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(Full Paper)

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ABSTRACT

Solar power generation has become one of the main sources of power resources, but solar power stations are mostly built in desert areas with large wind and sand, and solar panel arrays need to be cleaned frequently to ensure power generation efficiency. In order to effectively improve the cleaning efficiency of solar panels, reduce the labor intensity, and better meet the requirements of photovoltaic power station for power generation efficiency, based on an existing solar panel cleaning robot, an improved design method is adopted to solve the charging problems, wind overturning problems and transportation difficulties. The innovative design on structure and shape of solar panel cleaning robot products is done, and the 3D model is established by using 3D modeling software. The design ideas and structural principles of several different design schemes are described in detail, which provides reference for the upgrading of solar panel cleaning robot. The role of big data and artificial intelligence in design is analyzed, and that will bring new development direction of intelligent cleaning robot for solar panel. Finally, the work is summarized and the research prospect is put forward.

Keywords: solar power panel, intelligent cleaning robot, wind resistant design, convenient transportation design, structure and shape design.

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INTRODUCTION

Solar Power Generation

Solar energy is a renewable, clean and reliable energy source. In recent years, the national and local governments have strongly supported photovoltaic power generation, and the installed capacity of photovoltaic power generation in China is increasing by a large margin every year (Zhang *et al.* 2017). Solar panel is an important power generation device for photovoltaic power generation. In order to ensure power generation efficiency and absorb as much sunlight as possible, it is particularly important to clean the solar panel (Bernard, 2018). At present, the technology of solar panel cleaning equipment is not mature, the price is expensive, and the cleaning efficiency is not high. There are still various problems in the specific use of the formed products. In view of this situation, the structure and shape of the solar panel cleaning robot are innovatively designed, which is mainly used to solve the practical problems in the use of products.

Solar panels typically consist of photovoltaic (PV) cells covered by a protective glass coating, which generate electricity when subjected to radiations. However, the capability of electricity generation is constrained due to layer of dust on PV modules. The solar panels in the Middle East and North Africa are easy to be polluted by sand dust. Photovoltaic power stations in China are mostly built in desert areas as shown in Figure 1, which is windy and dusty, so solar panels need to be cleaned frequently. In some areas, if not cleaned up for one month, the power generation will be reduced by about 10% (Zhang *et al.* 2019; Fan *et al.* 2018). Hassan *et al.* (2017) designed a robotic cleaner for cleaning PV modules of Quaid-e-Azam Solar Park (QASP). The mechanism primarily consists of ducted fan, roller brush and blower fan. Also Said *et al.* (2018) presented an innovative low-cost cleaning technique for photovoltaic panels. From this it can be seen the importance of solar panel cleaning to guarantee the efficiency of the electricity generation.

Status of cleaning robots

Riawan *et al.* (2018) said Industrialization in our modern society is reflected by the transformation from traditional life style into modern one. The transformation can be seen from development of technology that occurs rapidly. Today, the use of robots reaches all aspects of human life, both in the industry and in everyday activities. Robots have assisted people in everyday activities and its application helps human activity to reduce level of accident. Type of works that are suitable for robots are tedious, dangerous, and boring jobs such as the cleaning of solar panel.

In recent years, solar panel cleaning robot has gradually developed and replaced manual cleaning. The appearance and working principle of the robot are various, but they can be mainly divided into two types: small-scale trackless walking type and big crossing track walking type, as shown in Figure 2. The three types of robots on the left side of the figure are suitable for cleaning solar panels which are arranged approximately in a straight line, and need to have a specifically set walking track or

be displayed by the composed solar panel supports; the three cleaning robots on the right side of the figure are similar to the common household sweeping robots, which are more suitable for occasions where the tilt angle of solar panels is not too large, and can walk freely without relying on the track but arranged by program. It is easy to work on solar panels arranged in sheets.

Source: Taken from North-West of China.
Figure 1: Solar power station.

Source: Download from website (https://image.baidu.com/).
Figure 2: Two main categories of cleaning robot for solar panel.

