Product Radical Innovation based on Global Idealization

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Abstract. Radical innovation as a revolutionary technology is a key for enterprises to update product technology and enhance market competitiveness. This paper proposes a method of the radical innovation based on global idealization. A target product is proposed and developed based on customer requirements and market changes. Opportunity of the radical innovation is identified based on the patent analysis using technology growth rate, technology maturity coefficient, and technology aging coefficient. The target product is designed based on the global idealization to build its function model. The global idealization is implemented using methods of trimming and function reorganization in the resource analysis, function-oriented search and effect search. Inventive problems are solved using TRIZ tools. Solutions are evaluated by the level of ideality based on the analytic hierarchy process and definition of the radical innovation. Feasibility and effectiveness of the proposed method is verified in the radical innovative design of a dust-removal device on solar panels.

Keywords: Radical innovation, TRIZ, Patent analysis, Product life cycle, Global idealization, Function reorganization
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1 INTRODUCTION

Product innovation is a process to constantly search for idealization [20, 29]. Radical innovation (RI) is required in product improvement and development using innovative technologies. It is generally believed that RI occurs in the mature stage of a product life cycle [14, 22]. The starting point of a new S-curve is an indicator of RI. Henderson et al. [10] defined that RI should be satisfied two conditions, that is, a new product concept and a significant change in the connection between core components of a product. Surprising product features are crucial for designing products to potentially trigger attention and curiosity [1]. Leifer et al. [22, 23] believed that the result of RI can change the working principle of a product, improve five or more times performance, or reduce 30% or more cost of the product. In this paper, RI should be satisfied one of the following two conditions, namely, a change of principle and a significant change in the connection between the core components of a product. RI has recently gained much attention among practitioners and scholars. Zhang [28] and Miriam [16] discussed the influence of internal and external factors (i.e., risk-taking, environmental uncertainty and intellectual capital) on RI of enterprises. In order to identify the RI opportunity, He et al. [9] combined the technology effect matrix and identification of the technology readiness level to build a three-dimensional technology effect model for a comprehensive analysis of the patent information. Yang et al. [25] used a radical trimming method for the fuzzy front-end stage of product development to improve the efficiency of RI. The above research provides some guidance in business, management and theoretical methods. However, the most of existing studies mainly accidentally form a RI solution without considering the long-time effect and high risk of the solution [4]. It is necessary to develop an effective RI method.

Idealization is an abstraction of objects and can be used in an innovative process. Idealization includes local and global idealizations in TRIZ (invention problem solving theory) [22]. Local idealization refers to using different methods to realize the same principle. Global idealization, choosing different principles to realize a same function, can guide decision making of a product design process [22]. It considers the function forbidden, system forbidden and principle changed in a system. Individually pre-conceived expectations are crucial to surprise emergence. These expectations relate to functional, behavioral or structural variables. Different forms of stimuli, especially for a scope allowing users to undertake the widest exploration possible, have a great influence on the ideation creativity [2]. TRIZ can be used as tools to analyze and solve innovation problems [6, 12]. TRIZ tools are also exploited to support problem solving in the problem solution network approach [8]. In this paper, a method of RI is proposed based on the global idealization. According to customer and market requirements, a target product is proposed and developed based on the patent analysis. The occurrence stage of RI is identified by the patent search and analysis. The target product is designed based on the global idealization to build its function model. The global idealization is implemented using methods of the trimming and function reorganization, such as the resource analysis, function-oriented search (FOS) and effect search. Inventive problems are solved using TRIZ tools. Solutions are evaluated by the level of ideality based on the analytic hierarchy process (AHP) and RI definition. RI design of a dust-removal device on solar panels is developed using the proposed method.

2 PROPOSED METHOD

RI can improve the leading role of an industry in the market [26]. Product RI occurs in the mature stage of a product life cycle. Global idealization is introduced in this paper for product RI. Function reorganization is realized by using the resource analysis, FOS and effect search. TRIZ and ideality are used in the solution generation and evaluation.

2.1 Determination Opportunity of RI

Global idealization considers the infancy, growth, maturity and withdrawal stages of a product life cycle in an S-curve [22] as shown in Figure 1 (a). RI occurs in the mature stage. Based on customer requirements and market changes, a target product can be identified. Related patents can then be searched using keywords [5] through patent software tools. Denoising is a common auxiliary retrieval strategy to further screen information irrelevant or insufficient for patent analysis purposes [13]. For example, in the process of denoising, the patent applicant's name, title of the invention patent, and legal status are selected as screening objects. Furthermore, these stages can be determined by the patent analysis, that is, the opportunity of radical innovation can be identified.

