Artificial Intelligence and Human-Computer Interaction
Y. Ye and H. Zhou (Eds.)

doi:10.3233/FAIA250152

Design of Sustainable Outdoor Delivery Personnel Apparel

Meizhen DENG[1], Yuanqi LIU and Yuhang LUO
College of Engineering and Design, Hunan Normal University, Changsha, China
ORCiD ID: Meizhen DENG https://orcid.org/0009-0008-6923-6624

Abstract. Focusing on the outdoor delivery industry, specifically the food delivery sector, this study initiates from the cycling activities of delivery personnel. By investigating the characteristics of food couriers during their cycling duties, this research employs methods such as surveys, interviews, and experimental measurements to integrate flexible solar panels with delivery uniforms. This integration allows for continuous power supply through solar energy during the delivery process, promoting sustainability in today's era of advocating for sustainable development. While conserving resources, the proposed design also brings convenience to the couriers. The proposed design methods and concepts provide guidance for the research and development of professional attire in the delivery industry, enhancing the convenience of professional workwear and thereby fostering the growth of the delivery sector.

Keywords. Sustainable energy; delivery apparel; delivery industry; food delivery uniforms; flexible solar panels

1. Introduction

Since the concept of sustainable development was introduced by the United Nations World Commission on Environment and Development (WCED) in 1987, it has become an important global concept. Defined in the report "Our Common Future," sustainable development is described as a mode of development that meets the needs of the present without compromising the ability of future generations to meet their own needs [1]. Solar-powered clothing is an innovative product that emerges under the umbrella of sustainable development, combining solar technology with garment design [2]. It harnesses solar panels or other solar collectors to convert solar energy into electricity, which powers electronic devices embedded in the clothing, as well as heating and lighting functions, thereby achieving green energy generation on garments.

2. Design concept

With the rapid economic development in our country, all sectors are demonstrating robust vitality, particularly the delivery industry. Within this industry, food delivery services stand out as an indispensable part of daily life. The design of delivery personnel apparel

[1] Corresponding Author: Meizhen DENG, College of Engineering and Design, Hunan Normal University, Changsha, China. E-mail: dmz@hunnu.edu.cn.

in this project involves the placement of flexible solar panels on the garments, utilizing optical principles to convert sunlight into electrical energy, thereby powering USB charging devices. This technology is commonly used in outdoor sportswear [3]. Outdoor sportswear is characterized by prolonged exposure to sunlight and large surface areas, making flexible solar panels suitable as mobile power sources. Similarly, food delivery personnel also work outdoors, navigating through city streets and alleys with extensive exposure to sunlight. Given that delivery personnel frequently use mobile phones during their shifts and have high electricity needs, the development of sustainable outdoor delivery apparel is evidently feasible.

3. Circuit construction

The electrical energy converted by flexible solar panels cannot be directly utilized or stored, necessitating various auxiliary circuits to manage the use and storage of this energy [4]. These auxiliary circuits are designed to provide functions such as voltage stabilization, priority load power supply, automatic power switching, and battery protection. Additionally, considerations must include ease of operation, comfort in wear, uniform heat distribution, and durability and safety to meet the immediate needs and practical demands of the delivery industry [5].

3.1. Selection of solar panels

The choice of solar panels for integration into clothing depends on multiple factors. Firstly, the efficiency and performance of the panels must be considered [6]. Flexible polymer solar panels are soft and lightweight, making them suitable for flexible products like clothing, but they suffer from low efficiency and short lifespans, which may not meet usage requirements. Polycrystalline silicon solar panels have a relatively simple manufacturing process, long lifespan, and moderate price, but their efficiency is slightly lower and their rigid material is unsuitable for use in clothing. Monocrystalline silicon solar panels, on the other hand, offer a long lifespan, high efficiency, and a good cost-performance ratio, though their manufacturing process is complex [7]. Additionally, the installation and maintenance of the panels must be considered to ensure that their mounting on the clothing is reliable and safe, and that they are easy to clean and maintain. The optimal choice would be flexible monocrystalline silicon solar panels that provide a long lifespan, high efficiency, and a favorable cost-performance ratio [8]. Hence, the selection of 2901802.5mm flexible solar panels is made.

3.2. Selection of energy storage battery

Compared with other batteries, lithium batteries are chosen as the energy storage solution based on their high energy density, lightweight design, low self-discharge rate, long lifespan, and high safety [9]. These characteristics allow lithium batteries to store more energy within a relatively small volume and provide longer operating times. Additionally, the lightweight design of lithium batteries makes them easier to carry, and their low self-discharge rate ensures that the batteries maintain a certain level of charge even after extended periods of non-use. The long lifespan of lithium batteries enables them to withstand hundreds of charging and discharging cycles, while safety measures effectively reduce the risk of accidents [10]. Given these features, lithium batteries are an ideal choice to meet the requirements, thus the circuit utilizes a 5V2A lithium battery with a capacity of at least 4000mAh and a weight not exceeding 95g.

3.3. System design framework

The entire system is designed based on the full utilization of solar energy resources, in line with current low-carbon and environmentally friendly living concepts. The system is structured according to the actual usage process. Initially, the output from the solar panels undergoes voltage stabilization. Subsequently, the circuit determines its operating status, meeting the physiological, safety, and functional requirements of the delivery industry. The system design framework is illustrated in Figure 1.

