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Research and Design of Smart Care-Giving Clothing for Disabled Elderly

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Abstract
In current society, smart clothing technology has become a critical way to improve the life quality of the elderly. This work conducted a category product evaluation and user demand system through the bibliometrics method, product evaluation analysis, focus group interviews and questionnaires. Based on the system, we designed smart clothing from the aspects of the clothing structure, hardware, software program and intelligent terminal platform to meet the needs of disabled elderly people and their caregivers in multiple scenarios. According to the test results of the smart clothing, the average error of temperature and humidity monitoring is 0.20°C and 2.88%RH. The time of putting on-taking off clothing in 6 representative daily scenarios was reduced by 51.67%. The daily body checking times, uncomfortable behaviours, and the anxiety of caregivers was decreased by 42.31%, 28.52% and 74.37%. Compared with ordinary clothing, six of the eight comfort performances are basically the same, and two are slightly worse.

Keywords
Smart clothing; disabled elderly; patient care; health monitoring; clothing design.

1. Introduction

The global aging population, structural changes in society and accelerated population mobility have triggered an increase in empty nesting, aging and incapacity [1]. The demand of long-term care for the disabled elderly is growing. How to provide quality care services for the disabled elderly at minimal social cost has become an urgent research topic. With the support of technologies such as the internet of things and flexible wearable sensors, smart clothing is expected to become an effective way to solve the health care problems of the disabled elderly in the future society due to its advantages of real-time, continuity and environmental perception [2].

There have been some substantial advances in smart clothing and wearables for patient rehabilitation and elderly care. Korzeniewska et al. developed a smart glove to assist in the rehabilitation of stroke patients with hand paralysis. The smart glove was based on a flexible substrate, and the vapour deposition method was used to make a conductive film on a textile substrate, using electrodes to release an electric current to stimulate the patient's fingertips in order to improve hand sensitivity in stroke patients to help them to restore hand muscle strength and sensation [3]. Bariya et al. developed a glove capable of autonomously collecting natural sweat [4]. The glove's multi-regional sensing platform is distributed in locations with high sweat glands such as the fingertips, palm and back of the hand, and the NBR material maximises the amount of sweat accumulated, which has positive significance for the monitoring of sweat-related physiological indicators. Wang developed and designed smart clothing with built-in special posture monitoring sensors to support upper limb rehabilitation training for stroke patients, and obtained favourable feedback in clinical trials [5]. Luo et al. developed smart clothing for menopausal transition recognition by collecting and calculating important biological signals corresponding to the main symptoms of menopause in women, which is important for the prevention and clinical treatment of menopause-related symptoms [6]. Geng designed an intelligent system for rapid response remote rehabilitation care through smart medical technology and lower limb kinematic models with a lower limb joint rehabilitation wearable as the primary means [7]. Yapici presents smart clothing for monitoring the bioelectric potential of the heart from the wrist or neck, which imposes very few restrictions on regular wearing habits. A comparison of electrocardiogram (ECG) recordings obtained from the wearable prototype with conventional wet electrodes shows a high degree of coherence and spectral coherence between the two signals [8].

Current results of smart clothing for patient rehabilitation and smart care-giving clothing for the disabled elderly pay more attention to sense technologies for the collection of key physiological indicators for a single condition. It is rarely common that the integrative design of smart care-giving clothing takes into account multiple use scenarios, oriented to the multidimensional needs of the disabled elderly and their care-givers. Specifically, there is a lack of research into the use of multiple data collection and garment construction to monitor the daily body comfort and abnormal health status of the disabled elderly, or to improve the user's experience of the value of dignity and the carer's work experience. Through this research, the researchers hope to propose a reference for a new way of thinking about the design of smart clothing: to make products more generally available in the field and to serve users through appropriate sensing and design technologies, starting with their needs. This study used smart care-giving clothing for the disabled elderly as the research object, adding new caring functions to the clothing through data