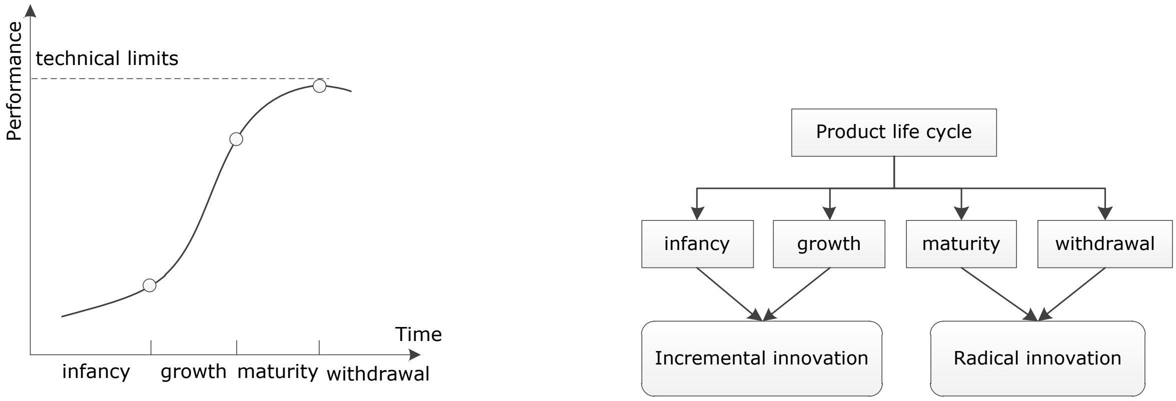
Based on four stages of technology development, an innovation direction can be selected based on Figure 1(b). An index measurement method is used to predict product maturity [18, 27]. Indicators are developed using data features to reflect changes in the number of different types of patents, that is, technology growth rate V, technology maturity coefficient α, and technology aging coefficient β. According to different characteristics of different indicators in different stages, the product maturity is decided. For the RI direction, according to the number of related patents such as invention patents, utility patents and appearance patents, three statistical parameters can be obtained for a quantitative analysis of patents, namely technology growth rate V, technology maturity coefficient α, and technology aging coefficient β [18, 27], as shown in Equations (2.1), (2.2) and (2.3).

$$V=\frac{a}{A} \tag{2.1}$$

$$\alpha=\frac{a}{a+b} \tag{2.2}$$

$$\beta=\frac{a+b}{a+b+c} \tag{2.3}$$

where a is the number of invention patent applications in the year, A is the total number of invention patent applications in the past five years, b is the number of utility patent applications in the year, and c is the number of appearance patent applications in the year.



(a) S-curve of product life cycle (b) Decision-making of innovation direction

Figure 1: Product maturity prediction and decision-making.

The linear trend of three statistical parameters can be used to determine stages of S-curve. The product is in the infancy stage or growth stage when the linear fitting of *V* is on the increase. Otherwise, there will be a linear fitting trend of α. A decreasing trend means that the technology becomes mature, the product is in the mature stage. If not, β shows a decreasing trend, the product is in the withdrawal stage. When the product life cycle is in the mature or withdrawal stages, RI is required for enterprises to improve the product as shown in Figure 1 (b).

2.2 Realization of Global Idealization

The occurrence stage of RI is determined in Section 2.1. The function model is built based on the component and interaction analysis to help engineers analyzing product functions. System components are obtained through the system decomposition. Subsystems are obtained from the total system gradually to form representative components as shown in Figure 2. In addition, according to product constraints, supersystem components are obtained. An interaction matrix can be built to explain interactions between two components. Table 1 shows interactions of components, such as the system component, supersystem component and object, where "+" stands for the interaction between them, columns list active components and rows are passive components. The function model is then built as shown in Figure 3. A function is formed by two components and their interactions in the function model.

Components	S_1 (system)	S_2 (system)	S_3 (system)	S_4 (supersystem)	S_5 (object)
S_1 (system)			+		
S_2 (system)	+				
S_3 (system)	+	+			+
S_4 (supersystem)		+	+		
S_5 (object)					

Note: "+" stands for the interaction between them, the column is the active component and the row is the passive component.

Table 1: Component interaction matrix.