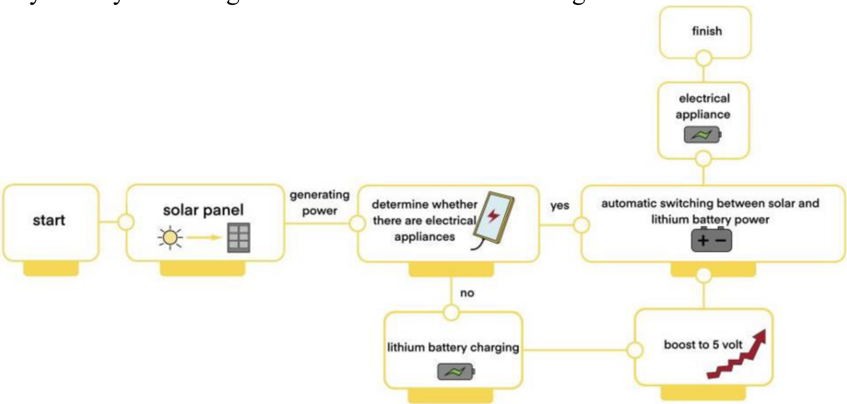

Figure 1. System design framework.

3.4. Circuit design concept

3.4.1. Priority load supply circuit

The priority load supply circuit primarily functions to prioritize charging devices over charging the storage lithium battery when both need power simultaneously. This circuit consists of components such as Schottky diodes, transistors, and resistors. Its working principle is that when a device, such as a mobile phone, is connected to the output, the base potential of the transistor is lowered, causing the transistor to cut off and thereby prioritize power supply to the device first,as shown in Figure 2.

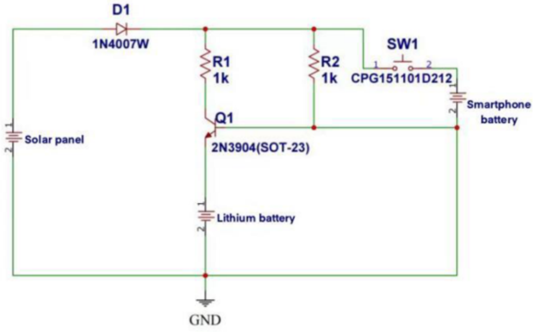

Figure 2. Priority load supply circuit.

3.4.2. Automatic power switching circuit

When the solar panel is the sole power source, Q1 is cut off, preventing current from back feeding into the lithium battery. The power from the solar panel passes through diode D1 to the output. When only the lithium battery provides power, with a battery voltage of 3.7V, the source terminal S of Q1 (after the body diode) is at 3V, and the gate terminal G is at 0V. Q1 is then conductive, directing output to VOUT. When PMOS is conductive, the body diode is cut off, stopping current flow through the body diode. When both the solar panel and the lithium battery supply power, the gate terminal of Q1 is at 5V, and the source is below 5V, keeping Q1 cut off. Therefore, when the solar panel has sufficient voltage, current, and power, it exclusively prioritizes the external output of voltage,as shown in Figure 3.

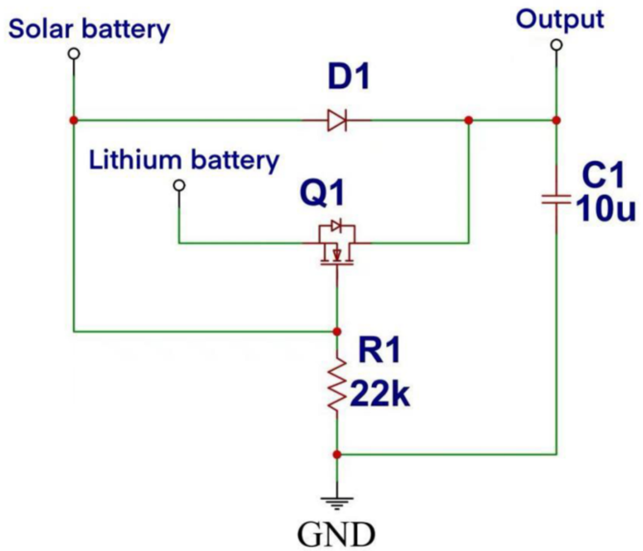

Figure 3. Automatic switching circuit.

3.5. Module circuit

3.5.1. 5V Voltage stabilization output module

Here, the USB 5V voltage stabilization output module, which is integral to the solar panel, is selected as the power supply component. This module offers stable output voltage and is compatible with USB interfaces. It can be directly connected to the solar panel, where it regulates the output voltage to provide the necessary 5V power supply for the entire system. Additionally, this module includes overcurrent protection, overvoltage protection, and short-circuit protection features. These protective mechanisms enhance the system's safety and stability.

3.5.2. Lithium battery protection board module

In this case, a pre-existing battery protection board is chosen, which features constant voltage output, short circuit protection, and protection against overcharging and over-discharging of the battery. Moreover, this protection board can achieve a 5Voutput, enhancing the output power [11]. It boasts very stable and reliable performance, ensuring the safe operation and longevity of the battery. Additionally, this protection board effectively prevents abnormalities within the circuit.

4. Layout of flexible solar panels

The placement of flexible solar panels must take into account the relationship between the panels and the human body. The layout should not only be based on the characteristics of the functional devices but also on ergonomic principles. Structural design considerations should include weight, impact on movement, and exposure to sunlight, aiming to minimize the impact of solar panels on both the clothing and the wearer [12].