Patil *et al.* (2017) reviewed different exiting methods of solar panel cleaning, after considering advantages and limitations of each, they got a conclusion that a brush type solar panel cleaning could be ideal as it requires no water or a little water for removal of dust. Also, it is low cost and can be indigenously developed. It also operates and considered as an auxiliary unit of the exiting solar PV system. But there are still several points to be improved. Under investigation and analysis, the existing solar panel cleaning robot products are classified and summarized as in Table 1.

Table 1: The status of cleaning robot for solar panel.

Style / No.	Small-scale trackless walking type	Big crossing track walking type
1.	The model is compact and convenient to handle and use, but the battery capacity is limited, so it is not suitable for long time and large area operation	The model is too large, and the transportation is not very convenient. It usually needs split transportation, on-site assembly, and the continuous working time is limited, which needs to be improved
2.	Basically realize the cleaning function, and divided into dry and wet cleaning technology, dry is more suitable for the working environment, will not leave clean water stains	It is mainly used for water-free cleaning operation such as roller brush and row brush, which is suitable for the occasion with linear arrangement, small distance between front and back and small height difference between upper and lower
3.	The electronic control technology is used to plan the walking track, which is easy to cause the problems of insufficient cleaning or repeated cleaning	The walking path is controlled by the track, and the surface of the solar panel can be cleaned completely
4.	It is not suitable for working on the solar panel with large tilt angle, and it is easy to be blown over by	It is suitable for working on the solar panel with any tilt angle, and the problem of preventing being blown

	wind	over by wind should also be considered

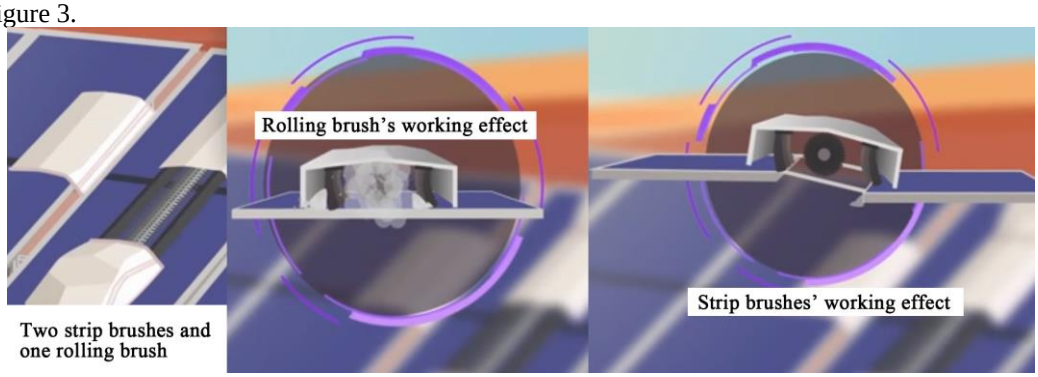
Source: This study.

Since most solar panels are inclined, the inclination angle is related to the solar altitude angle, and the theoretical optimal inclination angle is equal to 90 degrees subtract the local solar altitude angle. However, due to the continuous change of solar altitude angle, and the solar panels are mostly fixed angle type, so they are mostly installed at about 40 degrees. Therefore, compared with the small-scale trackless walking cleaning robot, the crossing track walking cleaning robot is more suitable for the working environment, has more stable working performance, better cleaning effect and higher working efficiency. As can be seen from the analysis in Table 1, there is still some problems to be solved even for the crossing track walking type cleaning robot.

STUDY OF DESIGN FOUNDATIONS——ORIGINAL SCHEME

The original scheme has a good cleaning ability, and through the design of the walking mechanism, it can realize automatic adjustment within a certain range, so as to cross certain obstacles. The specific advantages are as follows:

① The setting of two strip brushes and one rolling brush overcomes the shortcomings of ordinary single rolling brush cleaning robot, such as soft and long bristles, easy knotted when stained with water and ash, high-speed rotation damages photovoltaic panel, and the bristles are too soft to remove bird droppings and other sticky substances. The middle row brush is used to push away the coarse sand and gravel, so as to prevent the rolling brush from rolling with gravel and damaging the photovoltaic panel. At the same time, the strip brush can also help the dust fall along the edge better to avoid dust residue on the PV panel. As shown in Figure 3.