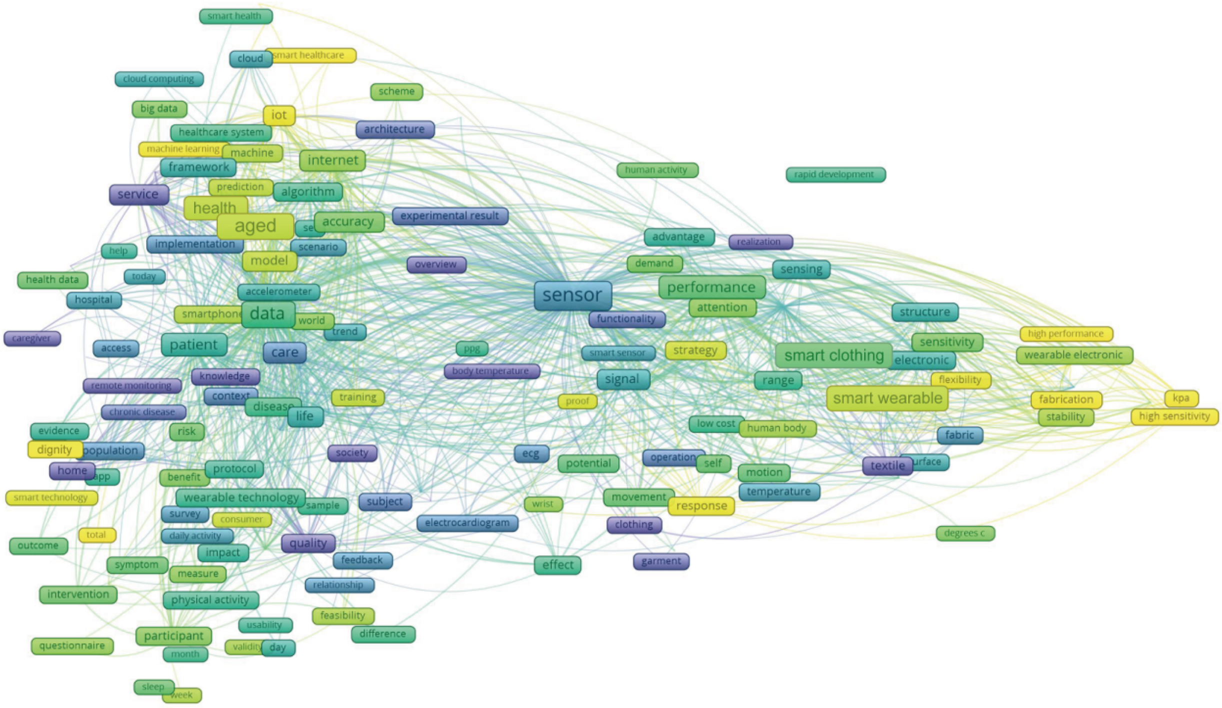

Fig. 1. Knowledge map of time frame subject keywords

collection, computation, transmission and interaction. In addition to the caring functions, the researchers designed the structure, fabric, colour, appearance of the hardware and the way it is integrated into the clothing to better meet the needs of the disabled elderly in multiple aspects of the caring process. The aim is to grant the elderly more independence and respect in their health care experience.

2. Method

2.1. Knowledge mapping bibliometrics

Knowledge mapping can help researchers to comprehend the whole situation of the established academic system in the target subject area through retrospective quantitative analysis, so that they can better judge and plan the direction of research on the topic. With sufficient dynamic searches to find matching literature, the researchers identified the search terms: “smart clothing” and “health”, based on the analysis of typical literature and case studies. Considering that the term ’smart wearable’ is often used in the literature as a near synonym for smart clothing, the researchers identified ‘smart wearable’ and ‘health’ as another set of search terms to supplement the literature in order to make the literature collection as comprehensive as possible. The researchers conducted a combined search for subject keywords in the Web of Science core database for literature up to October 2021 and combed and filtered the search results. The researchers obtained text data information from a total of 1168 relevant documents. The researcher used VOSviewer software version 1.6.11, issued by the Center for Science and Technology Studies, Leiden University, in the Netherlands, to analyse the text data for topic keyword clustering, inter-topic relationship, and distribution time; the text data were debugged by filtering out keywords below 20 frequencies as well as weak specific real meaning keywords, and adjusting the visualisation mapping information masking. A final knowledge map of the topic keyword co-occurrence clustering with timeline attributes was obtained, shown in Figure 1. From the results presented in the knowledge map, it can be seen that the hot research themes of international scholars in this direction mainly focus on sensors, smart clothing, smart wearables, the aged, data, accuracy, performance and other directions. In the last three years, thematic keywords such as dignity, smart healthcare, iot, covid, machine learning, and flexibility have been studied with high frequency.

2.2. Product and user analysis

2.2.1. Analysis of category product user ratings

Consumer evaluations of category products are a high quality source of reference data for product development planning [9]. Traditional evaluation data collection methods easily tend toward incomplete data sources and inadequate sample sizes, which in turn can lead a partial product development [10]. The development of big data and intelligent data analysis techniques has helped researchers to collect and process larger volumes of product evaluation text data more effectively. The researchers used ROST-CM6 software, version 5.8.0.603, developed by the ROST team at Wuhan University, China, to perform word frequency and sentiment analysis for the evaluation of health smart clothing category items for the elderly. The data sources selected for this study were available Chinese mainstream online public media news and the content of user discussions on major online social media platforms. The search keyword combinations were ’elderly’, ’caring’, ’smart clothing’ and ’smart wearable’. A time range was set before October 2021. The researcher entered the 2159 texts automatically obtained by the intelligent algorithm into the ROST-CM6 software to process and analyse. Finally, the related product evaluation’s word frequency and sentiment analysis results were achieved.

Words related to product function accounted for 21% in total; words related to product use scenarios for 16% in total; words related to product technology for 12% in total; and words related to product materials and components accounted for 9% in total. The top 15 high-frequency words and their frequencies are shown in Table 1. It is clear that the function and usage scenario of smart care-giving clothing for the disabled elderly are the two most popular points of concern. The results of the sentiment analysis of the category product evaluation show that positive attitude takes up 71.51%, intermediate attitude 11.43% and negative attitude 17.06%. This shows that society and consumers are generally positive and optimistic about smart care-giving clothing for the disabled elderly; but there are still some users who present a wait and see attitude or have a negative attitude towards these products. Further analysis reveals that the negative sentiment mainly focuses on the function and structure of the product. The top 15 negative emotion high-frequency words and their frequencies are shown in Table 2.

