Gu, Y, Li, Y and Shaw, A

Development and performance of flexible temperature-sensing fabric

http://researchonline.ljmu.ac.uk/id/eprint/16380/

Article

Citation (please note it is advisable to refer to the publisher's version if you intend to cite from this work)

Gu, Y, Li, Y and Shaw, A (2021) Development and performance of flexible temperature-sensing fabric. Journal of the Textile Institute. ISSN 0040-5000

Development and Performance of Flexible Temperature-Sensing Fabric

Yiming Gu[a], Yanmei Li[a] and Andy Shaw[b]

[a]School of Textiles and Fashion, Shanghai University of Engineering Science, PR China; [b]Faculty of Engineering and Technology, Liverpool John Moores University, Liverpool, England

ABSTRACT
In this study, a textile-based flexible temperature-sensing fabric is designed. Organization of the fabric is stitching double weaves arrangement, and a continuous temperature-sensitive Pt fibre is embedded into the woven fabric through the common weaving technology. The design of the double-layer woven structure forms a relatively stable protection for the temperature-sensitive fibres, which greatly improves the durability of the fabric. Through experimental tests that simulate practical applications at 20-50 ℃, the fabric exhibits good temperature sensing performance, its temperature coefficient of resistance is higher than 0.00213 ℃$^{-1}$, the resistance-temperature relationship fitting linear coefficient is greater than 98%, and it has a hysteresis of only 3.65%. When the fabric is subjected to the external force of pressure and tension, the temperature-sensing area presents a relatively stable resistance, and when it is affected by bending, the electrical signal of the fabric presents an obvious negative correlation with the bending angle. Under different ambient temperatures, the resistance of the fabric remains stable, which is convenient for design in various parts of clothing and realises daily monitoring of human body temperature.

KEYWORDS
Flexible sensor, temperature sensor; woven fabric; stitching double weaves; temperature-sensitive wire

1. Introduction

With the continuous development of today's information society, the field of wearable technology has developed vigorously in recent years, and its applications have already penetrated many aspects of life. Wearable devices often integrate sensors or electrodes that can collect into objects that are in close contact with the human body to collect important psychological parameters of the human body, such as electronic bracelets, Google glasses, and other commercially available products; however, the hardware sensing device will have a greater sense of rejection if theyit areis in direct contact with the human body for a long time. Textiles, which are in close contact with the human body during long periods, are excellent carriers of sensing technology [1]. A flexible sensing fabric can achieve all-weather monitoring of vital signs and help manage the information collected, thus facilitating diagnosis and early warning of health issues.

The body temperature is an important vital sign for the medical assessment of health status, and daily monitoring of changes in human body temperature is particularly important for health assessment. In recent years, domestic and foreign scholars have successively carried out research on flexible sensor elements for body temperature monitoring. Among them, the use of chemical agents to modify fibres or the use of coatings to finish textiles to achieve the purpose of flexible temperature sensing is the main idea of further research. However, a temperature-sensitive fabric prepared by chemical modification or coating is not suitable for pathological skin use, and its application range is significantly reduced. Moreover, the electrical properties of such flexible sensing elements, such as temperature coefficient of resistance and hysteresis, are generally less than ideal compared to the properties of thermal resistance temperature-sensing elements. Therefore, in recent years, research on resistive temperature-sensing elements has gradually attracted attention. Dankoco et al. used a compound with silver as the main component of a conductive ink and obtained a silver-plated layer deposited on a polyimide film by inkjet printing, which was used to measure the body surface temperature of the human body. The temperature coefficient of resistance obtained in the range of 20~60 °C is 0.00219 °C^{-1}, and the linearity can reach 99.98% [2]. Using a similar method, Xu Xiaowen designed silver resistance flexible temperature sensors with snake-shaped graphic structures. The temperature coefficient of resistance can reach up to 0.0021 °C^{-1}, and the linearity can reach 99.8% [3]. However, silver is easily oxidized in the air; thus, so He [4] and others developed a temperature sensor with a platinum film temperature sensor element with a serpentine structure. The obtained temperature coefficient of resistance at the best linearity is 0.00235 °C^{-1}; Chu Yongzhi [5] and others used photolithography and bending methods to fabricate a flexible temperature sensor with nano-cracks on a polydimethylsiloxane (PDMS) substrate. The sensor has a temperature coefficient of resistance of up to 0.0014 °C^{-1}. Other researchers [6] carbon nanotubes(CNTs)/polydimethylsiloxane(PDMS) composites to exhibit negative resistance temperature characteristics, which are obtained by adding a small amount of CNTs to form a conductive path, and the temperature coefficient of resistance value is the best at -0.0021 °C^{-1}. At the same time, because the film-like platinum and alumina substrates are closely attached, stress inevitably occurs during thermal expansion and contraction. Therefore, the thermal hysteresis of the film-type platinum resistance thermometer at 0 °C is much greater than that of a platinum wire-type platinum resistance thermometer [7].