4.1. Installation location of flexible solar panels

4.1.1. Weight

The placement of devices on clothing depends not only on the weight of the devices themselves but also on the load-bearing capacity of different parts of the body. Choosing parts with a higher load-bearing capacity can significantly reduce the perceived weight of the devices [13]. Clint Zeagler et al. point out that if a certain weight is added to clothing, the design of its weight distribution must ensure that it is not placed near nerves, arteries, or veins [14]. Therefore, the placement of devices on clothing must consider the local load-bearing capacity of the body [15]. As shown in Figure 4, the hips, back, and shoulders have stronger load-bearing capacities.

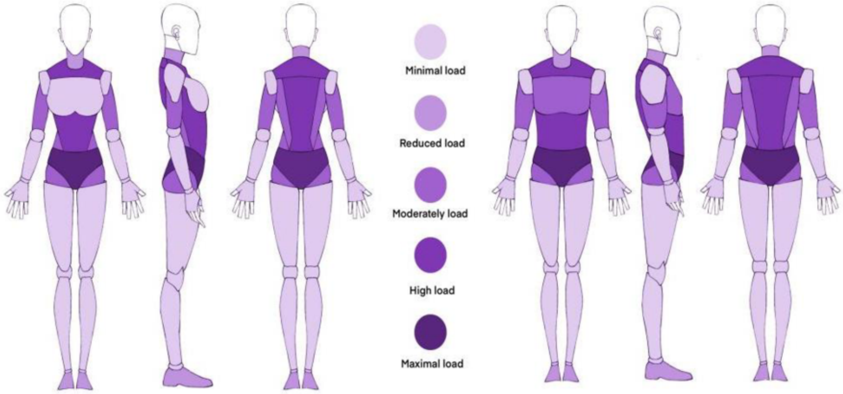

Figure 4. Human load-bearing pressure distribution map.

4.1.2. Temperature

The temperature of the human body is constantly changing, and when installing devices on clothing, it is important to consider the impact of the device on local body temperatures [16]. Direct sunlight on flexible solar panels and the friction they create with the clothing can lead to localized temperature increases [17]. As indicated in Figure 5, during rest, the upper body temperature primarily ranges from 34° to 35° Celsius. The cooler parts of the body are the arms and palms, while the front of the torso and upper back experience higher temperatures.

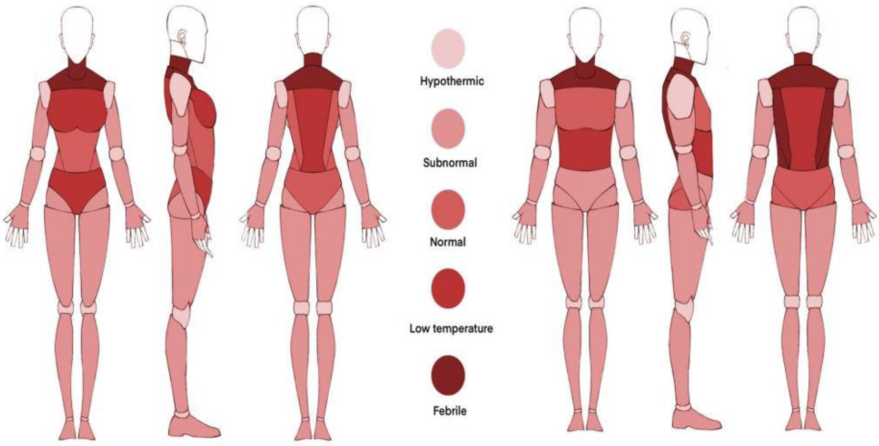

Figure 5. Human body surface temperature map.

4.1.3. Activity impact

When selecting placement locations, it is crucial to avoid areas of the body with large ranges of movement, such as joints, as this can not only impede human activity but also damage the solar panels [18]. Figure 6 illustrates the optimal placement of wearable devices on the body. According to the diagram, the areas on the clothing that have the least impact on the body are the chest, upper arms, and thighs. Secondary areas include the back and the back of the legs. Places that should be avoided include the abdomen and joints. Figure 7 shows that during work, when body movements are frequent, care must be taken to ensure that devices are not positioned where they are likely to be accidentally touched [19]. The diagram indicates that the back is a difficult area for the right arm to reach, and the legs are also hard to reach.

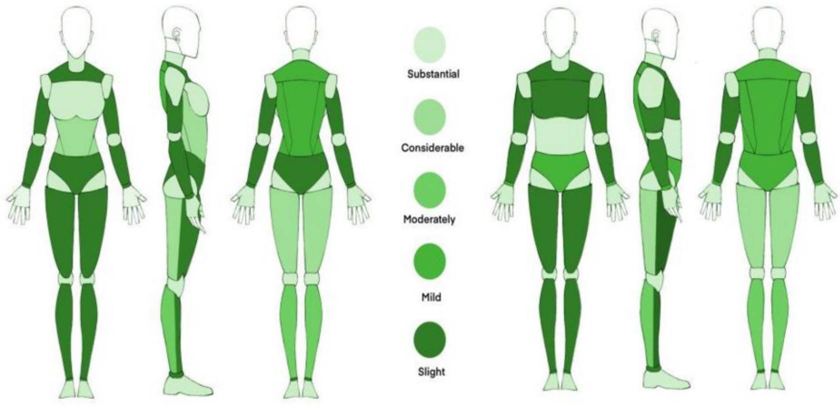

Figure 6. Activity impact range map.