Source: This study.

Figure 3: Cleaning structure of the cleaning robot.

② It can climb a slope with an inclination of 28 ° and a plane dislocation with an angle of 12 ° and is automatically adjusted after the tilt is not synchronized. This can avoid the uneven driving power from different wheels caused by bad moving posture, which weakens the ability to cross obstacles and even damage the motor. This ability also allows photovoltaic panels not to be completely aligned, thus expanding the working range of the robot. As shown in Figure 4.

③ The maximum height difference of 5cm can be crossed. When the height difference between adjacent panels exceeds the radius of the wheel, it will return automatically after three trials under the action of sensors and controllers.

④ It is equipped with two sets of brushes, soft brush and hard brush. According to the type of dirt on the photovoltaic panel, the brush can be replaced. The hard brush is used to clean the sticky substances such as bird droppings and insect eggs, and the soft brush is used to clean up fine dust.

In use and transportation, it is found that the original scheme still has several defects which need to be improved, mainly focusing on three aspects: first, the working hours are limited by the battery power; second, it is inconvenient to transport; third, it is to prevent wind overturning.

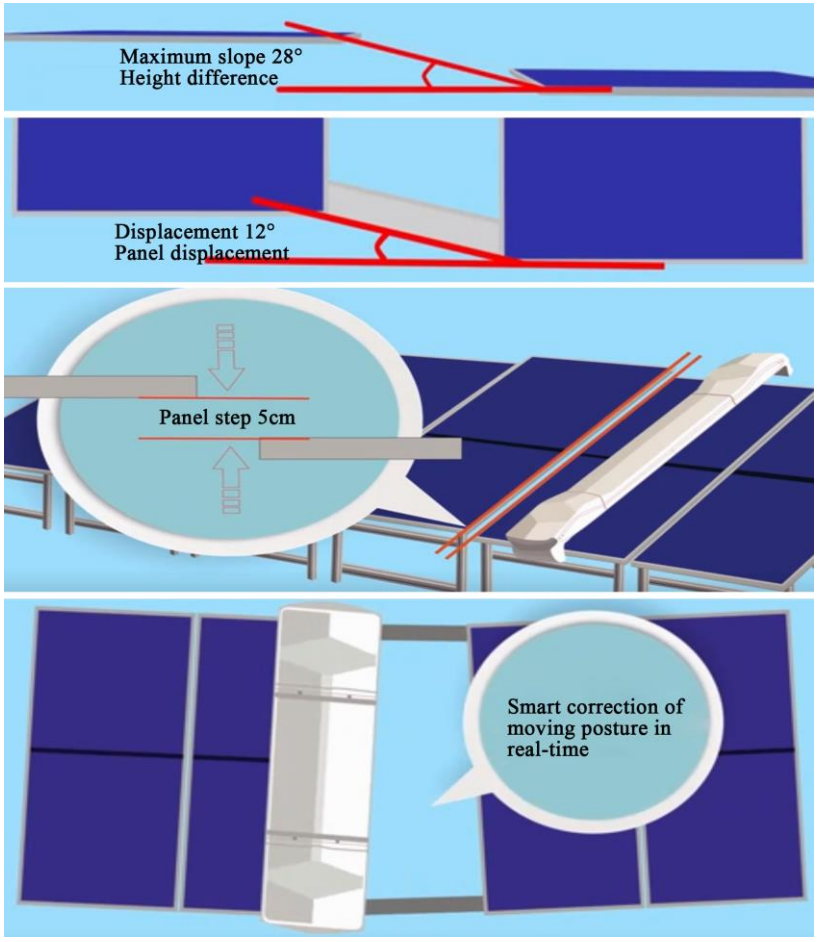
RESEARCH ON DEFECTS-ORIENTED DESIGN

Design to prevent overturning by wind

The shell of the original scheme is divided into three sections, which are made of plastic material and are made by suction molding process. They are installed above the internal structure of the product, such as walking and cleaning, in a semi enclosed shape. In the process of use, due to the bad working environment of the solar panel cleaning robot, windy weather is often encountered. The strong wind will not only bring certain wind resistance to the robot, but even overturn the