This paper presents an innovative method for designing thermal resistance temperature-sensing fabrics, in which a platinum wire with high resistivity and low specific heat is used as the metal wire for temperature sensing, and it is embedded in a double-layer fabric stitched using a loom. A temperature-sensitive metal wire is used as the stitching yarn to sense the temperature while preventing the fabric from being easily deformed. The stitching double weaves arrangement can protect the metal wire to a certain extent. In this study, a flexible temperature-sensitive fabric was manufactured based on this design and its laboratory performance was preliminarily characterised. The achieved temperature coefficient of resistance of the sample is higher than 0.00213 °C^{-1}, thus reaching the current research level. It can be used to monitor the human body temperature continuously in daily environments.

2. Design of Flexible Temperature-Sensing Fabric

A continuous metal wire is integrated into a woven fabric composed of non-conductive yarns produced with the conventional weaving technology to develop a thermal resistance temperature-sensing fabric. Given that the matrix material [8] has no significant influence on the sensing performance, the temperature conduction depends on the temperature-sensitive metal itself, and the response time also depends on this metal fibre. A common polyester cotton yarn is selected as the basic material to make the fabric soft, comfortable, and breathable.

2.1. *Choice of temperature-sensitive wire*

Research has shown that, compared with a conductor of thermocouple nature, a temperature-sensitive metal whose resistance increases with increasing temperature [9] offers a simpler manufacturing process, simpler measurement circuits, and better accuracy and stability. Therefore, it is the most suitable material for the development of temperature-sensing fabrics.

When selecting the temperature-sensing wire, platinum and copper wires are the most commonly employed. Although it has a lower cost, copper has a resistivity of only 1.7 * 10^{-8} Ω · m, compared to the high resistivity of platinum, 10.6 * 10^{-8} Ω · m. Thus, to achieve similar initial resistance, a significant length of copper wire is required. The length of copper wire is not conducive to weaving, and the temperature coefficient of resistance of copper is slightly lower than that of platinum. Therefore, this study uses platinum wire metal fibre with a purity of up to 99.9% and a resistance ratio of 1.391, and two platinum wire flexible temperature-sensing fabrics with fineness of 0.02 and 0.03 mm, respectively, are designed.

2.2. *Choice of fabric weave*

Some researchers have proved that sensing can be achieved by embedding metal wires into textile structures. For example, metal wires [10] are woven in a serpentine manner using knitting, embroidery, or simple weaving techniques. The twill weave of one up and three down prevents the metal wires from contacting each other and stably exists in the woven fabric; however, the simple twill weave structure exposes the temperature-sensitive metal wire directly to the external environment. The metal wire is soft and easily damaged, and the durability of the sensing fabric is then significantly reduced. Moreover, the surface shapes of the front and back of the fabric are different, and the performance is unstable during application; therefore, in this study, a double weave structure was stitched, and a platinum wire was embedded in the continuous two-layer fabric that the binder yarns formed. A double-weave structure protects the temperature-sensing element, while the characteristics of the woven fabric can ensure the stability of the flexible sensor.

The double weave stitch was woven with the temperature-sensitive wire as the stitching weft. The surface weave adopted a one up and three bottom right twill weave, and the inner weave adopted a three up and one right twill weave, the arrangement ratio of the front and back warp and weft yarns was 1:1, and the weft: stitching yarn was 2:1. A looming draft is shown in Figure 1.

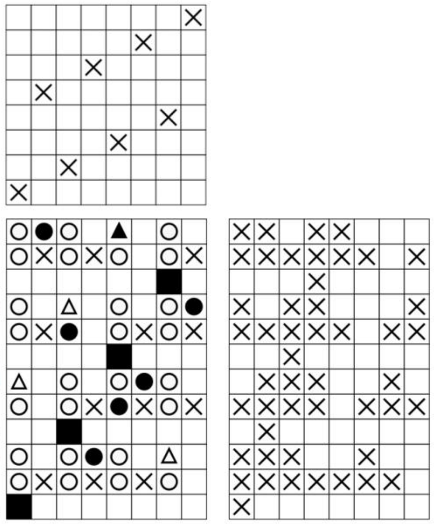

Figure 1. Looming draft

This double-weave structure of the junction makes the platinum wire stably embedded in the fabric, and the structure is not easy to deform. The junction point is the weft weave point, that is, the junction weft is located above the surface warp or below the inner warp. A weft cross-sectional view of the fabric is shown in Figure 2.