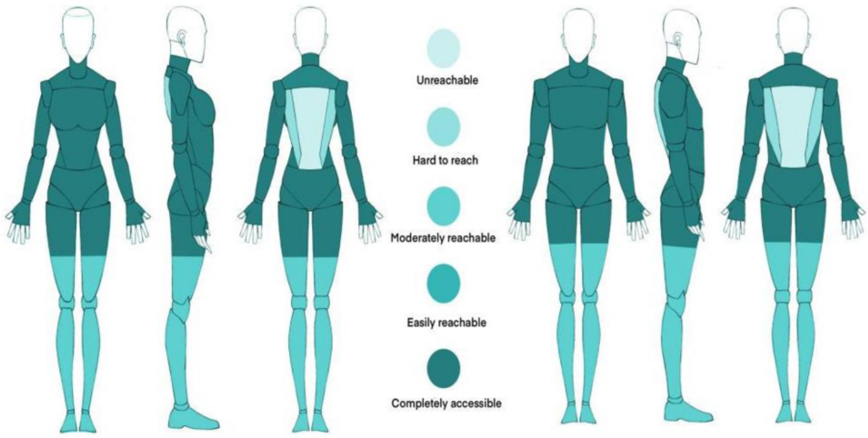

Figure 7. Human body reachability map.

4.1.4. Sunlight

Solar panels function by converting sunlight into electrical energy to meet basic power generation needs [20]. Therefore, it is essential to place flexible solar panels on the surface of clothing where they can receive sunlight. Considering the range of light reception [21], the front and back of the upper body of a delivery person in action receive the most sunlight, with the back area having the largest exposure.

Considering all the above requirements—the human body's reachability, movement impedance (activity impact), load-bearing capacity of the body (weight), body temperature distribution (temperature), and areas most exposed to sunlight while cycling—the back has been selected as the optimal location for the flexible solar panels. This area has a strong load-bearing capacity, falls outside the range of frequent body movement, and receives the most sunlight exposure.

4.2. Wiring layout of flexible solar panels

4.2.1. Wire selection for solar panels inside clothing

The wires used inside clothing for connecting solar panels must meet basic waterproofing, abrasion resistance, and high-temperature resistance requirements. They should be non-hazardous to human health, highly flexible, and suitable for installing electronic devices inside clothing [22]. Additionally, it should be possible to detach the connecting wires of the flexible solar panels from the garment for washing, as well as the USB port used for charging mobile phones, allowing the clothing to be washed separately [23]. The wiring connections between electronic devices should be as short and internal as possible. The longer and more numerous the wires, the greater the extent of electric current that passes through the body via these wires, increasing the potential threat to human safety. Furthermore, longer wires have a greater impact on body movement, and correspondingly, body movement can affect the durability of the circuits inside the clothing. Therefore, it is advisable to minimize and shorten the connections between electronic devices [24].

4.2.2. Wiring layout for solar panels inside clothing

The layout of the internal USB wiring must consider not only the fixed position inside but also which exit point is most convenient for the user. According to ergonomics, the front pocket area is easily accessible for both hands and suitable for extending a charging cable. Therefore, the exit position of the cable is designed at the front pocket. See Figures 8 and 9 for details: 1 represents the internal detachable charging cable, 2 is the Velcro used to secure the detachable charging cable, which wraps around from the waist, offering the shortest distance and minimizing restrictions and threats to bodily movement. The charging is accomplished through 3, which is a three-in-one charging head, capable of accommodating various phone models. This setup also meets the delivery personnel's needs to place the phone on the bike, in hand, or in a pocket at varying distances.

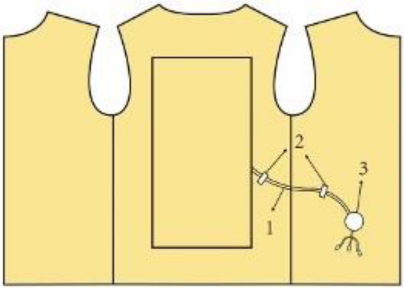

Figure 8. Schematic diagram of internal wiring fixed and laid flat.

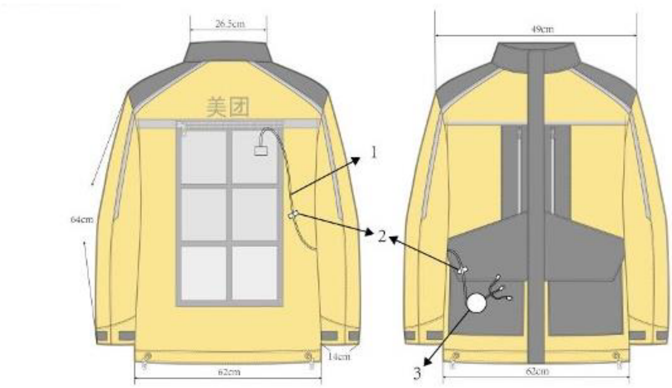

Figure 9. Schematic diagram of three-dimensional wiring fixation.

5. Apparel design plan

Functional clothing must not only fulfill the practical needs of the wearer [25] but should also align with modern aesthetic standards in style, fabric, and color choices. Notably, most solar-powered functional apparel tends to prioritize material and circuit design, often at the expense of essential attributes such as aesthetics and comfort. In designing sustainable apparel for outdoor delivery personnel, considerations extend to style, color, and fabric, responding to the specific demands of delivery work. This design strategy integrates technology with art and melds aesthetics with utility, crafting multifunctional apparel that embodies both functionality and style.