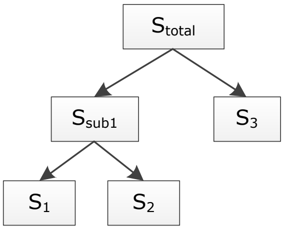


Figure 2: System decomposition.

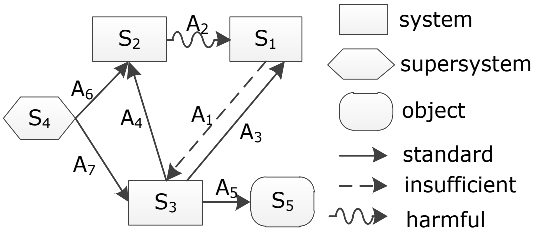
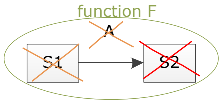


Figure 3: Function model of the target product.

Global idealization has three patterns of the function forbidden, system forbidden and principle changed. Product RI is to change the principle of the main function of a product while keeping its main function unchanged. Trimming and resource analysis can remove harmful functions, forbid auxiliary subsystems or change principles. Trimming principles based on the global idealization are shown in Table 2 [21]. The missed function is defined and generalized in a form of "verb + noun". Function reorganization is realized using the available resource analysis, FOS and effect search. Available resources are divided into internal and external resources in TRIZ including material, energy, field, information, space, time, function, derived and differential resources. FOS and effect search can be implemented based on the case, patent and effect libraries by using computer-aided innovation (CAI) software tools. When inventive problems are found, solutions can be obtained using TRIZ tools such as inventive principles and sub-field analysis.

NO.	Graphic trimming	Illustration	Global idealization
1		If there is no S2, the function of S1 is not needed, and S1 and A can be trimmed. So, the function F is forbidden.	Function forbidden

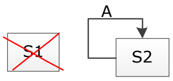
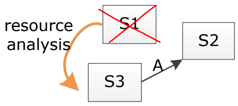
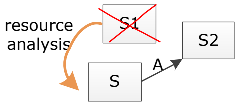
2		S2 can perform the function of S1 by itself, and S1 can be trimmed. So, subsystem S1 is forbidden.	System forbidden
3		Other existing units in the technology system or supersystem can complete the function of S1. S1 can be trimmed.	Principle changed
4		S is introduced from a new technology system and can complete the function of S1. S1 can be trimmed.	Principle changed

Table 2: Trimming based on the global idealization.

2.3 Solution Evaluation and Simulation

The goal of innovation is to continuously improve the level of product idealization. Solutions can be evaluated by the idealization level as follows.

$$I = \sum UF / \sum HF \tag{2.4}$$

where UF is a useful function, HF is a harmful function.

For the easy analysis, the idealization level can be expressed as Equation (2.7) based on Equation (2.4). AHP has three level sets. The first level set is goals and objectives, the second level is criteria, and third is decisions [19, 24]. After the hierarchy is established, alternatives are compared each other in pairs at each level. Judgment matrix A is then obtained. CI (consistency index) is decided using Equation (2.5). Random consistency index R is introduced to measure CI. R is related to the order of A as shown in Table 3. To remove random causes leading to inconsistency, CR (consistency ratio) is calculated using Equation (2.6). When CR<0.1, the consistency of the judgment matrix is acceptable, otherwise the judgment matrix should be modified appropriately [24]. Weight coefficients e and h are determined used AHP in a pairwise comparison. Solutions are evaluated using Equation (2.7) and RI definition. Figure 4 shows a model of product RI using the global idealization based on the patent analysis and TRIZ.

$$CI = (\lambda_{max} - n) / (n-1) \tag{2.5}$$

where λ_{max} is the maximum eigenvalue of the judgment matrix A; *n* is the order of the judgment matrix A.

n	1	2	3	4	5	6	7	8	9	10
R	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 3: Standard values of average R (R varies slightly with different standards).

$$CR = CI / R \tag{2.6}$$

$$I = \frac{\frac{1}{m}\sum_{i=1}^{m} B_i}{\frac{1}{m}\sum_{i=1}^{m} e \bullet E_i + \frac{1}{m}\sum_{i=1}^{m} h \bullet H_i} \tag{2.7}$$

where m is the number of system constituent elements; B_i is the benefit parameter to meet function requirements of product elements; E_i is the expense parameter affecting the realization of function requirements of elements; H_i is the harmful parameter affecting the realization of function requirements of elements; *e* is the weight coefficient of expenses; *h* is the weight coefficient of harms.