Figure 2. Fabric weft sectional view

In the figure, the purple line represents the surface tissue, the yellow line represents the inner tissue, and the green line represents the temperature-sensitive wire used as the stitching weft. The solid line is the stitching weft of row a, and the dashed line is the stitching weft of row b. The metal wire is interwoven between the upper and lower layers to stabilise the fabric structure, and it is covered and protected by a double-weave structure, which improves the durability of the metal wire. Moreover, the metal wires do not touch each other, which ensures the conductive properties of the fabric.

Figure 2 shows that a small number of platinum wire formation points are exposed on the front and back of the fabric, but because the fineness of the metal wire is much smaller than that of the other yarns, these organisational points are hidden between two adjacent weft floating long lines. In the woven fabric, these points are covered by adjacent weft floats; thus, they will not be exposed on the front and back sides of the fabric and will not be worn or oxidised in actual use.

2.3. *Fabric weaving process*

The flexible temperature-sensing fabric is woven using a semi-automatic loom model SGA598. The weaving process used in the temperature-sensing area is presented in Table 1.

Table 1. Weaving process of temperature-sensitive area

	Surface warp	Inner warp	Side yarn	Temperature-sensitive wire
Raw material	Polyester cotton yarn	Polyester cotton yarn	None	Platinum wire
Degree of fineness	$20^S/2$	$20^S/2$	None	0.02 mm, 0.03 mm
Quantity	32 pieces	32 pieces	0 pieces	8 weft

Because the body temperature rises and falls at a low speed and requires high measurement accuracy, the initial resistance of the design is approximately 100 Ω. Therefore, the 8-latitude metal wire is continuously embedded during weaving, and this area is used as the temperature-sensing area, and 5 cm at both ends is reserved for experiments. As the base material, the non-sensing area uses the same polyester cotton yarn as the stitching yarn.

3. Performance Characterisation of Flexible Temperature-Sensing Fabric

In this study, a self-built test system that can simulate the actual application is used to characterise the performance of the flexible temperature-sensing fabric, which is mainly divided into two parts: temperature control and data acquisition. In practical applications, the fabric and the human body are often in contact on one side. Thus, under the conditions of laboratory temperature of 25±2 °C and humidity of 65±2 %, a Jinyan 260 mm * 260 mm stainless steel heating platform with digital display of temperature control was used to simulate skin heating. The selected model was the MPLK-701. The device feeds back and displays the panel surface temperature in real time while adjusting the temperature.

The temperature sensor mainly characterises the measured temperature by converting it into an electrical signal. Based on the inherent characteristics of the metal, the resistance responds with the change in temperature; therefore, this study connects a PC for data collection through a UNI-T UT61E high-precision four-and-a-half-digit digital multimeter. The overall test system is illustrated in Figure 3.

Figure 3. Test system that can simulate actual application

3.1. Static performance test of flexible sensing fabric

The main static performance indicators of the sensor include static sensitivity, resolution, linearity, hysteresis, and repeatability. The output change caused by the measured unit change is called static sensitivity, and the temperature coefficient of resistance is commonly used in thermal resistance temperature sensors to characterise its static sensitivity [11]. Body temperature monitoring often requires sensors with high accuracy and stability. The platinum resistance has better linearity than thermocouples and thermistors, and it has stable chemical properties and strong oxidation resistance, which can provide long-term stable temperature monitoring. Therefore, the performance indicators that are mainly considered in the test in this study are the temperature coefficient of resistance, linearity, and hysteresis.

3.1.1. Temperature coefficient of resistance of flexible sensing fabric

The fabric sample is placed on the heating plate maintaining a clamping distance of 3 cm at both ends, and it is connected with the multimeter, making full contact with the surface of the heating table. The temperature is gradually increased in the range of 20~50 °C with unit increments of 1 °C. Each data collection is guaranteed to be carried out when the temperature of the heating table is relatively stable.