5.1. Design considerations for sustainable outdoor delivery apparel styles

The style is set as a 3-in-1 shell jacket, focusing on functionality and practicality [26]. In autumn, delivery personnel can wear just the outer shell or the inner lining alone to meet the basic needs for warmth and breathability during cycling tasks. In winter, the inner lining and outer shell can be combined, providing a warm and comfortable experience during cold outdoor rides.

1) Open the outer jacket zipper and place the inner liner inside the jacket.

2) Attach the collar fixtures to secure the inner liner.

3) Position the sleeves of the inner liner into the sleeves of the outer jacket, securing at the cuff fixtures.

4) Zip up the zippers between the outer jacket and the inner liner.

The green, functional delivery jacket with charging capabilities is detailed in Figure 10. In it, '4' represents the flexible solar panels that convert sunlight into electrical energy; '5' denotes the direct-insert 3D pockets, from which a 3-in-1 charger can be extended for charging and power sustenance; '6' is the detachable zipper, facilitating easy washing of the garment; '7' refers to reflective strips that enhance safety at night; '8' is a zipper pocket, which increases storage space. '9' stands for toggle clasps, and '10' for Velcro, both of which mainly serve to adjust the hem and cuffs freely, providing wind protection and warmth.

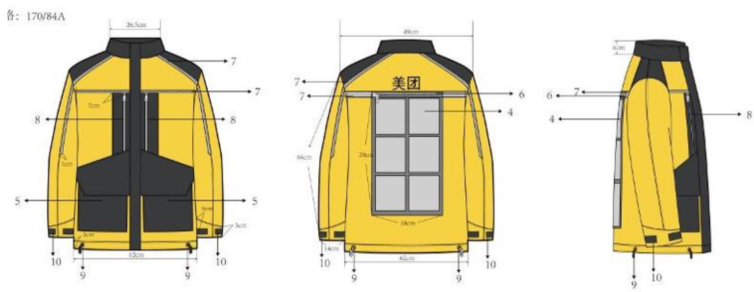

Figure 10. Three-view effect of the jacket.

Figure 11 the liner is designed in an H-shape with a stand-up collar, which works in conjunction with the outer jacket to provide double protection against wind and cold. The liner includes reflective strips'11'to enhance safety even when worn alone. Features'11'and'12'represent the elastic hem and elastic cuffs, respectively, designed to prevent wind and rain from entering during cycling. '13'refers to the pockets, which cater to the basic storage needs of delivery personnel during their work.

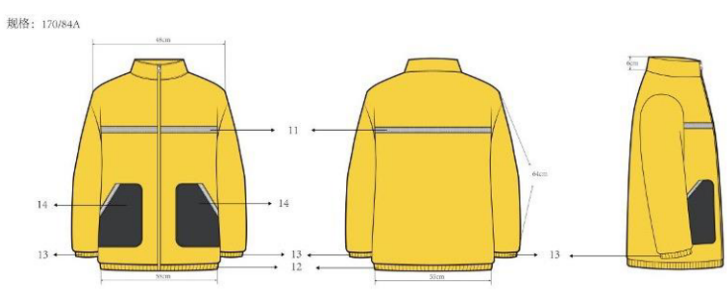

Figure 11. Three-view effect of the liner.

5.2. Fabric selection for sustainable outdoor delivery apparel

To accommodate the outdoor working conditions of delivery personnel, the fabric for solar-powered clothing must possess not only the typical outdoor functionality of durability and warmth but also superior moisture absorption, breathability, and waterproof capabilities due to the presence of electronic components. This is essential to prevent changes in electrical resistance caused by internal moisture, which could lead to the risk of electric shock [27]. In other words, the performance requirements for sustainable delivery apparel must include windproof, waterproof, and wear-resistant properties while also providing warmth. This helps to effectively block cold air and moisture, preserving body heat and protecting against cold weather. Therefore, the outer jacket is made from a blend of various fibers and cotton materials, featuring a special surface coating that provides waterproof, oil-repellent, and stain-resistant functions, as well as breathability and moisture drainage [28], as shown in Figure 12. The lining is made from all-polyester fabric, offering moisture-wicking and sweat-absorbent properties with a soft, skin-friendly touch as shown in Figure 13. The inner lining is designed for significant warmth retention, hence, fleece fabric is used to maintain body temperature, as depicted in Figure 14.

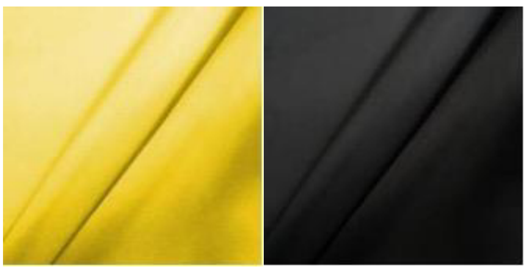

Figure 12. Outer jacket fabric.

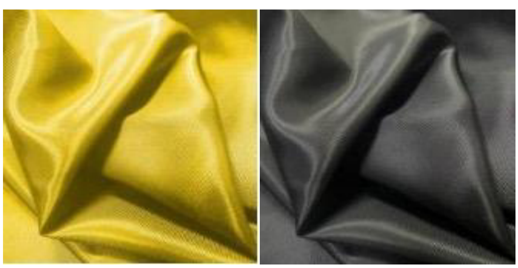

Figure 13. Lining fabric.