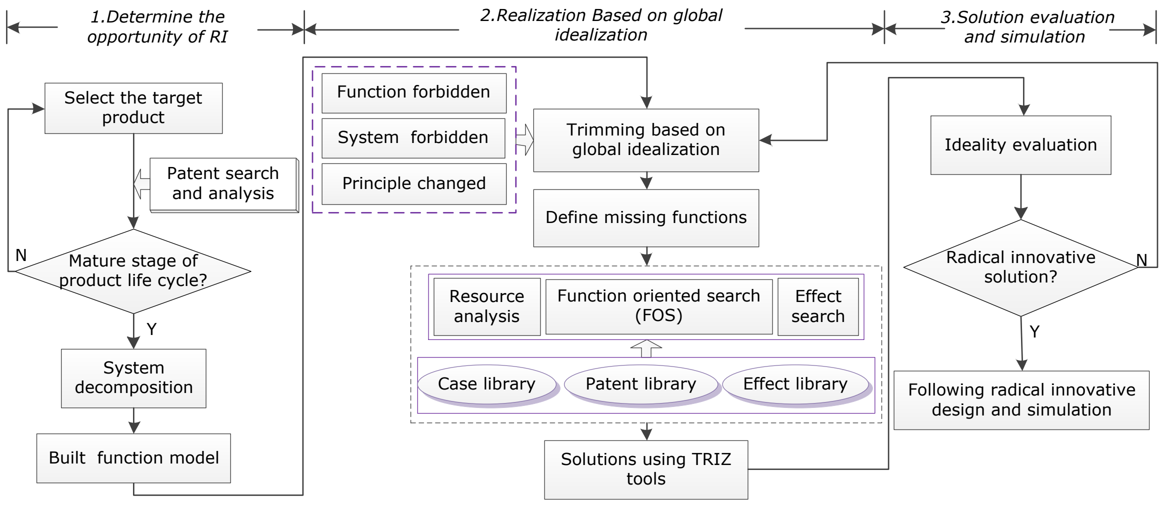


Figure 4: Modeling of product RI based on global idealization.

3 CASE STUDY

Solar energy is widely used as the green energy. Power generation by the solar energy uses photovoltaic and photothermal processes. Dust depositions on the solar panel will degrade the efficiency of the solar photovoltaic (PV) conversion, which has a great impact on the power generation efficiency and battery life of solar systems. Existing methods of the dust removal consider reducing dust on the solar panel in isolation, such as using compressed air on the solar panel to remove the dust, and the analysis of cloud-dust for the system performance [3, 11]. It is therefore critical to have a comprehensive method to reduce the dust deposition on the solar panel for the efficient photoelectric conversion.

Solar panels are mostly fixed in installation without following changes of the sun direction [15]. The solar panels cannot effectively receive the sunlight, which seriously affects the photoelectric conversion. Main ways of the dust removal of solar panels are the manual work, water syringe and waterless robot. However, these methods need extra resources, which greatly increases the cost of dust removal.

3.1 Determination of the Stage of Product Life Cycle

Using keywords of the solar or photovoltaic panel and removing dust or impurity, 1011 patents are searched using the Patsnap software [17]. 562 effective patents are obtained after screening. A trend of patent applications in recent ten years is analyzed as shown in Figure 5. Using Equations (2.1), (2.2) and (2.3), trends of three statistical parameters V, α, β of the dust-removal system of solar panels are obtained as shown in Figure 6. V and α decrease linearly in Figure 6. Therefore, the dust-removal system of solar panels is in the mature stage according to Section 2.1. Then, RI design of a dust-removal device on solar panels is proposed based on Figure 1 (b). The water syringe dust-removal device is selected as the target product as shown in Figure 7 (a).

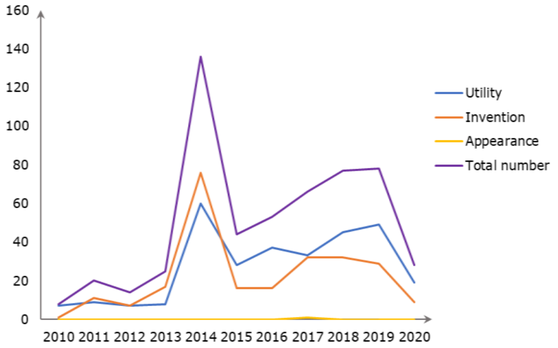


Figure 5: Patents application in recent ten years.