The temperature coefficient of resistance [12] reflects the degree of sensitivity of the sensing fabric to temperature and is the most important indicator for measuring the temperature-sensing performance. It is usually expressed by the relative change in resistance when the temperature changes by 1 °C.

$$\alpha = \frac{R_T - R_{T_0}}{R_{T_0}\left(T - T_0\right)} \tag{1}$$

where:

α Temperature Coefficient of Resistance

R_T Resistance value of metal wire at T

R_{T_0} Resistance value of metal wire at an initial temperature of T_0

During the test, the accuracy of the increase and decrease in temperature was controlled at 0.1 °C. Because the variation range of the human body temperature is generally between 30 and 40 °C, the temperature coefficient of resistance in this range is mainly studied. Figure 4 shows the relative resistance change of the flexible sensing fabric when the temperature changes.

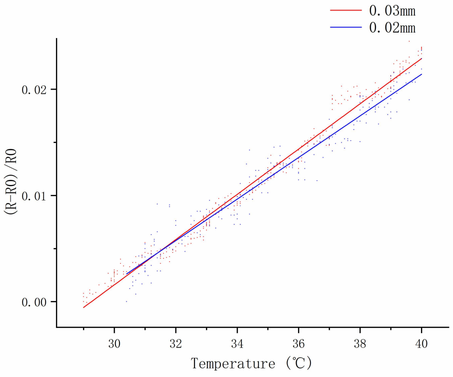

Figure 4. Relative resistance change

Under the conditions of the laboratory heating table, the temperature coefficient of the flexible sensing fabric is lower than that of the bare platinum wire, but it is still better than that offered by most forms of coating, embedding, and the new developed materials [8]. The station of the heating experiment simulated the body surface in contact with one surface and the other surface in contact with air, while it cooled the fibre via heat transfer by conduction in contact with the heat source side. The relative change of resistance decreases, which leads to the decrease of the temperature coefficient of the fabric obtained by experiment compared with the actual situation. The fabric sample using 0.03 mm fineness platinum wire as the temperature-sensing element has a higher temperature coefficient of resistance, and the sensitivity [7] is directly related to this coefficient. To create a high-precision, high-resolution temperature-sensing fabric, 0.03 mm fineness platinum wire was used as the fabric sample of the temperature-sensing element.

3.1.2. Linearity of flexible sensing fabric

Linearity refers to the correlation coefficient of the resistance temperature relationship of the temperature-sensitive fabric during linear fitting. For various reasons, the sensor input/output relationship is sometimes not a straight line, so this characteristic represents the degree to which the calibration characteristic curve of the actual resistance temperature does not match the reference straight line; this part of the experiment content is consistent with the experimental content of the temperature coefficient of resistance; the measured experimental resistance value is linearly fitted, and R^2 is used to characterise the difference between the experimental value and the polynomial; the closer R^2 is to 1, the higher the linearity of the resistance-temperature relationship of the flexible sensing fabric. The results are presented in Table 2.

Table 2. Temperature coefficient of fabric samples of various specifications

Platinum wire/mm	Temperature Coefficient of Resistance (1/℃)	R^2
0. 02	0. 00196	0. 95
0. 03	0. 00213	0. 98

Figures 5 and 6 show the resistance temperature relationship of the flexible sensing fabric when the platinum wire is 0.02 mm and 0.03 mm, respectively.

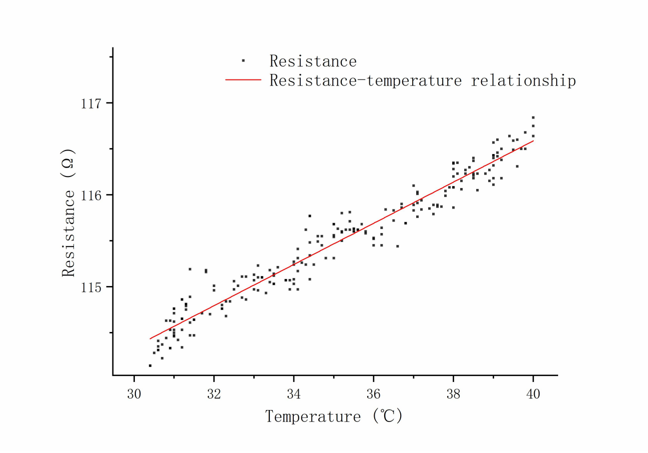

Figure 5. Resistance temperature relationship of the sample using 0.02 mm platinum wire