Table 1. Top 15 high-frequency words from social media

Rank	Word	Frequency
1	Function	476
2	Monitor	443
3	Smart	378
4	Protect	281
5	Home	264
6	Fall	259
7	IOT	213
8	Fever	185
9	AI	177
10	Bed	143
11	Graphene	99
12	Wash	90
13	Safe	86
14	Sensor	82
15	Lost	81

Table 2. Top 15 negative emotion high-frequency words from social media

Rank	Word	Frequency
1	Inaccurate	31
2	Inconvenient	30
3	Ugly	30
4	Unsafe	28
5	Low endurance	25
6	Tight	21
7	Heavy	21
8	Expensive	19
9	Not smooth	17
10	Difficult	16
11	Lag	12
12	Strange	11
13	Redundant	11
14	Outdated	10
15	Not practical	10

2.2.2. Analysis of target users and usage scenarios

Guided by the results of the knowledge mapping and category product evaluation analysis, the researchers conducted and recorded individual interviews with a total of 10 experts consisting of one professor, two associate professors, and seven doctoral students in the fields of design and textile science at Jiangnan University, China, for the target users and usage scenarios of smart care clothing for the disabled elderly. The average duration of the experiment was 30 minutes for each expert interviewed. Two researchers (two of the authors) were present during the interviews as experiment facilitators and recorders, respectively, and joined the discussion at the end of each session. The interview questions are shown in Table 3. After a basic collation of the audio data received from the open-ended focus interviews, the researchers conducted an in-depth coding analysis of the data on the NVivo12 software platform, distributed by QSR Australia, through a rooted theory research approach. Three user category codes and 15 usage scenario codes were filtered using a minimum word frequency threshold of five times, as shown in Table 4.

Table 3. Open-ended questions for expert interview

No.	Interview questions or conversation contents
1	Introduce the purpose, content, steps and time of this interview.
2	Have you ever presided over, participated in or known research on smart care-giving clothing for the disabled elderly or other related topics? Please say about your experience.
3	Are there disabled elderly or their caregivers around you? Please put forward some helpful design schemes or ideas for the disabled elderly or their caregivers from your professional perspective.
4	What categories do you think the users of smart care-giving clothing products for the disabled elderly can be divided into?
5	In what scenarios do you think smart care-giving clothing products can serve disabled elderly users?
6	Imagine you are a disabled elderly person now, what would you like to receive through smart care-giving clothing products?
7	Imagine you are a caregiver of a disabled elderly person, what would you like to receive through smart care-giving clothing ?
8	What would we do if you worked with us to design smart care-giving clothing for the disabled elderly?

2.2.3. Analysis of user needs

In addition to the individual interviews, the researcher organised a joint user needs focus group interview with those 10 industry experts. The interview was based on Norman’s Emotional Hierarchy Theory [11], which explores three dimensions: perceived understanding (instinctive level), usage scenarios (behavioural level) and lifestyle change (reflective level). In the interview, the

Table 4. Coding analysis of target users and usage scenarios

User category coding		Usage scene coding	
Number /name	Word frequency [times]	Number/name	Word frequency [times]
A1 Elderly with perceptual disabilities	201	B11 Painless	12
		B12 Blindness and visual impairment	5
		B13 Alzheimer's disease	19
		B14 Tactile deficit	11
		B15 Autism	8
A2 Elderly with expression disabilities	245	B21 Narrative disorder	6
		B22 Communication barriers	20
		B23 Patients who have lost their voices	5
		B24 Disorganisation of language	14
		B25 Intellectual disability	27
A3 Elderly with movement disabilities	118	B31 Bedridden	31
		B32 Urine bag aid	9
		B33 Incontinence	22
		B35 Impaired mobility of the limbs	9
		B34 Hemiplegic patients	6
		B35 Wheelchair users	5

Table 5. System of demand elements for smart care-giving clothing for the disabled elderly

Second level elements	Third level elements
B1 Perceptual understanding (instinctive layer)	C11 Continuous monitoring C12 Exception alarm C13 Mobile terminals C14 Comfort C15 Danger tips
B2 Use in scenarios (behavioural layer)	C21 Fashion sense C22 Sense of value C23 Familiarity with semantics C24 Daily mimesis C25 Behavioural guidance
B3 Lifestyle (reflective layer)	C31 Dignity of independence C32 Care-giving knowledge C33 Science and wellness C34 Community exchange

researchers selected five secondary elements and 14 tertiary elements to form a hierarchy of demands for smart care-giving clothing for the disabled elderly, shown in Table 5.

A Likert scale questionnaire was generated from the focus group interviews and administered to 90 randomly selected households of disabled elderly people in Wuxi, China. The participants of this questionnaire survey came from the elderly communities in the Binhu district, Xinwu district and Xishan district, Wuxi City, China. We numbered a total of 125 target families, and then used the random number table to generate 90 random numbers. The families corresponding to the generated serial number became the research group. The questionnaires were completed by their caregivers, taking into account the bias of the questionnaire due to physical or cultural cognitive problems of the disabled elderly people. A total of 84 questionnaires were successfully returned and 3 invalid questionnaires excluded, resulting in a total of 81 valid questionnaires. Based on the hierarchical structure of the elements, the researchers used hierarchical analysis to determine the influence of the weights of the elements of each criterion level on the target level and finally synthesized the weights, shown in Table 6. As a result, the researchers constructed a system of key user requirements, in which the core elements are C14 comfort, C12 abnormal alarm, C31 independent dignity, C11 continuous monitoring, C13 mobile terminal, C24 daily mimicry, and C23 familiarity with semantics; the peripheral elements are C15, C25, C32, C33, C22, C21 and C34.

