A design of solar battery cleaning system by modularity method

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Abstract. According to the World Bank statistical report, Vietnam has an average of 1,600-2,700 hours of sunshine and normal direct radiation averaging 4-5 kWh per square meter a day. Before 2017, solar energy was considered worthless in Vietnam's energy development strategy, but by the end of 2019, Vietnam overtook Malaysia and Thailand to become the country with the largest solar panel installation capacity in Southeast Asia. The photovoltaic projects in Vietnam has reached 5 gigawatts (GW), far exceeding from the target of 1 GW that proposed by the Government in 2020 [1]. The strong development of solar energy from industry to civil activities has led to the development of ancillary services such as installation, maintenance and commerce. To ensure the productivity, all solar panels must be cleaned to absorb solar energy as much as possible. In the paper, we mention on the design of a solar panel cleaning robot that has a compact size, easy to move through the panels, taking advantage of domestic factors to have an edge price. The highlight point in that work is our application of the modularity method to gain the best competition with the other existing products on the market.

1 Introduction

The application of modularity method for design of mechanical products has developed rapidly in recent years [1]. At present, it has become a perfect and effective method that can help the design to overcome so many proposed conditions such as: low price, high productivity, interchangeability ... [2, 3]. Due to the trend of the diversification of customers' demands, small product batches with high varieties, the modular design has been applied widely [4] in this paper.

From the above demands, the application of modular design of the mechanical systems is indispensable. The objective of the modularization design in the article is the solar panel cleaning system or solar panel cleaning robot [5, 6] that could gain the following competitive points: compact size, effective working on effective clean panel surfaces, easy to activate, and lowest price by taking advantage of domestic factors.

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2 Method of design process

Application of the functional analysis [7] for solar battery cleaning system, from the above complete general demands, we divided the sub-functions as in the Fig. 1.

![Functional schema of solar battery cleaning system.](image)

Proposing ideas for the design problem [7]: Deploy ideas for each function, systematically combine ideas, we get 4 ideas for the design of cleaning solar panels as in Table 1.

| Function       | Idea 1                                      | Idea 2                                      | Idea 3                                      | Idea 4                                      |
|----------------|---------------------------------------------|---------------------------------------------|---------------------------------------------|---------------------------------------------|
| Power supply   | Power supply from solar panels              | Power supply from outside source            | Power supply from solar panels              | Power supply from outside source            |
| Water Supply   | Pump                                        | Pump                                        | Pump                                        | Pump                                        |
| Transmission   | Transmission by coupling and gears          | Transmission by coupling and belt           | Transmission by gearbox and belt            | Transmission by coupling and gears          |
| Rotation       | Motor                                       | Belt                                        | Belt                                        | Motor                                       |
| Moving         | Servo motor DC                              | Servo motor DC                              | Servo motor DC                              | Servo motor DC                              |

Preliminary concept evaluation for designed product [7]: The ideas are listed on the first horizontal row of the selection matrix. The selection criteria are arranged along the left column of the matrix. Choose one of the above ideas as a base. Analysis of each idea: ideas are compared with base one according to the selection criteria and scored in the corresponding box (Table 2). From the above ideas we consider that the ideas 1 and 3 are feasible when design the robot.

Calculating the ideal scores for the final product design [7]: Decision matrix with additional weight column. Selection criteria are assigned a weight (in percentage), which are determined by consensus of the design team. Analysing each idea: the ideas are compared with the standard idea according to the selection criteria and scored in the corresponding box. Calculate the total score of each idea by the formula:

\[ S_j = \sum_{i=1}^{n} r_{ij} w_i, \] (1)
where: $r_j^i$ - the first criterion point of idea $j$; $w_i$ - the weight of the $i$-th criterion; $n$ - total number of criteria; $S_j$ - total score for idea $j$.

Rank the ideas by total score are showed in Table 3.

**Table 2. Matrix of evaluation the ideas.**

| Criteria                           | Ideas       |
|-----------------------------------|-------------|
|                                   | 1 (selected as base) | 2 | 3 | 4 |
| Logical productivity +            | 0           | 0 | 0 | + |
| Effective hygiene +               | 0           | 0 | 0 | + |
| Facility to activate -            | +           | + | + | - |
| Saving resources 0                | 0           | 0 | 0 | - |
| High longevity, high reability +  | 0           | 0 | + | + |
| Ease to maintenance +             | +           | 0 | + | + |
| Applicable remote control technology + | +           | + | + | + |
| Logical price 0                   | 0           | + | + | - |
| Use recyclable materials +        | +           | + | + | + |
| Total marks (+)                   | 6           | 4 | 6 | 6 |
| Total marks (0)                   | 3           | 5 | 3 | 0 |
| Total marks (-)                   | 1           | 0 | 0 | 3 |
| Ultimate total marks              | 5           | 4 | 6 | 3 |
| Range                             | 2           | 3 | 1 | 4 |
| Continue or stop                  | Yes         | No | Yes | No |