whole robot when it is serious. In the face of this problem, thinking of the reason that "Dayu flood control" Dredging and drainage are better than blocking, it is also associated with the problem of wind resistance in the driving of the car. Observing the shape of the car, in addition to the conductivity of the vehicle shape, the front part of the car is also designed with a ventilation area. To solve the windproof problem of the solar panel cleaning robot, we should also take the way of relieving the wind. The design results are shown in a, b, c, d, e, f in Figure 5.

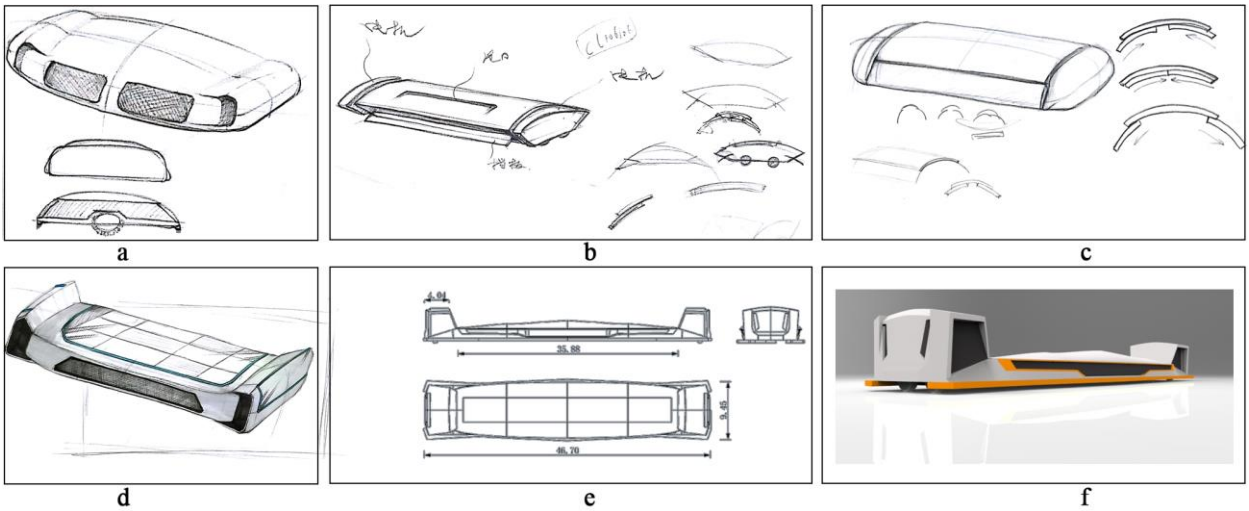
Figure 5a shows the sketch of the design scheme for simulating the shape of the front of the car and streamline modeling of the body with design of vent channels. Figure 5b shows the design based on the same principle by observing the wind deflector at the air outlet of the air conditioner. The upper air outlet is set at the upper part of the shell. The wind resistance pressure sensor

controls the motor to drive the wind deflector to operate. Figure 5c shows the design through thinking of the aircraft wings running under the condition of wind. The two sides of the robot are wind boards. The motion principle of the wind board is slide track type. The body is equipped with weather sensing system, which can control the wind board to slide in different degrees by sensing the weather. Figure 5d shows the hand-painted effect picture of the final scheme, and the side vent is set to relieve the wind that causes the robot to be overturned. Figure 5e shows three views of the final scheme. Figure 5f shows the effect picture after modeling and rendering of the final scheme. The shell is designed and deformed according to the shape of the front of the car. The motor parts at both ends are made into similar convex lamp forms, the fuselage is made into streamline like automobile, the gray parts are vents, and the overall material is PC or ABS.