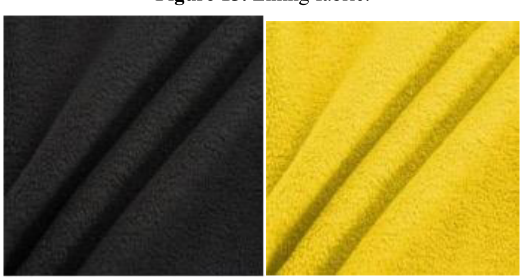

Figure 14. Lining fabric**.**

5.3. Color selection for sustainable outdoor delivery apparel

The color of outdoor workwear needs to ensure safety, and thus must be distinctive and recognizable [29]. Research has shown that when elderly people and children wear brightly colored red or yellow garments while outdoors, it enhances their safety and reduces the incidence of traffic accidents [30]. Therefore, the primary color selected for this design is bright yellow. To enrich the color scheme, charcoal black is chosen as the secondary color, combining a bright with a dark hue to enhance the overall appeal. The bright yellow makes the jacket stand out in a crowd, thereby improving the visibility and safety of delivery personnel. It also allows customers to quickly spot the delivery personnel when receiving orders. Charcoal black, being a solid and subdued color, adds a sophisticated and understated quality to the apparel. The combination of these two colors not only projects vibrancy but also stability, conveying a sense of reliability and reassurance.The overall color scheme is shown in Figure 15.

Figure 15. Color scheme of the delivery apparel.

6. Experimental testing and analysis

To ensure the normal functionality of the assembly structure of the flexible solar panels integrated with the apparel, tests were conducted on the circuit components. The method involved connecting the solar panels to the storage battery and testing the total amount of energy stored during periods of strong sunlight within a day. The collected data were then analyzed to produce the experimental results.

6.1. Experimental testing

To ensure reliability in practical applications, two power output methods were utilized: during the day or when sunlight intensity is sufficient, power output is supplied by flexible monocrystalline silicon solar panels, with the converted electrical energy stored in a lithium battery when no devices are using power; at night or when sunlight intensity is inadequate, power is directly supplied to devices from the lithium battery [31]. Accordingly, output tests were conducted separately for the flexible monocrystalline silicon solar panels and the lithium battery, which has a nominal capacity of 3000mAh.

Table 1. Test results of battery charging during periods of good sunlight exposure on a winter day.

Temperature (°C)	Time	Solar Panel Output Voltage (V)	Stabilized Voltage (V)	Voltage Before Stabilization (V)	Stabilized Current Output (A)
6	10:30	3.60	3.32	5.19	0.85–1.1A
6	11:00	3.88	3.56	5.19	
7	12:00	4.09	3.78	5.19	
8	13:00	4.21	3.87	5.19	
8	13:30	4.26	3.95	5.17	0.57–0.76A
9	14:30	4.26	3.97	5.17	
7	15:30	4.27	3.98	4.97	

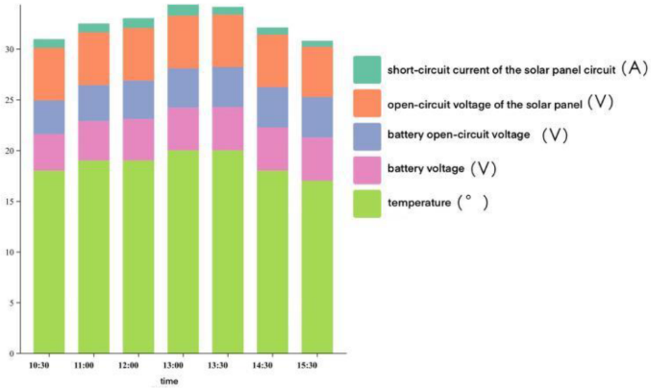

Figure 16. Test results of battery charging during periods of good sunlight exposure on a winter day.

Table 1 and Figure 16 illustrates the performance of flexible monocrystalline silicon solar panels throughout a day in winter, from 10:30 AM to 3:30 PM. The output of the solar panels follows a parabolic distribution, peaking during the midday when sunlight is strongest and decreasing as the intensity of sunlight diminishes later in the day. Furthermore, as the lithium battery approaches full charge, the charging rate decreases significantly. Calculations indicate that during the morning hours, when light intensity is sufficient, the solar panels can charge the lithium battery by approximately 50% (1500mAh) in two hours. If the battery capacity were larger, up to 4000mAh could be stored in a day, which meets the usage requirements of the delivery industry.

Considering the average smartphone battery capacity is about 4000mAh and delivery workers typically work around 10 hours per day, they frequently use their phones for order processing, navigation, and communication without much interruption. Assuming the phone is in high-use mode for these 10 hours, a smartphone might consume about 10%-20% of its battery per hour.

Table 2. Test results of battery charging during periods of good sunlight exposure on an autumn day.

Temperature (°C)	Time	Solar Panel Output Voltage (V)	Stabilized Voltage (V)	Voltage Before Stabilization (V)	Stabilized Current Output (A)
18	11:30	3.33	3.03	5.21	
19	12:30	3.95	3.74	5.22	0.95–1.12A
19	13:30	4.09	3.88	5.22	
20	14:30	4.17	3.97	5.22	
20	15:30	4.28	4.07	5.22	1.12–1.27A
18	16:30	4.37	4.11	5.22	
17	17:30	4.37	4.12	5.01	0.65A

Taking a median value of 15% hourly consumption, the phone's total battery usage over 10 hours of intensive use would be about 150%. This implies that delivery personnel might need to charge their phone from 0% to 100% and then up to 50% again to satisfy the continuous use over a 10-hour period. Overall, a delivery worker would require approximately 4000mAh for a full charge plus an additional 2000mAh for a half charge, totaling 6000mAh of energy to ensure their phone operates smoothly throughout the day. With a fully charged reserve battery and additional power from the solar panels, the total available power can reach about 8000mAh, adequately supporting the demands of the delivery industry.