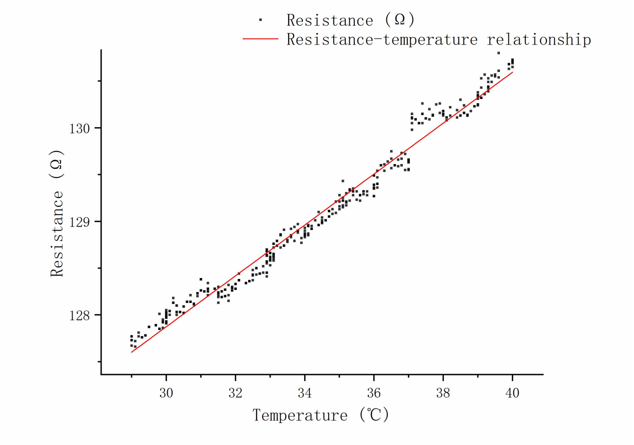

Figure 6. Resistance temperature relationship of the sample using 0.03 mm platinum wire

Table 2 and Figures 5 and 6 show that using a platinum wire with a fineness of 0.02 mm as the fabric sample of the temperature-sensing element, the test value fits well with the regression fitting curve value, and R^2 can reach above 0.95. However, the fabric sample using 0.03 mm fineness platinum wire as the temperature-sensing element shows a better effect, R^2 is greater than 0.98. The reason may be that the 0.02 mm platinum wire is more susceptible to the influence of the external environment and the weaving process, but the overall situation shows that the resistance temperature relationship of the temperature-sensing fabric remains stable under the simulated actual application.

3.1.3. Hysteresis of flexible sensing fabric

Owing to the influence of many external factors during the sensing process, the outputs of the positive and negative strokes corresponding to the same input of the sensor are inconsistent. Hysteresis is an indicator that reflects the degree of misalignment during a change in the positive and negative processes of the input. The maximum hysteresis error is the maximum difference in the corresponding resistance at the same temperature in a cycle, and it is the ratio of the maximum resistance difference in the full scale to the output full scale. The calculation formula and characteristic curve are as follows:

$$\delta_H = \frac{(\Delta y_H)_{\max}}{y_{FS}} \times 100\% \qquad (2)$$

where:

δ_H —Hysteresis index

$(\Delta y_H)_{\max} = \max(\Delta y_{i,H})(i = 1,2,\cdots,n)$

$y_{FS} = \bar{y}_n - \bar{y}_1$

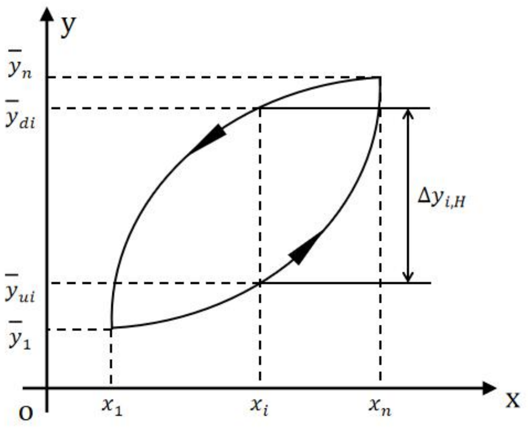

Figure 7. Hysteresis characteristic curve

On the basis of the above test, four cycles of heating and cooling were completed for fabric samples of 0.03 mm. First, a temperature increase test of 30~40 °C was conducted on the sample; then, a temperature drop test of 40~30 °C was performed after the heating stage was stabilised, and a hysteresis curve was obtained within one cycle. Figure 8 shows the cycle with the largest resistance gap among the multiple cycles.

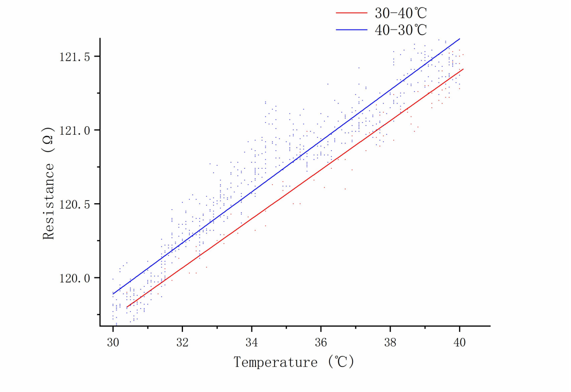

Figure 8. Temperature-sensing fabric; changes in resistance temperature relationship in a heating-cooling cycle

Through the calculation, it can be concluded that the maximum hysteresis of the temperature-sensing fabric under laboratory conditions is 3.65%. Owing to environmental influences, the cooling effect of the heating table is relatively good, and thus the sensing fabric shows good non-hysteresis [13].