Source: This study.

Figure 4: Working performance of the cleaning robot.



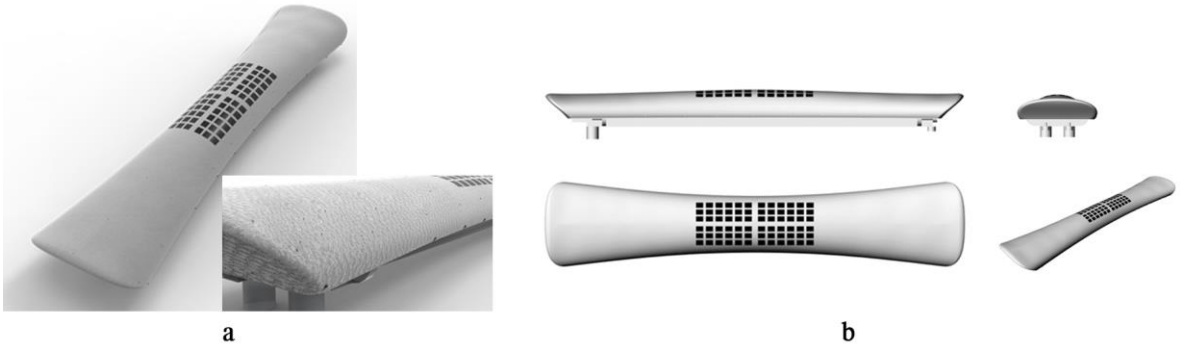
Source: This study.

Figure 5: Design of solar panel cleaning robot to prevent overturning by wind.

Convenient to transportation design

The shell of the original solar panel cleaning robot is made of rigid plastic processed by plastic suction process. The shell is divided into upper, middle and lower segment three parts. The whole is an axisymmetric model, that is, the upper and lower segments have the same modeling structure, while the middle part is basically a straight line segment without special structure. In the transportation process of the robot, the shell and the internal mechanical structure are transported separately. The internal mechanical structure is mostly rigid body. The robot with a span of more than 4 meters takes up a larger space, and the shell part is thin. Separate transportation can prevent the shell from crushing and damaging. At the same time, the shell is divided into three sections, which can appropriately save the occupied space during transportation. The Symmetrical structures can be transported in the form of stacking. However, there are some special convex and concave structures in the upper and lower sections, which can not save space very well. Therefore, the transportation of the original solar panel cleaning robot is not very convenient.

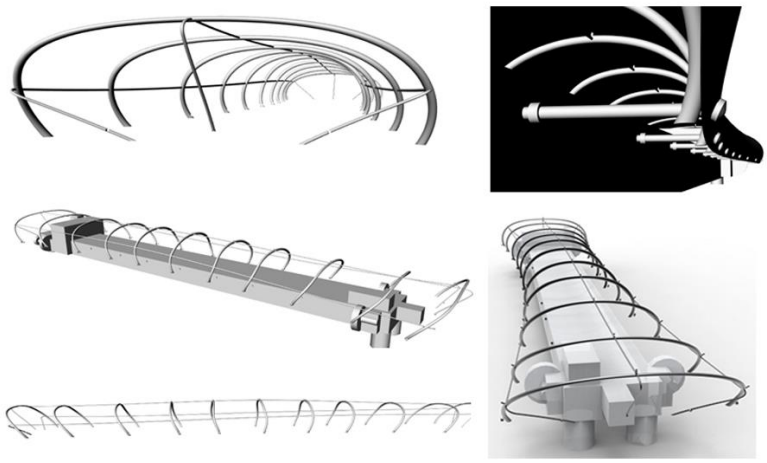
In the new design, the shell is redesigned from the original hard plastic material to flexible material. The robot shell is assembled on site. The flexible material can be folded and transported, which is very convenient. The design scheme is shown in Figure 6. Figure 6a shows the overall shape and material effect details of the design scheme; figure 6b shows the three views and the equal side view of the design scheme.



Source: This study.