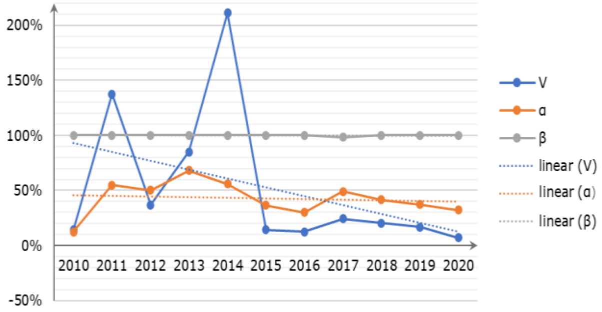


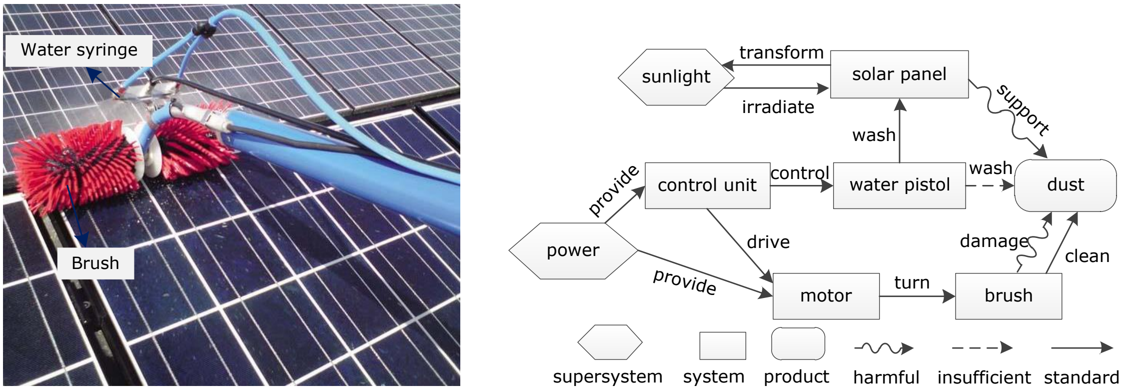
Figure 6: Trends of 3 statistical parameters.

3.2 Realization of Global Idealization

According to the system decomposition shown in Figure 2, the water syringe dust-removal system has five main components, S_{total}= {S_1, S_2, S_3, S_4, S_5} = {Control unit, Motor, Brush, Water syringe, Solar panel}. Through analysis of the related supersystem and object, there are two main supersystem components and one object as S_{super} = {S_6, S_7} = {Power, Sunlight} and S_{object} = {S_8} = {Dust}. Table 4 shows a component interaction matrix of the water syringe dust-removal device. A function model of the water syringe dust-removal device is built as shown in Figure 7 (b).

Components	S_1-Control unit	S_2-Motor	S_3-Brush	S_4-Water syringe	S_5-Solar panel	S_6-Power	S_7-Sunlight	S_8-Dust
S_1-Control unit		+		+				
S_2-Motor			+					
S_3-Brush								+
S_4-Water syringe							+	+
S_5-Solar panel							+	
S_6-Power	+	+						
S_7-Sunlight					+			
S_8-Dust					+			

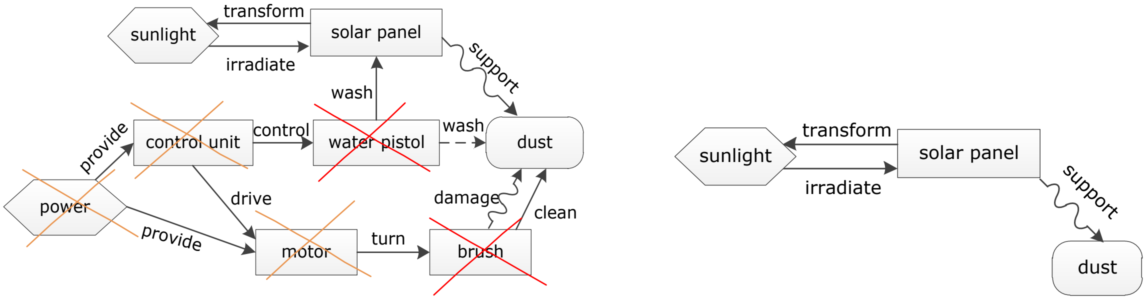
Table 4: Component interaction matrix of the water syringe dust-removal device.