2.3. Overall design scheme

The overall design of the smart care-giving clothing for the disabled elderly is divided into 4 modules: clothing design, the hardware sensing module, software system module and intelligent terminal interaction. The main scenario for the smart care-giving clothing is the home environment, hence the general clothing is based on home wear. The researchers made a further design for the structure of the clothing based on the silhouette and style of home interior clothing, concentrating on the fitness, protection, convenience of putting on and taking off, and the privacy of separate areas during wearing and releasing clothes. The hardware sensing module consists of body surface temperature and humidity data acquisition sensors, a power supply, a development board data processor, and data wireless transmitter. The sensors are built into the appropriate parts of the clothing according to the corresponding data characteristics [12]. The power supply provides power to the sensors and the data monitoring module. The development board controller analyses and processes the data information collected by the sensors and uploads the

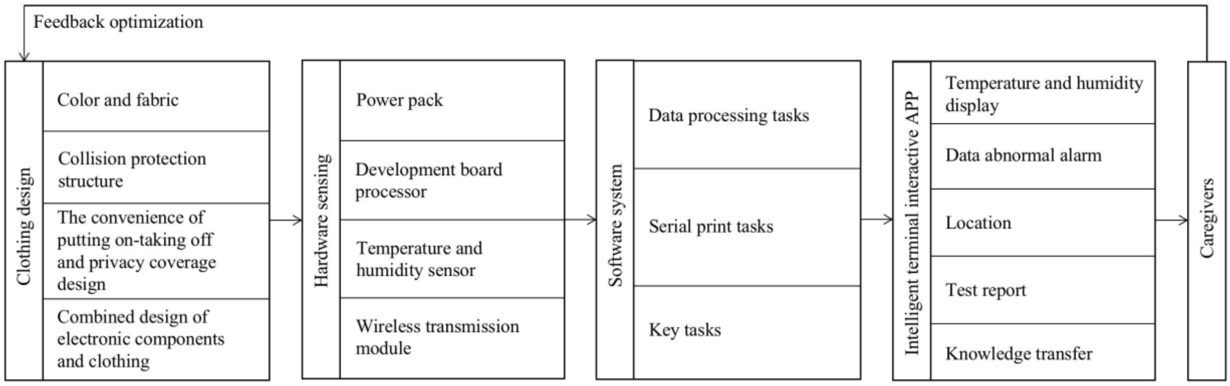

Fig. 2. Frame diagram of overall design scheme

Table 6. Composite weight analysis of questionnaire

Indicator layer	Guideline level			Weighting of the overall objective	Ranking of indicator weights
	B1	B2	B3		
C11	1952			985	4
C12	2321			1171	2
C13	1871			944	5
C14	2632			1328	1
C15	1223			617	8
C21		895		238	13
C22		1053		280	12
C23		2511		668	7
C24		3395		903	6
C25		2147		571	9
C31			4911	1127	3
C32			2436	559	10
C33			2244	515	11
C34			410	94	14
Impact factors	5045	2660	2295		

data via the wireless data transmitter [13]. The software system module assigns tasks by priority to the dispatch core through time-sharing cooperation. The intelligent terminal interaction module is responsible for storing and visualising the uploaded data and transmitting warning messages to the caregiver in case of data abnormalities. The framework of the overall design scheme is shown in Figure 2.

3. Design development

3.1. Hardware sensing design

The body surface temperature and humidity monitoring function is mainly achieved through a combination of components such as power packs, temperature sensors, humidity sensors, development boards and wireless transmitters. The development of material technology provides more options for taking electronic components with lighter mass, smaller size and lower power consumption [14]. According to the design requirements of the smart care-giving clothing, an LG BL-S6 battery, which is 30 mm×32mm, was chosen by the researchers. It has a good specific capacity, size and cycling stability. Its 3.85Vcc/570mAh performance provides good coverage for a single day of smart care-giving clothing. The acquisition of temperature and humidity data is achieved through a SHT21 temperature and humidity sensor. An STM32F103C8T6 micro-controller, which is small and has high-adaptability, was selected by the researcher as the development board to process the data. The micro-controller is based on the high performance ARM Corex-M4 32-bit core running at 168 Mhz. It supports all ARM single precision data processing instructions and data types. The small size and high performance ATGM336H-5N-7X module was selected for the GPS positioning module. The ATGM336H-5N-7X GPS features high cold start capture sensitivity, high positioning accuracy, low power consumption and small size. The module supports a wide range of satellite navigation systems as well as satellite augmentation systems. This GPS module can provide accurate and reliable location information support for smart care-giving clothing with relatively low power consumption and low cost. The wireless transmitter is a BT08B Bluetooth serial module, developed by Weixin, which has the advantages of low cost and high adaptability for short-range wireless data transmission functions. In the synergistic linkage of the components, the temperature and humidity sensor collects the human body surface temperature and humidity data, and the micro- control chip calculates and processes the data information. The Bluetooth transmission module transmits the data to an intelligent terminal platform (mobile phone application) for storage, display and interactive operation [15]. A description of the smart clothing sensor device is given in Table 7. The capacity values of the components in Table 7 are the maximum capacity during operation. Among them, the temperature and humidity sensor, GPS and Bluetooth modules all wake up regularly or in

Table 7. Description of smart clothing sensor device

Device	Type	Property	Capacity	Work environment	Supplier
Battery	LG BL-S6	3.85Vcc/570mAh	-	-20°C -60°C	LG corp.
Micro-controller	STM32F103C8T6	72MHz/64KB	≤26mA	2V-3.6V	ST Microelectronics
Temperature and humidity sensor	SHT21	±0.3°C@-20-80°C ±2%RH@0-100%RH	≤5.5mA	<5mA	SENSIRION corp.
GPS	ATGM336H-5N-7X	±2.5m	≤25mA	<525mA,3.3V	Zhongkewei corp.
Bluetooth	BT08B	Bluetooth 3.0	≤15mA	3.3V-5v	Risym corp.
Cable	KTFB275/2	14.7Ω/m	-	-100°C-800°C	Qianglun corp.