Figure 6: Design scheme of solar panel cleaning robot convenient to transportation.

However, although flexible materials can make transportation more convenient, due to the flexible materials easy to deform, it is difficult to form a certain shape. In order to further solve this problem, a support scheme with a certain shape under the flexible material is designed, and the whole flexible shell is supported by the corresponding shaped bracket. At the same time, considering the beauty and streamline of the overall shape, the shape imitates the streamline shape of the car, and the height of both sides is slightly lower than that of the middle part. The internal structure scheme is a fishbone like structure. A main support rod is designed, and then the bent bracket is fixed on both sides. The overall shape looks like a fish skeleton. This design can make the flexible material have more support points and form a fixed shape. Each supporting rod is connected by inserting, which is easy to disassemble and assemble. The internal structure is shown in Figure 7. The overall internal frame is built to look like a fish skeleton. The poles on both sides of the framework run through all the supports to stabilize the main body. The bracket forming the shell shape is inserted into the prefabricated holes on both sides of the main beam of the internal structure to fix the whole shell shape. At the fixed node of the bracket, the opening is positioned on the flexible material, and the metal ring is used to lock the edge. During the installation, the hole is inserted into the small stud on the fixed node, and then the nut is used to compress and fix, so that the whole flexible shell is in the tension state. The material can be made of elastic textile fabric, and the gap between the fabrics has certain wind ventilation effect.



Source: This study.

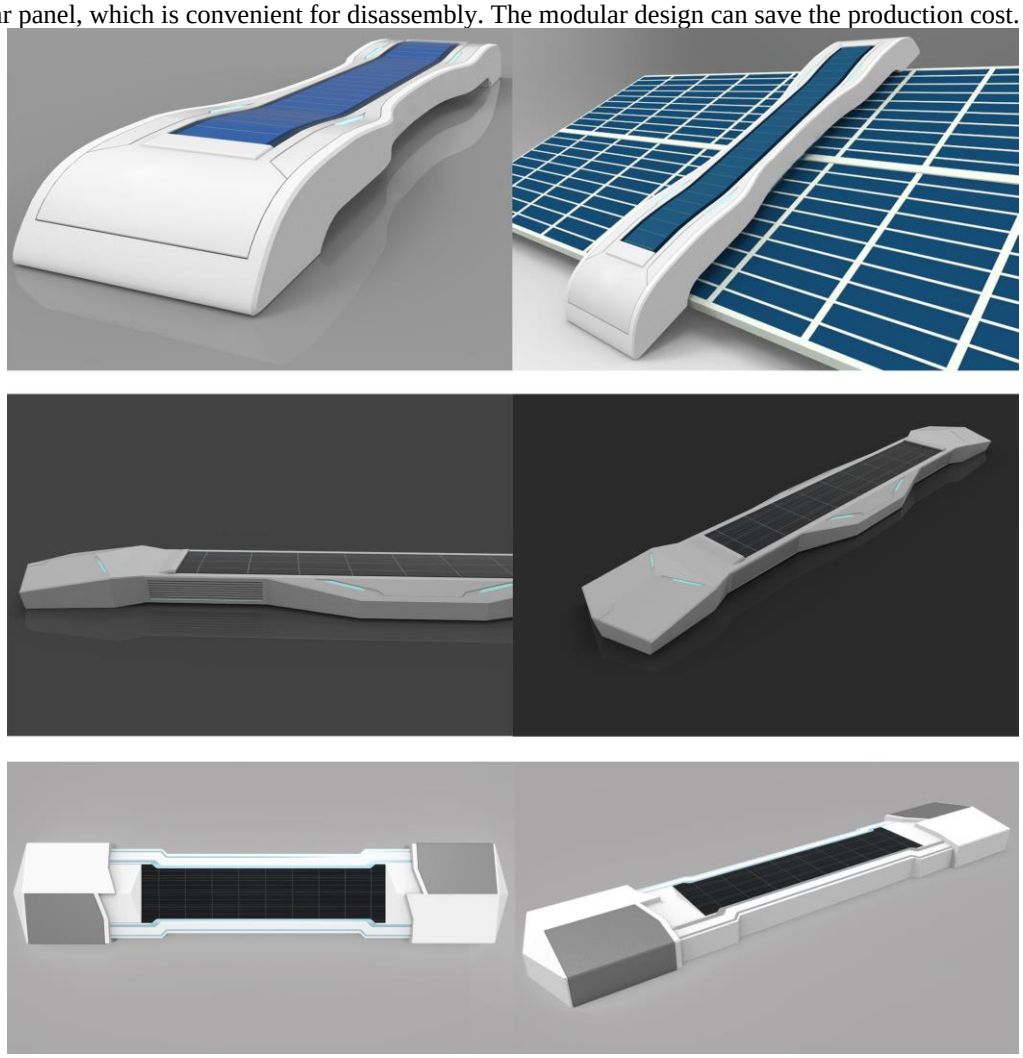
Figure 7: Shell support structure of solar panel cleaning robot convenient to transportation.