(a) On-site task (b) Function model

Figure 7: The water syringe dust-removal device.

RI is conducted using trimming based on the global idealization and functional reorganization as shown in Figure 4. Based on the trimming principle in Table 2, the brush is trimmed as it has a high hardness and may damage surfaces of solar panels in the dust-removal process. The motor is then trimmed. As water is lack in the northwest of China, the cost is very high if solar panels are washed by water. The water pistol is trimmed. The control unit and power are also trimmed as shown in Figure 8 (a). Therefore, the function model after trimming is shown in Figure 8 (b).



(a) The trimming function model (b) Function model after trimming

Figure 8: Function model based on trimming.

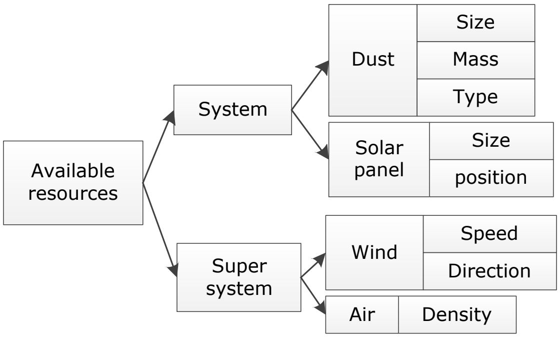


Figure 9: The available resources.

Figure 10: Function model using sub-field.

However, the system loses the "remove dust" function. Function reorganization is the premise of the successful implementation of system trimming. Important measures of this process are the resource analysis, FOS and effect search. The wind resource is selected based on the available resource analysis as shown in Figure 9. When wind acts the dust on solar panels directly, it cannot remove dust effectively. There is an insufficient action between wind and dust. According to standard solution No.14 (2.1.1)-series sub-field model in TRIZ, solution a is obtained. The wind amplification unit is introduced as shown in Figure 10.

According to searching function "increase speed" in the effect database [7], some effects are searched as listed in Table 5. Solution b, as the structure of a wind amplification unit, is developed based on effects of "Venturi Effect" and "Funnel" to increase the wind speed by area differences of wind inlet and outlet. In order to reduce cost, solution c uses the natural wind based on the "wind" effect. According to the "Fan" effect, solution d delivers wind into the device by a fan, and then to the surface of the battery panel through a hole. Solution e is obtained based on the "Gravitation" effect using a cylinder with cleaning cloth attached. It can roll by gravitational potential energy to remove dust. These solutions are shown in Table 5. Because the natural wind direction is variable, the fixed dust-removal device with natural wind has the low efficiency. A solar energy automatic tracking system is searched from the case library. Similarly, solution f uses motors in the dust-removal device to track the direction of sunlight and wind, which greatly increases efficiency of the dust removal.

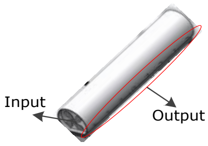
Effect name	Illustration	Solution
Venturi Effect	Reduction in the fluid pressure results from the fluid flow through a constricted section of pipe. The fluid velocity is increased through the constriction to satisfy the equation of continuity, while its pressure decreases due to conservation of energy: the gain in kinetic energy is balanced by a drop-in pressure or a pressure gradient force.	
Funnel	A funnel is a pipe with a wide, often conical mouth and a narrow stem. It is used to channel liquid or fine-grained substances into containers with a small opening. The speed of liquid passing through the thin part of a funnel will be greater than its speed in the wide part.	Solution b
Wind	The flow of air or other gases that compose an atmosphere.	Natural wind is selected as the dust removal power. Solution c
Fan	A device is used to produce flow in a gas (and, in principle, a liquid). Mechanical revolving blade fans are made in a wide range of designs. There are three main types of fans for moving air, axial, centrifugal (also called radial) and cross flow (also called tangential). For example, fan-powered vehicles or airborne vehicles are affected by an external fan.	 Solution d
Gravitation	A natural phenomenon by which objects with mass attract one another. In everyday life, gravitation is most commonly used by objects with mass.	Cleaning cloth is used to remove dust based on gravitational potential energy. Solution e
Wing in Ground Effect	A vehicle attains a level flight near surface of Earth, possibly by a cushion of high-pressure air from the aerodynamic interaction between the wing and surface (ground effect).	---------

