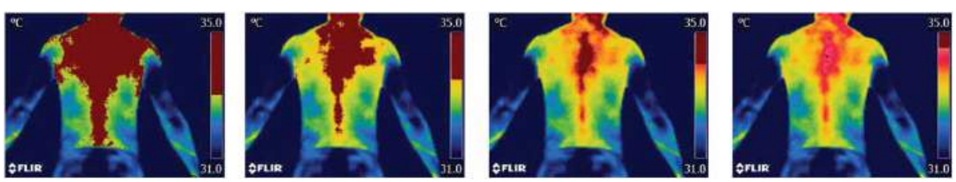

Fig. 15: From left to right, thermal imaging of torso with different temperature ranges.

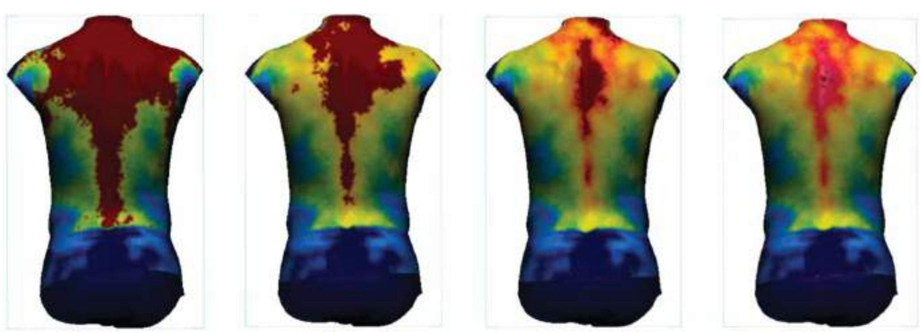

Fig. 16: From left to right, T-model with different temperature ranges.

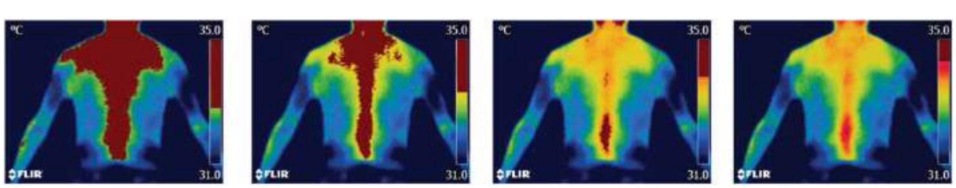

Fig. 17: From left to right, thermal imaging of torso with different temperature ranges (comparison subject).

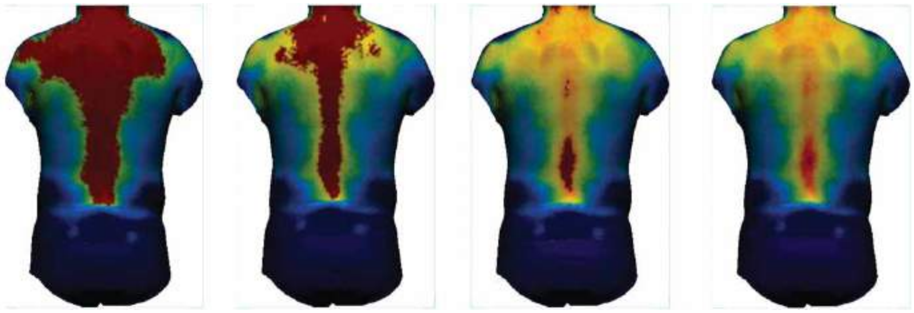

Fig. 18: From left to right, T-model with different temperature ranges (comparison subject).

6. CONCLUSION

Geometry human model presents the basic dimensional information of the human body. This pilot study initiates a novel thinking and innovative approach on functional human model design. The T-model innovatively endows the simple cloud point with thermal meaning by color spectrum, which is easily read and quantified. This new model can be used for functional product development, or even medical areas. Especially for functional clothing developers, they will be able to do 3D functional design, pattern making and virtual fitting in a relatively accurate and efficient way. As every human body has its own thermal distribution character, an individual based customized design on T-model is recommended. The setting of T-model database in the near future will be helpful for medical diagnoses and related functional product design. Due to the limitations in this pilot study on techniques, more details should be considered to improve this model in further research work.

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