Design adapted to new energy sources

The solar panel cleaning robot walks back and forth on the solar panel. In the original scheme, the power required for the robot to walk on the solar panel is provided by its own power carried, which is rechargeable battery pack. Due to the limited number of batteries carried, generally the robot needs to return to the fixed charging position for charging after working for a period of time, which wastes working time, reduces work efficiency. To improve the performance of the robot for its working environment, if it can make full use of solar energy to provide power for its own walking, it will be a good choice. Therefore, the power supply mode and energy source of the solar panel cleaning robot are improved. A flexible optical fiber panel is designed on top of the robot shell, which can not only provide walking power for the robot, but also not reduce the overall beauty of the robot. Therefore, an improving redesign of the shell shape is done. In the design, the flexible solar fiber panel as shown in Figure 8 needs to be embedded in the top of the solar panel cleaning robot shell. Considering the beautiful appearance and the installation of flexible optical fiber panel, the unnecessary lines are simplified as much as possible, which is brief but not simple.

Source: Taobao picture.
Figure 8: Flexible solar fiber panel.

Figure 9 shows three design schemes, which can better integrate flexible solar panels, so that the robot can constantly replenish energy while working. The design of plug-in block, pressure plate or sticker is used to fix and compress the edge strips around the flexible solar panel, which is convenient for disassembly. The modular design can save the production cost.



Source: This study.
Figure 9: Three design schemes of solar panel cleaning robot.

THE ROLE OF BIG DATA AND ARTIFICIAL INTELLIGENCE IN DESIGN

Multi-functional intelligent products design

With the advent of "industry 4.0" and the era of big data, the change of products is becoming more and more intense, and has evolved into the main melody of all walks of life, "the only constant is change" (Jyh-Rong Chou., 2020). The innovation ability of traditional industries is constantly improving, and the development opportunities are increasing. Under the influence of technologies such as artificial intelligence and virtual reality, industrial design ushers in great development opportunities (Jia, L. B. *et al.*, 2020). More and more multi-functional intelligent products appear, but how many of the functions of the products are popular with people and have high utilization rate? There are cognitive differences in modeling images. Professor Su J. N. and Zhang, X.X. *et al.* (2016) have carried out entropy evaluation research on them. The research points out that due to the differences of cognitive environment, knowledge background and experience, users, designers and engineers have different image cognition of products. Therefore, it is necessary to integrate the three modeling entropy evaluation models based on image cognition to determine the product shape. Many scholars all over the world have carried out research on intelligent product design (Pereira Pessôa, M.V. *et al.*, 2020; Chen, X. *et al.*, 2019). To judge the functional practicability of intelligent products, we should combine intelligent products with big data platform based on real feedback in actual use, collect and analyze objective utilization data and process data in the design process through big data platform, and guide the functional design of multi-functional products. This will be the research hotspots in the future.