3.2. Dynamic performance test of flexible fabric

In practical application, the fabric will be deformed to some extent when it is stressed. In order to explore the influence of deformation on the sensing performance of temperature-sensing fabric under small stress, the resistance changes were tested under the external forces such as pressure, tension and bending.

3.2.1. Performance test under pressure

By selecting weights with different weights to apply pressure, the resistance of the temperature-sensing fabric was tested with different pressures. To equalize the pressure, a piece of tissue paper with the same size (3.0 cm * 2.5 cm) was placed on the fabric, and then different weights were placed to adjust the applied pressure, as shown in Figure 9.

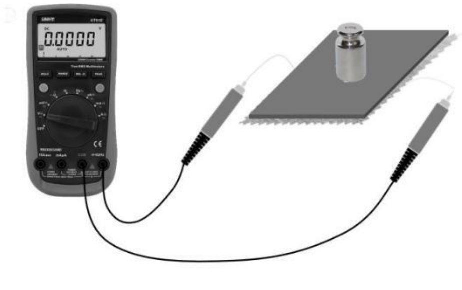

Figure 9. Schematic diagram of pressure test

The range of comfortable clothing pressure for human body when wearing comfortably is 0.49~2.60 kPa[14], and the final pressure set is shown in Table 3.

Table 3. Pressure parameter

No.	Weight(g)	Pressure(Pa)
①	0	0
②	0	6.79
③	10	137.46
④	20	268.13
⑤	30	398.79
⑥	40	529.46
⑦	50	660.13
⑧	60	790.79
⑨	100	1313.46
⑩	200	2620.13

Calculate the difference between the resistance value measured when different pressures are applied and the resistance value measured when no pressure is applied. The calculation results are shown in Table 4. It can be seen from the data in the table that the maximum value of resistance under different pressures is 2.1401 Ω, the minimum value is 0.0940 Ω, and the resistance change rate (resistance change/resistance value under no pressure) is between -5.040 % and -0.037 %, which indicates that the pressure has no obvious influence on the temperature response of the fabric.

Table 4. Resistance change of temperature-sensing fabric under different pressures

No.	Pressure(Pa)	Resistance change(Ω)	Resistance change rate(%)
①	0	0	0
②	6.79	−0.1802	−0.424
③	137.46	−0.1633	−0.385
④	268.13	−0.9807	−2.309
⑤	398.79	−1.6591	−3.907
⑥	529.46	−2.1401	−5.040
⑦	660.13	0.0156	0.037
⑧	790.79	0.0940	0.221
⑨	1313.46	−0.7815	−1.840
⑩	2620.13	−0.4865	−1.146

3.2.2. Performance test under tensile action

The tensile test provided a pre-stretch force of about 0.109 N when using the clamp for stretching. After 10 g as a unit, it is gradually increased, and a weight of 0~100 g is used for stretching. The experimental schematic diagram is shown in Figure 10.

Figure 10. Schematic diagram of tensile test

The breaking strength of 0.03 mm platinum wire is about 27.4 cN, which is equivalent to 27.959 g weight. In the test, the maximum weight of 100 g was used to stretch the fabric, and the platinum wire was not damaged, which indicated that the fabric structure greatly improved its durability and played a good role in protecting the temperature sensitive wire. Figure 11 shows the change of resistance in the temperature-sensing area under different stretching conditions. It can be seen from the figure that with the increase of stretching force, the resistance of the fabric shows a slow upward trend, and the maximum resistance change is about 2.3962 Ω, which indicates that the resistance output of the temperature-sensing fabric is relatively stable when stretched.

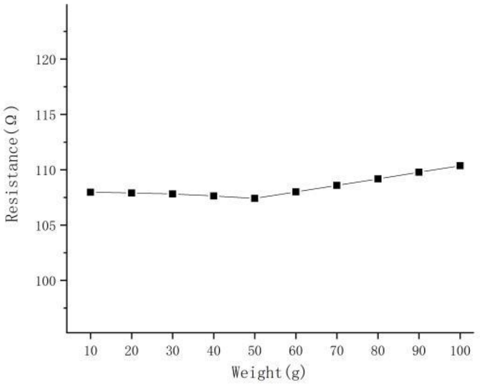

Figure 11. Resistance change under different tension

3.2.3. *Performance test under bending*

In the bending experiment, a 9.0 cm * 2.5 cm long fabric was selected, and the temperature-sensing area was located in the center of the fabric. Bend the fabric from both ends in such a way that the ends of both ends are simultaneously retracted by 0.5 cm each time, and the angle is from 0 to 90 degrees until both ends touch. The experimental schematic diagram is shown in figure 12, where *a* is the vertical distance from the end point to the lowest point of the fabric in bending state; *b* is the horizontal distance from the end point of the fabric to the lowest point in the bending state; *α* is the bending angle, and the experimental parameters are shown in Table 5.