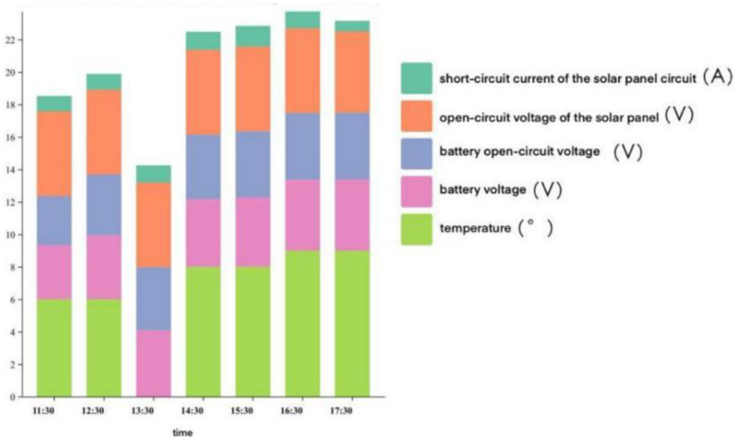

Figure 17. Test results of battery charging during periods of good sunlight exposure on an autumn day.

Table 2 and Figure 17 shows the test results of battery charging during periods of good sunlight exposure in autumn. From the data presented, it is evident that the intensity of sunlight in autumn is significantly higher than in winter. The output of the flexible monocrystalline silicon solar panels still follows a parabolic distribution, but both the intensity and duration of sunlight exposure are markedly better than in winter. Consequently, the power supply is adequate to meet the electricity demands of delivery personnel during their work.

Through the testing of the lithium battery, it was measured at the protection board module that the output voltage of the lithium battery is 5V, with the maximum output current reaching approximately 2A. The battery has a long charging cycle life, estimated at around 500 cycles. It is highly reliable, with strong stability and high output power, which allows for an excellent supply of electrical output.

6.2. Experimental analysis

The test results indicate that under clear sunny conditions in autumn and winter, the electricity generated by the solar panels is sufficient to meet the needs of delivery personnel. Considering the reduced solar intensity on cloudy or rainy days that may lead to insufficient power generation from the solar panels, a storage battery is incorporated within the apparel. This battery stores energy to provide charging capabilities, meeting the twice-daily endurance requirements of delivery workers. Furthermore, this charging apparel allows for the outer jacket to be worn alone in autumn for power supply, while in winter, the addition of the liner offers extra warmth. The apparel can be washed after removing the solar panels, and the charging cable is designed for easy access, with an adjustable length and multiple USB ports to fit different models. Overall, from a design perspective, the approach presents a theoretical and methodological integration of scientific technology and humanitarian concern.

7. Conclusion

The design of sustainable apparel for delivery personnel is a novel concept for the delivery industry, leveraging solar energy for self-sufficient power generation. This design not only addresses the limitations faced by delivery personnel who require power for their mobile devices while navigating the city but also steers the traditional uniform towards a sustainable future. It contributes positively to the burgeoning instant delivery industry in China. The convenience and professional well-being of instant delivery personnel are enhanced, reflecting a commendable spirit within the industry and further promoting the development of professional apparel in China's instant delivery sector.

Acknowledgment

We would like to thank the support of National Students' Platform for Innovation and Entrepreneurship TrainingProgram(S202310542053) & National Experimental Teaching Demonstration Center for Clothing Design and Engineering.