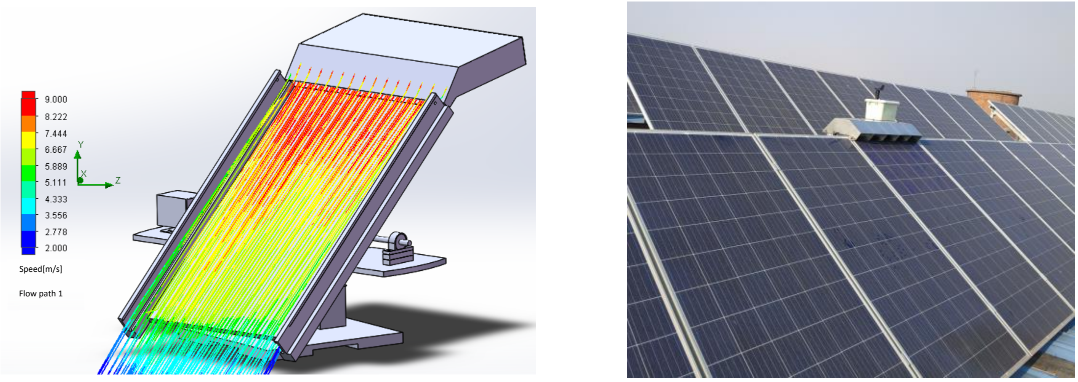
Table 5: Partial effects searched.

3.3 Solution Evaluation and Simulation

Therefore, three solutions are formed from the above analysis. Solution S1 consists of solutions a, b and c. Natural wind is selected as the dust removal power. The wind amplification unit is introduced to remove dust of the solar panels. Its structure is shown in Table 5. Solution S2 consists of solutions c and d. the wind is sent into the device by a fan, and then blown to surface of the battery panel through a hole. Solution S3 consists of solutions b, c, e and f. The device tracks the dust removal using a wind amplification unit and cylinder with cleaning cloth attached. Weight coefficients *e* and *h* are calculated based on the judgment matrix and expert score in AHP. According to customer requirements, the device should be reliable to remove dust with little water, and reduce manual operations. Therefore, the first level set is goal G= {Remove dust}, the second level is criteria C= {Efficiency, Reliability, Life, Automation level} and third is decisions D= {Expenses, Harms}. Weight coefficients are decided using the judgment matrix as W= {*e*, *h*} = {0.6, 0.4}. An expert evaluation method is used to evaluate benefits, expenses and harms of the solutions. Each evaluation is mainly based on experience and knowledge of the users. For a characteristic value interval of benefits, expenses and harms [0, 10] and values of indicators of the existing design [5, 5, 5], the ideality can be calculated using Equation (2.7) as shown in Table 6. Solution S3 is finally selected as its highest ideality. The wind amplification unit is designed. Its inlet area is three times of the outlet area. According to the simulation in Ansys, when the inlet speed is 3.5m/s, the outlet speed can reach to nearly 10m/s as shown in Figure 11 (a), which can blow the attached dust-off solar panels. The amplification effect of the wind amplification unit is verified based on the area ratio of the wind inlet and outlet. Dust can be blown when the wind speed of the outlet is more than 5.5m/s by the experiment as shown in Figure 11 (b).

Solutions	Benefits	Expenses	Harms	Ideality
Solution S1	7	2	2	3.50
Solution S2	8	3	2.5	2.86
Solution S3	8	2.5	1.5	3.81

Table 6: Ideality of solutions.



(a) Simulation in Ansys

(b) Experimental prototype

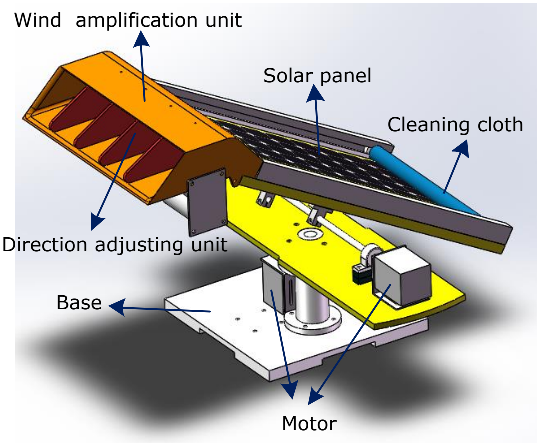
Figure 11: The wind amplification unit.