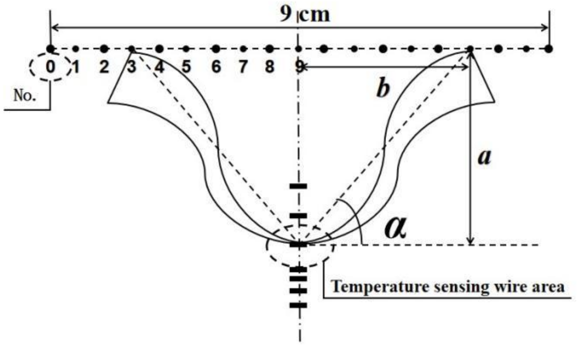

Figure 12. Schematic diagram of bending test

Table 5. Resistance change of temperature-sensing fabric under different pressures

No.	a(cm)	b(cm)	tan α	α(°)
0	0	4.50	0	0
1	2.40	4.00	0.6000	30.9638
2	3.00	3.50	0.8571	40.5999
3	3.50	3.00	1.1667	49.3995
4	3.90	2.50	1.5600	57.3391
5	4.10	2.00	2.0500	63.9967
6	4.30	1.50	2.8667	70.7695
7	4.42	1.00	4.4200	77.2518
8	4.47	0.50	8.9400	83.6176
9	4.50	0	None	90

The experimental results are shown in figure 13. With the increase of bending angle, the output resistance of the temperature-sensing fabric shows a slow decline trend, but the resistance changes little from point 5 to point 9 where both ends are completely attached, which indicates that when the bending degree is greater than a certain level (about 65 °), the resistance will gradually stabilize and will not decrease significantly. Therefore, it is suggested that the sensing parts should be avoided in the elbow, armpit and other parts that need to be bent frequently. The sensing area of the temperature-sensing fabric is very small, and the shape of the area can be adjusted according to the actual application, so it can be designed in the chest or back of clothing, and only needs to ensure the relative flatness of the sensing area, so it has good application value.

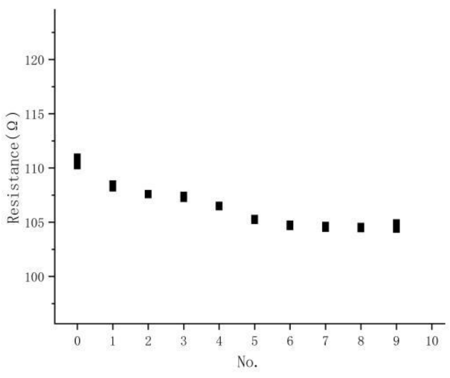

Figure 13. Resistance change under different bending

3.3. *Performance test under the impact of external ambient temperature*

In order to eliminate the impact of other factors on the experiment, all the above tests are tested under laboratory conditions. However, in practical application, the external environment of the applied fabric is varied, so this paper adds a test of the change of the electrical properties of the flexible temperature-sensing fabric when the ambient temperature changes from 5°C to 35°C under non-contact temperature.

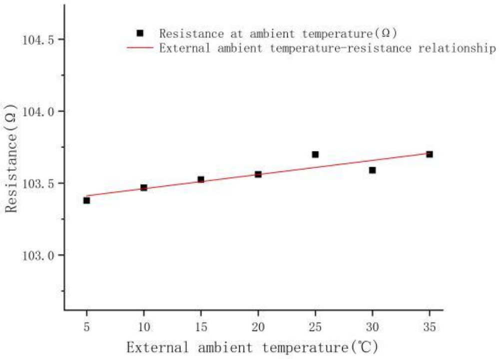

Figure 14. Resistance change at different external ambient temperatures

The test results are shown in Figure 14. The resistance of the flexible temperature-sensing fabric does not change obviously due to the increase of external ambient temperature, and the maximum resistance difference is only 0.32 Ω. The overall resistance has a very slow upward trend with the increase of temperature, which proves that the ambient temperature will not have a great influence on the electrical properties of the fabric.