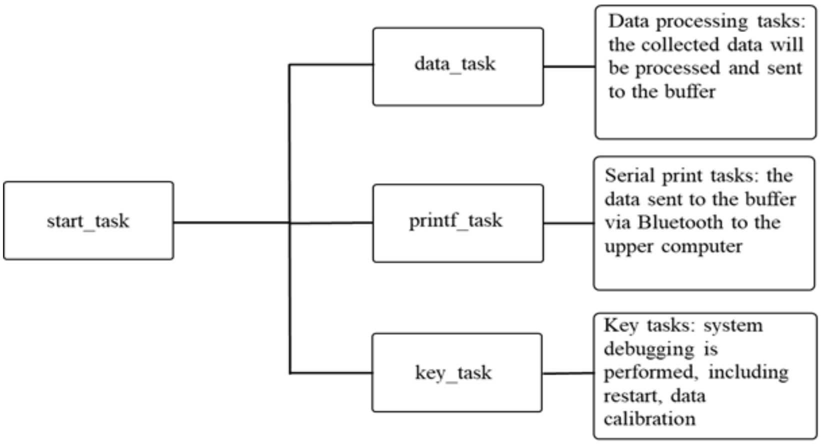

Fig. 3. Lower computer software system

linkage under abnormal conditions. After testing, the average continuous operation time of the whole system under normal working conditions is 27.55h, and the shortest operation time is not less than 26.08h.

3.2. Software system design

The real-time acquisition of multiple types of information about the human body is a priority when designing a software system for the lower computer in this study. This solution requires the lower computer software system to switch tasks at different times to collect and send data [16]. The lower computer software system is equipped with a u/cos-III real-time system kernel to complete the time-sharing scheduling of tasks, while the order of sending print and key tasks is determined by the priority of the tasks. The structure of the lower computer software system for this study is shown in Figure 3.

3.3. Clothing design

The smart care-giving clothing in this research is based on the silhouette and style of home underwear. Based on the dressing characteristics and functional needs of disabled elderly people, the researcher chose cotton fabric as the main fabric for the clothing by comparing the performance of the mainstream fabrics for home underwear, such as cotton, hemp, ramie and linen fabrics. From a psychological point of view, bright and light colours often give a hint of mental pleasure, help to release emotions and fit the sense of identity of the elderly [17]. The main and secondary colours of the clothing in this design were chosen to be bright and light.

3.3.1. The convenience of putting on-taking off and privacy coverage design

As the range of movement of the disabled elderly is relatively small, they are often assisted by their caregiver in their daily activities. Therefore, the design and structure of the clothing should be designed to be easy to put on-take off and for privacy coverage. In this study, the researcher used velcro instead of buttons, and the left and right cuffs and trousers can be opened and closed with a double-ended zip for putting on-taking off easily, as shown in the Figure 4. The trouser is designed with space for a catheter in the crotch to facilitate care-giver assisted toileting, bag use and cleaning care. The back of the trousers is hollowed out at the hip and has an external cover fabric which is attached with velcro tape. The cover fabric is used to cover the urinary catheter and private areas and is removable so that it can be replaced and washed at any time, as shown in the Figure 5. The overall structure of the clothing is designed to look the same as normal clothing, protecting the elderly's self-esteem and reducing the burden on caregivers.

3.3.2. Combined design of electronic components and clothing

The sensors used in this research are as flexible, thin and small as possible to ensure the comfort of clothes. The temperature and humidity on the body surface of various parts of the human body are different. In order to ensure the validity of the data measured, the researchers set the temperature and humidity sensor in the armpit close to the left chest where sweat glands are dense and the temperature is close to the