**Table 3. Matrix of scoring and selection of ideas.**

| Criteria                                 | Weights(%) | Ideas       |
|------------------------------------------|------------|-------------|
|                                           |            | 3           | 4           |
|                                           |            | Marks       | Marks       |
|                                           |            | Coarse      | Coarse      |
|                                           |            | Multiplied to weight | Multiplied to weight |
| Hygienic effect                          | 10%        | 4           | 0.4         |
|                                          |            | 3           | 0.3         |
| Easy to activate                         | 6%         | 2           | 0.12        |
|                                          |            | 4           | 0.24        |
| Resource saving                          | 15%        | 3           | 0.45        |
|                                          |            | 3           | 0.45        |
| High longevity, high reability           | 16%        | 3           | 0.48        |
|                                          |            | 5           | 0.8         |
| Easy maintenance                         | 10%        | 4           | 0.4         |
|                                          |            | 5           | 0.5         |
| Application of remote control technology | 6%         | 3           | 0.18        |
|                                          |            | 3           | 0.18        |
| Logical price                            | 22%        | 3           | 0.66        |
|                                          |            | 4           | 0.88        |
| Use recyclable materials                 | 5%         | 3           | 0.15        |
|                                          |            | 3           | 0.15        |
| Total marks                              | 100        | 3.24        | 3.8         |
| Ranking                                  | 2          | 1           |
| Continues?                               | No         | Yes         |

Based on the scoring matrix, the design team chooses an idea as a design concept. Solar battery cleaning system principle diagram as follows:
3 Results and discussion

After application of the design product modularization method [8] to design the system after analysing the demands of customer and choosing a design concept for the product, we combine the functional analysis diagrams and the design concepts in one structural – functional diagram that is illustrated in the following diagram:

List of the components and symbols is shown in Table 4:
Table 4. Parts designation solar battery cleaning system.

| Components          | Designation |
|---------------------|-------------|
| 1 Servo DC motor    | DDC         |
| 2 Flexible coupling | NTD         |
| 3 Reductive gearbox | HGT         |
| 4 Gear              | BR          |
| 5 Belt transmission | BTD         |
| 6 Wheel             | BX          |
| 7 Brush shaft       | TC          |
| 8 Pressure pump     | BAS         |
| 9 System of water   | HTN         |

The system-level specifications of the product are orderly sorted in a hierarchical structure in where the physical structure is divided according to the arrangement and the interactive state (direct or indirect), while the functional structure is divided according to the flow of energy, materials and information as in Figure 4.

Establishing the relationships of the details in the system [8] through the properties of physical structure and function of the system (Table 5), number 1 represents interaction, 0 represents no relationship system; NT- serial; SS- parallel; TT- direct interaction; GT-indirect interaction.

Fig. 4. Schema of structure and function of solar battery cleaning system
Determining the influence of System – Level Specification (SLS) on General Functional Requirements (GFR) [8]:

To determine the effect of the properties of machine on the functional requirements, we use a relationship matrix between machine design requirements and importance factors value:
1: the desired impact value;
0: the insignificant impact value;
-1: the undesirable effect value.

Then we build a matrix of relationships between Systems – Level Specification on General Functional Requirements (Table 6).
Table 6. Relationship matrix between SLS and GFR.

| System – Level Specifications (SLS) | General Functional Requirements (GFR) |
|-----------------------------------|--------------------------------------|
| Serial arrangement                | Ease of Service | Compactness | Performance |
| Parallel arrangement              | 0 | 1 | 1 |
| Direct interaction                | 1 | 1 | 1 |
| Indirect interaction              | 0 | 0 | 0 |
| Direct Energy                     | 1 | 1 | 0 |
| Indirect Energy                   | 1 | 0 | 1 |
| Direct transmission               | 1 | 1 | 0 |
| Indirect transmission             | 1 | 0 | 1 |
| Weight                            | 1 | 1 | 1 |

Applying Cluster Identification Algorithm (CIA) [8], we can determine the matrix of functional (Table 7), structural (Table 8) and overall similarity (Table 9).