4. Conclusions

In this study, a flexible temperature-sensing woven fabric with continuous embedding of platinum wires in a double-weave stitch structure was designed, and the temperature-sensing performance of the fabric was verified by simulating practical experiments. The experimental results show that ideal temperature-sensing effects can be achieved using platinum wires with two finenesses, 0.02 and 0.03 mm, as temperature-sensing wires. Among them, the temperature-sensing fabric with 0.03 mm platinum wire is easier to weave. The sensing performance was better, When the temperature is within 20-50 degrees, the minimum temperature coefficient of resistance was as high as 0.00213 $℃^{-1}$, the linearity of the temperature coefficient of resistance was greater than 98%, and the maximum hysteresis was only 3.65%. By applying different pressures and tensile forces, the fabric as a whole shows relatively stable electrical properties. In the bending experiment, the resistance of the fabric decreases with the increase of the bending angle, but it gradually stabilizes after reaching over 65 °. Therefore, it is suggested that the sensing area of the fabric should not be applied to the position where large bending will occur.

Compared with the existing research results, the flexible-sensing fabric developed in this paper has better temperature sensing performance, soft texture, stable sensing area, and is almost unaffected by the environmental temperature. It is convenient to design and monitor the body temperature in various parts of clothing, and is suitable for body temperature monitoring under non-clinical conditions and can provide timely and good physiological feedback for monitoring personnel to avoid further emergencies.

References

[1]Bao,S.Z., & Zhang,Y.P.(2004). Telemedicine:Wearable Biomedical Devices.*China Medical Device Information*,*10*(05),1-3. https://doi.org/10.3969/j.issn.1006-6586.2004.05.001

[2]M.D. Dankoco, Tesfay, G. Y. , Benevent, E. , & Bendahan, M. . (2016). Temperature sensor realized by inkjet printing process on flexible substrate. *Materials Science & Engineering B, 205*(Mar.), 1-5. https://doi.org/10.1016/j.mseb.2015.11.003

[3]Xu,X.W. (2016). *Flexible Multi-sensors/Arrays with the Embedded Heaters on Polyimide*.East China Normal University.https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CMFD201602&filename=1016126839.nh

[4]He,L.F., Dou,W.K., & Liu,J.S. (2018). Fabrication and Performance Test of Polyimide Flexible Temperature Sensors. *Mechanical & Electrical Engineering Technology,047*(011),5-8,80. https://doi.org/10.3969/j.issn.1009-9492.2018.11.002

[5]Chu,Y.Z., Guo,H.J., Yin,P.H., & Liu,J.S. (2018). Ultra-high Sensitivity Flexible Temperature Sensor Based on Nanoscale Cracks. *Mechanical & Electrical Engineering Technology, 47*(11), 47-49+73.https://doi.org/10.3969/j.issn.1009-9492.2018.11.011

[6]Wu,L.H., & Ye,S.L. (2019). Temperature sensitivity performance of flexible PDMS-based temperature sensor. *Modern Chemical Industry, 039*(005), 76-80.https://doi.org/10.16606/j.cnki.issn 0253-4320.2019.05.017

[7]Zhu,L. (2018). -Study on thermal hysteresis of 80 ～ 300 ℃ platinum resistance thermometer at 0 ℃ . *Measurement Technique*(5), 26-28.https://doi.org/10.3969/j.issn.1000-0771.2018.05.08

[8]Zhang,L.N.(2018).*Fabrication and characterization offabric temperature sensors*. Donghua University.

[9]MD Husain, Kennon, R. , & Dias, T. . (2013). Design and fabrication of temperature sensing fabric. *Journal of Industrial Textiles, 44*(3), 398-417.https://doi.org/10.1177/1528083713495249

[10]Li, Q. , Chen, H. , Ran, Z. Y. , Zhang, L. N. , Xiang, R. F. , & Tao, X. M. , et al. (2018). Full fabric sensing network with large deformation for continuous detection of skin temperature. *Smart Materials and Structures*.https://doi.org/10.1088/1361-665X/aac0b8

[11]Fan,S.C. (2010). Sensor technology and Application. Beihang University Press.

[12] Lee, C. Y. , Weng, F. B. , Cheng, C. H. , Shiu, H. R. , Jung, S. P. , & Chang, W. C. , et al. (2011). Use of flexible micro-temperature sensor to determine temperature in situ and to simulate a proton exchange membrane fuel cell. *Journal of Power Sources, 196*(1), 228-234.https://doi.org/10.1016/j.jpowsour.2010.06.051

[13]Liu,S.J.(2012). Research on FBAR temperature sensor. Zhejiang University.

[14]Jia, X.R., Xue, W.L., & Wei, J.B.,(2020). Study on the clothing pressure and sports comfort. *Melliand - China, 48(9), 6.*