The working process of the new design is shown in Figure 12. The final solution can remove dusts in day and night. It mainly generates electricity during day and removes dusts at night. The solar panel converts the received light into electrical energy through tracking the direction of sunlight during the day. The wind speed is amplified by the wind amplification unit. Wind at outlet of the wind amplification unit acts on the solar panel in parallel to remove dust. In order to maximize the collection of natural wind, the device can track wind using the direction adjusting unit and motors. In addition, when the solar panel turns in a vertical direction, cleaning cloth moves up and down on the panel based on its gravity to remove dust.

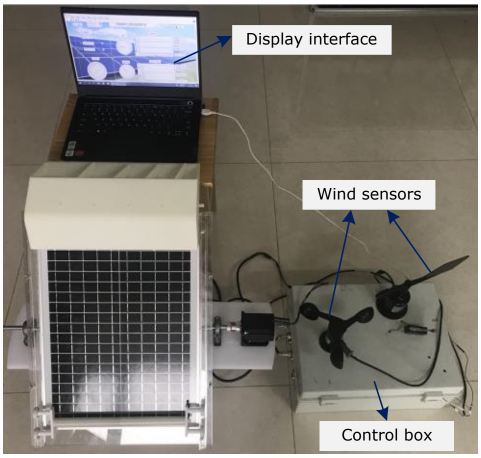
Furthermore, a prototype of the dust-removal device is tested in experiment. Ten groups of experimental data are collected as, V_0= (15.90, 16.06, 15.83, 15.44, 17.11, 17.67, 17.43, 17.35, 17.20, 17.00), V_1= (14.4, 14.74, 14.57, 14.43, 15.1, 15.95, 15.81, 15.76, 15.61, 15.41) and V_2= (15.21, 15.49, 15.25, 15.01, 16.27, 16.96, 16.81, 16.75, 16.62, 16.39), where V_0 is the output voltage of a dust-free solar panel, V_1 is the output voltage of a dusty solar panel, and V_2 is the output voltage of the solar panel after removing dust. According to changes of output voltage of the solar panel, the dust-removal effect is obtained based on Equation (3.1). Figure 13 shows that the device has a remarkable dust-removal effect.

$$efficiency = \left|(V_2 - V_1) / (V_1 - V_0)\right| \quad (3.1)$$

Natural wind is mainly used for the dust removal in the new design. The working principle of new design is changed as shown in Figure 12. According to the characteristics of RI, solution 3 is a RI solution. It mainly removes dust using wind by a wind amplification unit and track the direction of sunlight and wind. In addition, cleaning cloth is used based on gravitational potential energy. This RI solution improves the conversion efficiency and dust-removal effect.



(a) 3D model



(b) Prototype of the dust-removal device

Figure 12: Radical innovative Solution.

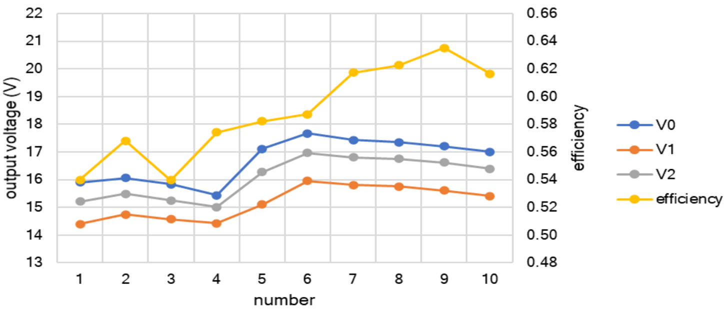


Figure 13: Comparison of dust removal efficiency.

4 CONCLUSIONS

A method of product RI was proposed in this research based on the global idealization. The opportunity of RI was identified based on the patent analysis. According to the patent search and analysis, a maturity prediction model was introduced to determine the occurrence stage of RI. A function model was built based on the system decomposition and component interaction matrix. The global idealization was used for the RI design by introducing TRIZ tools of trimming, FOS, and effect search. Solutions were achieved by applying TRIZ tools. The photoelectric conversion performance of solar panels and dust depositions on solar panels were considered in the RI design. The proposed method was verified in the RI design of a device of the dust removal.

This method provides ways to realize RI products for engineers from perspective of the global idealization. However, there are some limitations in the proposed method. Further work will improve and enrich the method by considering more factors and practical situations as follows: 1) combining the RI process with computer-aided innovation tools to improve efficiency of the solution search, 2) verifying results of the case solution through further experiments for RI.

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