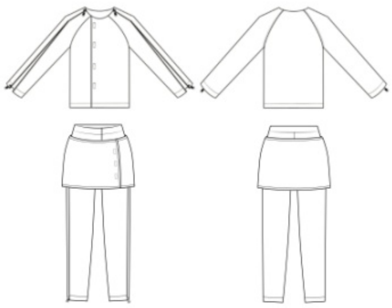

Fig. 4. Convenience of putting on-taking off design

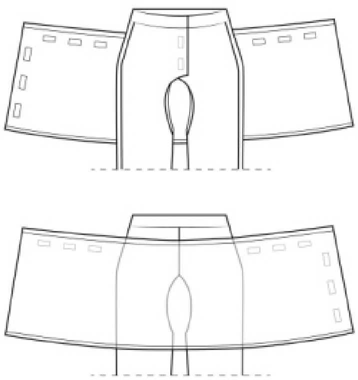

Fig. 5. Privacy coverage design

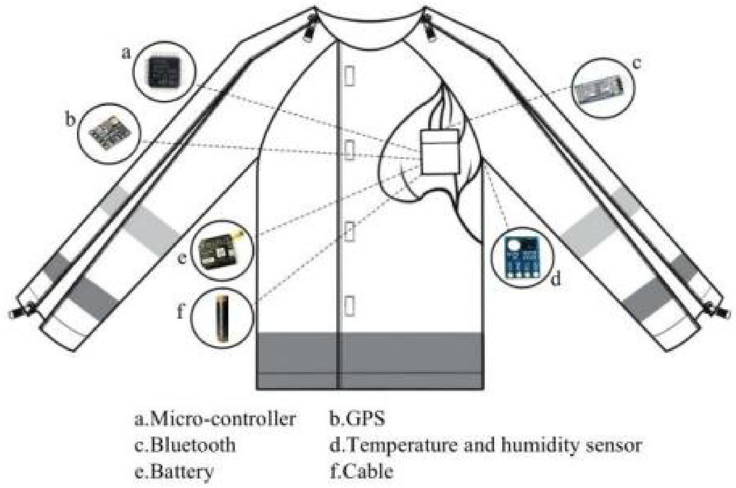

Fig. 6. Combination of electronic components and clothing

body temperature. The power supply, development board and data wireless transmitter are all integrated into the left chest by welding in order to reduce the length of the connection wires. The sensors that cannot be integrated in the left chest position are connected via KTFB275/2 washable textile yarn. Based on the user requirements for a core element of daily mimetic appearance, the researcher made a concealed three-dimensional pocket for all electronic components to be integrated. After integration, the electronic components are designed to facilitate disassembly. The textile yarn connecting electronic components is directly woven on the clothing with a clothing pattern similar to the design semantics of the elderly. The combined design of electronic components and clothing is shown in Figure 6. The appearance of a model wearing smart clothes is shown in Figure 7.

Fig. 7. Wearing appearance of design prototype

3.4. Intelligent terminal interaction design

The smart care-giving clothing stores and displays continuously and dynamically physiological health data of the disabled elderly via a mobile phone app. The caregiver can match the smart clothing with their mobile phone through the wireless transmission module and register for an account to get the body comfort information of the disabled elderly. When the wearer's body surface temperature is between 35.3°C and 36.6°C and the body surface humidity is between 20% and 50%, the mobile phone app will not alert the caregiver [18].The researchers added to the range of body comfort surface temperature and humidity values an allowable device error, resulting in the above monitoring alert thresholds. When the wearer's body surface temperature or humidity is not within the normal threshold, the mobile app will send an alarm to the caregiver. The monitoring report in the mobile app provides the caregiver with body surface temperature and humidity information for three days. The app also offers regular updates on care-giving knowledge for the elderly to caregivers to view and learn. The operation and display is shown in Figure 8.

4. Experiments

As a discussion on the preliminary evaluation method of the design prototype, the researchers used the experimental test method of relatively small samples in this research. To verify the various properties of the smart care-giving clothing designed in this research, the researchers randomly selected eight out of 21 disabled elderly persons as subjects for a multi-group experiment. The experiments were conducted on an Arduino open source electronic platform.

4.1. Body comfort monitoring utility

The experiments were carried out in an indoor environment at a temperature of 26±2°C and humidity of 50±5% RH. The researchers dressed 8 disabled elderly people in smart care-giving clothing, and

Table 8. Experimental results of the utility of body surface temperature and humidity monitoring

Subject number	Average temperature [□]			Average humidity [%]		
	Sensors	Thermometer	Error	Sensors	Moisture meter	Error
1	36.2	36.4	-0.2	56	51	+5
2	36.1	36.1	+0.0	47	44	+3
3	36.3	36.4	-0.1	58	59	-1
4	36.1	36.3	-0.2	40	36	+4
5	35.8	35.9	-0.1	44	45	-1
6	35.5	35.8	-0.3	45	47	-2
7	36.4	36.8	-0.4	41	39	+2
8	35.9	36.2	-0.3	50	45	+5

Fig. 8. Intelligent terminal app operation interface

turned on a serial monitor to record the body surface temperature and humidity data in a 30-minute period. During the same 30-minute period, a mercury thermometer and skin hygrometer were also used to measure the body surface temperature and humidity of the above eight participants three times in the same body part, and the average measurement value of each participant was recorded, shown in Table 8.

The researchers used the Correl function to calculate the correlation coefficient between the data measured by the care-giving clothing and traditional methods. The correlation coefficients of temperature and humidity were 0.97 and 0.96, both close to 1. This demonstrates that the correlation between the two measurement methods is strong, which means the smart monitoring system has good stability. After calculating the above experimental data, it can be seen that the average error of body surface temperature monitored was 0.2°C and the body surface humidity error 2.88%RH by the smart care-giving clothing. Both groups of data show good accuracy and are within the allowable range.

4.2. Care utility experiment

4.2.1. Frequency of body check

The disabled elderly person requires regular body checks by their caregivers to confirm their health status because of their lack of perception, expression or mobility. The body check activity here includes all the behaviors of state confirmation by touching the disabled elderly's body in daily life. Studies have shown that reducing the number of body checks and attendance at the clinic can improve the quality of life and health of patients [19]. Reducing the frequency of body checks is effective in improving the quality of life of the elderly while ensuring their health status, and also greatly enhances their experience of independence and dignity.