References

[1] Achala S, Theodore H, Tilak D. A Review of Solar Energy Harvesting Electronic Textiles [J]. Sensors (Basel, Switzerland), 2020, 20(20): 5938-5938. DOI:10.3390/s20205938.
[2] Teona T, Wanqing Y, K. M W, et al. Analysis of the Scale of Global Human Needs and Opportunities for Sustainable Catalytic Technologies [J]. Topics in Catalysis, 2023, 66(5-8): 338-374. DOI:10.1007/S11244-023-01799-3.
[3] You Jiexi, Yan Taohai, Lin Mingcang. Overview of Research on Carbon Fiber Heated Fabrics Based o n Flexible Solar Panel Technology [J]. Textile Industry and Technology, 2015, 44(01): 75-77.
[4] Kumar M G. A new solar-powered robotic arm guided master–slave electric motors of biomass convey or [J]. Journal of Engineering, Design and Technology, 2024, 22(3): 739-762. DOI:10.1108/JEDT-09-2021-0496.
[5] Goran K, Drago B, Alen B. Comparison of Two Different Battery Charging Methods [J]. BH Electrica l Engineering, 2023, 17(1): 17-25. DOI:10.2478/BHEE-2023-0003.
[6] Chen C, Yang H, Li X, et al. Optimization of solar and heat pump complementary powered desiccant a ir conditioning system [J]. Journal of Building Engineering, 2024, 87109084. DOI:10.1016/J.JOBE.2024.109084.
[7] Zhang Jingshuang, Hu Zhanhan, Wang Meili, et al. Progress in Solar Cell Research [J]. New Chemical Materials, 2016, 44(11): 1-4.
[8] Raut K, Shendge A, Chaudhari J, et al. Modeling and simulation of photovoltaic powered battery-super capacitor hybrid energy storage system for electric vehicles [J]. Journal of Energy Storage, 2024, 82110324. DOI:10.1016/J.EST.2023.110324.
[9] Chen Shiqing. Preparation and Performance Study of Solid Electrolytes for Solid-State Lithium Batteri es [D]. Ningbo University, 2019. DOI: 10.27256/d.cnki.gnbou.2019.001000.
[10] Li Yali. Research and Evaluation of Adjustable Temperature Heated Clothing with Flexible Film Solar Cells [D]. Beijing Institute of Fashion Technology, 2012.
[11] Kok L C, Fu X, Koh Y Y, et al. A Novel Portable Solar Powered Wireless Charging Device [J]. Electr onics, 2024, 13(2). DOI:10.3390/ELECTRONICS13020403.
[12] Fredric L, Anirudh A, Tae W J, et al. Offline Multiobjective Optimization for Fast Charging and Reduc ed Degradation in Lithium-Ion Battery Cells Using Electrochemical Dynamics [J]. IEEE CONTROL S YSTEMS LETTERS, 2021, 5(6): 2066-2071. DOI:10.1109/LCSYS.2020.3046378.
[13] Xiao Ding, Lv Huiyue, Shou Fengping. Progress in Research on Wearable Technology in Textile and A pparel [J]. Textile Science Research, 2023, (08): 62-64.
[14] K. Kukkonen, T. Vuorela, J. Rantanen, et al. The design and implementation of electrically heated cloth ing [A]. Fifth International Symposium on Wearable Computers [C]. Zurich, Switzerland, 2001; 180-181. DOI:10.1109/ISWC.2001.962136.
[15] Zeagler, Clint & Gandy, Maribeth & Baker, Paul. (2018). The Assistive Wearable: Inclusive by Design. 12. 11-36.
[16] Zhu Yechao, Zhang Jisheng, Bai Yue, et al. Zone Design of Women's Warp-knitted Yoga Wear Based o n Thermal and Humidity Comfort [J]. Chemical Fibers and Textile Technology, 2023, 52(11): 168-170.
[17] Cen Chan. Study of Heat Transfer Process Under Clothing in Outdoor Environment [D]. Donghua Uni versity, 2022. DOI: 10.27012/d.cnki.gdhuu.2022.001581.

[18] Shen Lei, Sun Tian. Current Status and Development Trends of Intelligent Wearable Technology [J]. Jo urnal of Apparel, 2023, 8(02): 125-133.
[19] Zhou Xiaoqi, Gu Jiawen, Wang Jun. Progress in the Application of Accelerometers in Intelligent Weara ble Devices [J]. Shanghai Textile Science & Technology, 2023, 51(06): 55-59+64. DOI: 10.16549/j.cnk i.issn.1001-2044.2023.06.072.
[20] Meng Xiuli. Design and Development of Functional Solar Clothing [J]. Shanghai Textile Science & Te chnology, 2011, 39(06): 39-41. DOI: 10.16549/j.cnki.issn.1001-2044.2011.06.016.
[21] Zhou Ao, Liu Chengxia, Dong Yi, et al. Development and Functional Testing of Solar Clothing [J]. Sil k, 2019, 56(02): 63-70.
[22] Zhao Jin. Research on the Functional Design of Outdoor Sportswear [J]. Journal of Henan Institute of Engineering (Natural Science Edition), 2011, 23(4): 13-17.
[23] Ren Ping, Liu Jing. Research Progress in Heatable Clothing Technology [J]. Textile Science Research, 2008(3): 12-18.
[24] Li Yali, Zhao Yuxiao, Su Jianmei, et al. Application of Flexible Solar Cells in the Apparel Field [J]. Sha nghai Textile Science & Technology, 2013, 41(02): 1-4. DOI: 10.16549/j.cnki.issn.1001-2044.2013.02. 001.
[25] Wang Yao, Xue Yuan, Xu Rongting. Design of Summer Environmental Sanitation Cleaning Uniforms Based on Safety Protection Functions [J]. Shandong Textile Science & Technology, 2023, 64(03): 15-1 7.
[26] Gu Xueyang. Research on the Functional Design of a Three-in-One Outdoor Shell Jacket Based on Ven tilation [D]. Donghua University, 2021. DOI: 10.27012/d.cnki.gdhuu.2021.000295.
[27] Li Zhuoyang. Research and Application of Humanized Design of Solar Panels and Outdoor Shell Appa rel [D]. Dalian Polytechnic University, 2018. DOI: 10.26992/d.cnki.gdlqc.2018.000027.
[28] Ren Xiangfang, Shen Lei, Ning Yanan. Design Study of a Smart Sanitation Uniform [J]. Packaging En gineering, 2017, 38(14): 164-168. DOI: 10.19554/j.cnki.1001-3563.2017.14.036.
[29] Wang Kai. Research on Color Recognition in Professional Apparel Design [D]. Donghua University, 2 017.
[30] Li Qing. Discussion on the Humanized Representation of Popular Colors [D]. Wuhan Textile Universit y, 2012.
[31] Fu X, Zhang C, Xu Y, et al. Statistical Machine Learning for Power Flow Analysis Considering the Infl uence of Weather Factors on Photovoltaic Power Generation [J]. IEEE transactions on neural networks and learning systems, 2024. DOI:10.1109/TNNLS.2024.3382763.