Big data as a new design factor

As one of the "national big data strategy" of the "13th five year plan", China's big data industry is in a period of rapid development, and new products and services are constantly launched. The significant trend of big data development makes data become a new "factor of production", leading the design and development of products. In the era of big data, although 59% of the data is invalid, 70% - 85% of the data is too complex, 85% of the enterprise data architecture can not meet the demand of data volume and complexity growth, and 98% of the enterprises can not provide the correct information for the business in a timely and accurate manner. However, the application of big data is constantly studied in various fields, such as performance means and design methods or product functions in design are constantly absorbing the advantages of big data and designing more, newer and more market-oriented products from the perspective of user experience. The emergence of big data opens great opportunities. Big data may provide reference answers for human beings to make decisions through mining and analytical processing, but it could not replace human thinking. (M.Chen, 2014)

Artificial intelligence as means or function in design

Since the birth of artificial intelligence, the theory and technology are increasingly mature, and the application fields are also expanding. It can be imagined that the scientific and technological products brought by artificial intelligence in the future will be the "container" of human intelligence. Big data can be regarded as one of the three carriages driving artificial intelligence, which can provide power source for the development of artificial intelligence. The important thing of big data is the whole process of data processing, mining, analysis, visualization and application, and data source is the primary problem. The combination of artificial intelligence and design is mainly reflected in two aspects: the development of artificial intelligence products and the application of artificial intelligence technology in product design, such as intelligent sweeping robots and intelligent bracelets in life are both artificial intelligence products. For example, a chair designed by Stark relying on artificial intelligence technology during the Milan Design Week 2019 reflects the application of artificial intelligence technology in product design for the first time. However, recently, Sun L. Y.'s team of Zhejiang University (2020) conducted a study on the current situation and development trend of human centered intelligent product design, pointing out that the field of artificial intelligence is facing an important transition from technology driven to people-oriented, and the application of artificial intelligence should assist and enhance human beings, rather than replace human beings.

Big data, artificial intelligence and design

In summary, the application concept of big data in various stages of product design has been basically mature. For example, in the demand analysis stage, demand information extraction, demand function transformation, demand preference analysis and demand trend prediction can be carried out through data conversion and collection; in the scheme generation stage, function mapping, scheme optimization and overall innovation can be achieved through data storage and processing; in the scheme evaluation, product performance acquisition, index weight analysis and scheme selection evaluation can be completed through data analysis and data interpretation. The design based on big data can focus on real people and real events, pay attention to product service, use environment and information feedback, which will help to better understand the essential needs of users for products in the whole product R & D process. The design oriented to users' essential needs can adapt to the development and progress of human beings and society. However, the specific application and solution of data-driven product innovation design need to be studied. For the development of artificial intelligence products, data is the underlying foundation for the learning ability of intelligent products. At the same time, artificial intelligence products should also become the source of supporting the continuous enrichment and improvement of big data. The collection, storage and upload of user use information by artificial intelligence products will help enrich and optimize big data resources. Therefore, in the design of intelligent products, it is necessary to collect and return some objective data in the user's use of the product as much as possible on the premise of protecting the privacy of users. In addition, in view of the differences between the machine thinking of artificial intelligence and the design thinking of human beings, the design process can not completely rely on big data and AI technology, and the participation of designers cannot be shielded to think about user needs sensibly, strive to achieve the human centered intelligent product design.

CONCLUSION

In summary, with the continuous development of new energy and new technology, new demands and automation products are constantly emerging. More and more fields can liberate human hands and realize mechanization. Combined with the problems found in the production, transportation and use of products, solutions are given respectively, and some solutions can be combined to solve multiple problems comprehensively. For example, vent can be opened on the side of the shell embedded with flexible solar panel, and the shell surface with support structure and flexible material can also be attached with flexible solar panel. Problem driven design, in the future use of solar panel cleaning robot, there will be more room for further development and improvement, such as the application of artificial intelligence technology, which can realize robot information feedback, big data platform can support the construction of integrated management system, timely tracking and discovering the use of robots and problems, and even remote maintenance, It will be the direction of future research. The improved design of the shell combined with the technology of the cleaning robot provides a reference for the upgrading of the solar panel cleaning robot, and can also be applied in the design of similar products.

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