Table 7. The structural similarity matrix.

|       | DDC | NTD | HGT | BR | BTD | BX | TC | BAS | HTN |
|-------|-----|-----|-----|----|-----|----|----|-----|-----|
| DDC   | 5   | 2   | 2   | 2  | 2   | 0  | 0  | 0   | 0   |
| NTD   | 2   | 5   | 5   | 2  | 0   | 0  | 0  | 0   | 0   |
| HGT   | 2   | 2   | 5   | 0  | 0   | 0  | 0  | 0   | 0   |
| BR    | 2   | 2   | 2   | 5  | 0   | 0  | 0  | 0   | 0   |
| BTD   | 2   | 2   | 2   | 5  | 0   | 0  | 0  | 0   | 0   |
| BX    | 2   | 2   | 2   | 5  | 0   | 0  | 0  | 0   | 0   |
| TC    | 2   | 2   | 2   | 5  | 0   | 0  | 0  | 0   | 0   |
| BAS   | 0   | 0   | 0   | 0  | 0   | 0  | 0  | 0   | 5   |
| HTN   | 0   | 0   | 0   | 0  | 0   | 0  | 0  | 0   | 5   |

Table 8. The functional similarity matrix.

|       | DDC | NTD | HGT | BR | BTD | BX | TC | BAS | HTN |
|-------|-----|-----|-----|----|-----|----|----|-----|-----|
| DDC   | 4   | 4   | 4   | 4  | 4   | 4  | 0  | 0   | 0   |
| NTD   | 4   | 4   | 4   | 4  | 4   | 4  | 0  | 0   | 0   |
| HGT   | 4   | 4   | 4   | 4  | 4   | 4  | 0  | 0   | 0   |
| BR    | 4   | 4   | 4   | 4  | 0   | 4  | 0  | 0   | 0   |
| BTD   | 4   | 4   | 4   | 0  | 0   | 4  | 0  | 0   | 0   |
| BX    | 4   | 4   | 4   | 4  | 0   | 0  | 0  | 0   | 0   |
| TC    | 4   | 4   | 4   | 4  | 0   | 0  | 0  | 0   | 0   |
| BAS   | 0   | 0   | 0   | 0  | 0   | 0  | 0  | 0   | 4   |
| HTN   | 0   | 0   | 0   | 0  | 0   | 0  | 0  | 0   | 4   |

Table 9. The general similarity matrix.

|       | DDC | NTD | HGT | BR | BTD | BX | TC | BAS | HTN |
|-------|-----|-----|-----|----|-----|----|----|-----|-----|
| DDC   | 9   | 6   | 6   | 6  | 6   | 6  | 0  | 0   | 0   |
| NTD   | 6   | 9   | 6   | 6  | 4   | 4  | 0  | 0   | 0   |
| HGT   | 6   | 6   | 9   | 9  | 4   | 4  | 0  | 0   | 0   |
| BR    | 6   | 6   | 9   | 0  | 0   | 9  | 0  | 0   | 0   |
| BTD   | 6   | 6   | 9   | 0  | 0   | 0  | 0  | 0   | 0   |
| BX    | 6   | 4   | 4   | 9  | 0   | 0  | 0  | 0   | 0   |
| TC    | 6   | 4   | 4   | 9  | 0   | 0  | 0  | 0   | 0   |
| BAS   | 0   | 0   | 0   | 0  | 0   | 0  | 0  | 0   | 9   |
| HTN   | 0   | 0   | 0   | 0  | 0   | 0  | 0  | 0   | 9   |
Combine details into modules: use Cluster Identification Algorithm CIA identification algorithm to cluster details. Details in the product are shown in the table below:

| No | Clusters denomination | Design for selection | Design for manufacturing |
|----|------------------------|-----------------------|--------------------------|
| 1  | Servo DC motor         | ✓                     |                          |
| 2  | Coupling               | ✓                     |                          |
| 3  | Reductive gearbox      | ✓                     |                          |
| 4  | Belt transmission      | ✓                     |                          |
| 5  | Gears                  | ✓                     |                          |
| 6  | Wheels                 |                        | ✓                        |
| 7  | Brush shaft            |                        | ✓                        |
| 8  | Roller bearings        | ✓                     |                          |
| 9  | Pressure pump          | ✓                     |                          |
| 10 | Machine frame          |                        | ✓                        |

3 Conclusion

The results show that the modules of physical structure and function are suitable: Module 1: Wheel and brush drive function; Module 2: Function of water supply for cleaning process. Seven clusters are designed for selection (purchasing from market), three parts are designed for manufacturing by ourselves. Modular design improved the design efficiency, product quality and reliability, good maintainability. Solar panel cleaning module provides an economic and effective method for cleaning the solar panel.

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