The researchers recorded the body check times of 8 participants in a single day when they were wearing the care-giving clothing and ordinary clothing. As shown in Table 9, compared with the ordinary clothing experimental group, wearing care-giving clothing reduced the body check times of the disabled elderly in a single day by 42.31%. According to the descriptions of the experimentees and their caregivers, the real-time monitoring of health data by the smart care-giving clothing was the main reason for the decrease in the number of examinations.

4.2.2. Time of putting on-taking off clothing

It is common for the disabled elderly to suffer from a decline in physical function and mobility, such as incontinence, urinary bag assistance, lying in bed, and difficulty in lifting and turning on their hands and knees [20]. Problems with perception and expression also result in the need for caregivers and medical staff to frequently remove parts of their clothing to examine the body. Therefore, the ease of putting on-taking off clothing has become an important factor in the quality of life of the disabled elderly and the workload of caregivers. The experiment recorded the time that it took for the participant to be assisted in putting on and taking off the care-giving clothing and ordinary clothing in each of the six representative daily scenarios. The experimental results from Table 10 show that the effective time to put on and take off care-giving clothing in the six representative daily scenarios was less than that of ordinary clothing. The total putting on and taking off clothing time of

Table 9. Comparison of the frequency of body checks

Group number	Times of body check per day with ordinary clothing [times]	Times of body check per day with care-giving clothing [times]
1	3	2
2	5	3
3	4	2
4	2	2
5	2	1
6	4	2
7	3	1
8	3	2
Average	3.25	1.875

Table 10. Comparison of putting on and taking off time in six representative daily scenarios

Scene	Part	Smart clothing [s]	Normal clothing [s]	Reduction [%]
Standing	Upper clothing	19.21	46.12	58.35
Standing	Trousers	16.13	51.44	68.64
Lying in bed	Upper clothing	41.57	77.67	46.48
Lying in bed	Trousers	35.23	54.43	35.27
Toilet	Trousers or crotch unit	14.10	22.67	37.80
Arm injections	Upper clothing or sleeves	12.76	35.25	63.80
Total		139.00	287.58	51.67

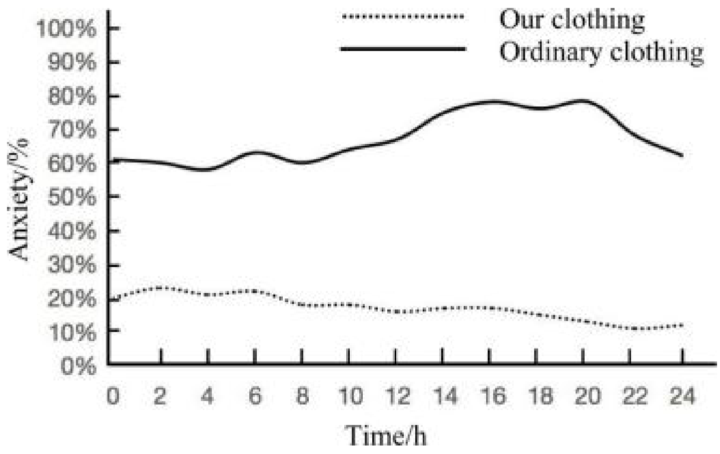

Fig. 9. Comparative experiment result of caregiver's anxiety

the care-giving clothing was reduced by 51.67% compared to the ordinary clothing in the six scenarios, which greatly saved the daily workload of the disabled elderly and their caregivers. This is due to the convenience of putting on and taking off as well as the detachable structure of the modular unit.

4.2.3. Frequency of uncomfortable behaviour

The number of discomforting behaviours per day was recorded for each of the 8 experimentees wearing normal clothing and the care-giving clothing. The results showed that the average uncomfortable behaviour times of the eight participants wearing ordinary clothing was 2.63 in a day. While the results of the care-giving clothing group was 1.88, a 28.52% decrease compared to the normal clothing, showing a significant effect. When the disabled elderly person is wearing care-giving clothing and their body surface temperature fluctuates or they sweat excessively, the caregiver can be alerted by the mobile to provide timely and effective care for the elderly person, such as seeking medical treatment, adding clothing, removing clothing or cleaning the body to make them feel comfortable. This is the main reason for the reduction in the number of uncomfortable behaviours.

4.2.4. Caregiver anxiety

In the study of the disabled elderly, caregivers as the actual implementer of care- giving behaviours, play a very important role in the process of caring for disabled elderly people. Either the children of the disabled elderly or professional caregivers may feel anxious in the process of caring for an elderly person with dementia due to various factors. Considering that the reduction of caregiver anxiety is one of the important objectives of this study, the researchers recorded 24-hour anxiety scores of the caregivers of the eight participants. The test participants recorded their anxiety level on a scale of 0-100% for every two hours of care-giving work during a single day. 0% means no anxiety at all and 100% - anxiety at the limit of their tolerance. The results are shown in Figure 9. From the experimental results, it can be learned that the average anxiety of caregivers decreased by 74.37% per day. When the disabled elderly was not wearing smart care-giving clothing, the average anxiety level of the caregivers was higher, and the anxiety of the night-time caregivers was the heaviest; when the disabled elderly were wearing smart care-giving clothing, the average anxiety of the caregivers was lower and showed a flat decline. On detailed inquiry, this was related to caregivers gradually adapting to and confirming the utility of the smart care-giving clothing in the process of use.

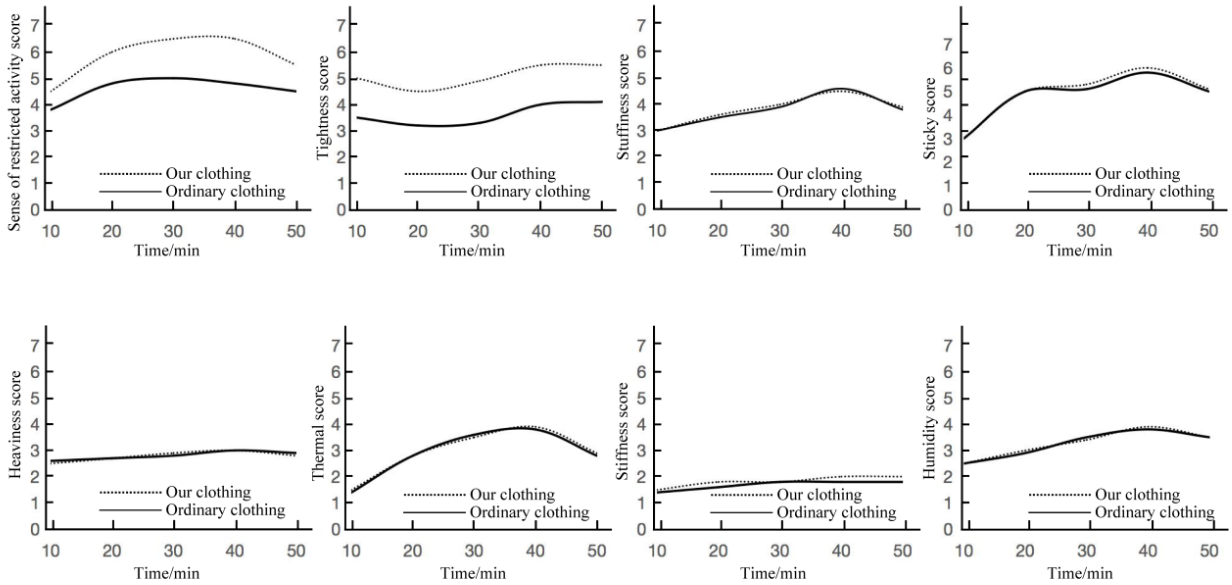

Fig. 10. Subjective rating scores for clothing comfort

4.3. Comfort experiment

The function-oriented design of the clothing structure and built-in sensor hardware have an impact on the comfort of the clothing [21]. Comfort is one of the key elements in the previous analysis of product types and user requirements. The researcher therefore undertook a subjective evaluation method to compare the comfort of smart care-giving clothing with similarly styled general clothing.

Subjective comfort evaluation can intuitively and effectively reflect the wearer's subjective feelings towards the clothing. The subjective evaluation index system contains the eight dimensions of heat, wetness, stuffiness, stickiness, heaviness, restricted movement, stiffness and tightness [22]. The Fritz seven-level semantic difference scale was chosen as the scale for evaluation. The participants in the objective evaluation experiment were 10 elderly people with normal perceptual expression. The average height of the participants was 168±3cm and their weight - 60±5kg, taking into account the size of the experimental clothing. The test environment was an artificial climate chamber manufactured by Espec, Japan. Before the test all participants were informed of the specific steps of the experiment in this research and the related tasks that require their cooperation. The subjective evaluation experiment was divided into 5 stages: Stage 1 was a 10min sedentary session; Stage 2 was a light exercise session where the participant was required to exercise on a treadmill at a speed of 3km/h for 10min; Stage 3 was a moderate exercise session where the participant was required to exercise on a treadmill at a speed of 6km/h for 10min; Stage 4 was 5 sessions of the combined action of stretching, kicking and squatting for 10min. Stage 5 was a 10min meditation. At the end of each stage, a subjective evaluation was performed and scored.

Figure 10 shows the scores of the subjective evaluation, which were averaged from the those of the participants. It can be seen that the smart care clothing is almost indistinguishable from ordinary clothing in terms of stuffiness (-0.31%), stickiness (-0.27%), heaviness (-0.07%), thermal (-0.70%), stiffness (-4.68%), and humidity (-1.20%), but less comfortable than ordinary clothing in terms of restricted movement (-23.5%) and tightness (-32.17%).

5. Conclusions

Based on the actual care needs of the disabled elderly, this study proposes the design of smart care-giving clothing in terms of functionality, comfort and dignity value experience in multiple scenarios. The research design was tested and proven to be generally functional and complete, and can play an intelligent role in multiple aspects of care work for the disabled elderly. The average error of temperature and humidity monitoring is 0.20°C and 2.88%RH. The time of putting on-taking off clothing in the 6 representative daily scenarios was reduced by 51.67%. The daily body checking times, uncomfortable behaviours and the anxiety of caregivers was decreased by 42.31%, 28.52% and 74.37%. Compared with ordinary clothing, six of the eight comfort performances are basically the same, and two are slightly worse. The researchers hope that this study will provide a theoretical and practical reference to alleviate the pressure on the social care system brought about by the accelerated aging. At the same time, there are still shortcomings in this study. Due to the fact that all the functional hardware cannot be built into the clothing, the comfort of the smart care-giving clothing is not consistent with that of ordinary home wear owing to restricted movement and tightness. The electronic components' lifespan of the smart care-giving clothing varies with attrition, hence the overall daily durability of the clothing still needs to be understood and improved. The research was conducted with a small number of participants, thus it is still in the preliminary evaluation stage. The evaluation method proposed in this study will continue to be studied and developed in the future.

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