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A multi-principle module identification method for product platform design

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Summary of the recently published paper in the module identification field

1. internal interactions clustering viewpoint:

The internal clustering viewpoint requires that components with a high degree of interactions should be clustered to form an individual module

2 . External interactions independence viewpoint:

The external independence viewpoint suggests that the coupling degree between different modules must be minimized

3 . Overall system reliability viewpoint:

The overall system reliability viewpoint requires that the components that may affect the same set of functional requirements should be grouped together to form a module.

Modeling of Multi-Principle Modularization

The identified principles are treated as a 'three objectives' optimization problem, and the Improved Strength Pareto Evolutionary Algorithm is used to find the Pareto-optimal set. The fuzzy-based selection mechanism is also used to extract a Pareto-optimal solution as the best compromise

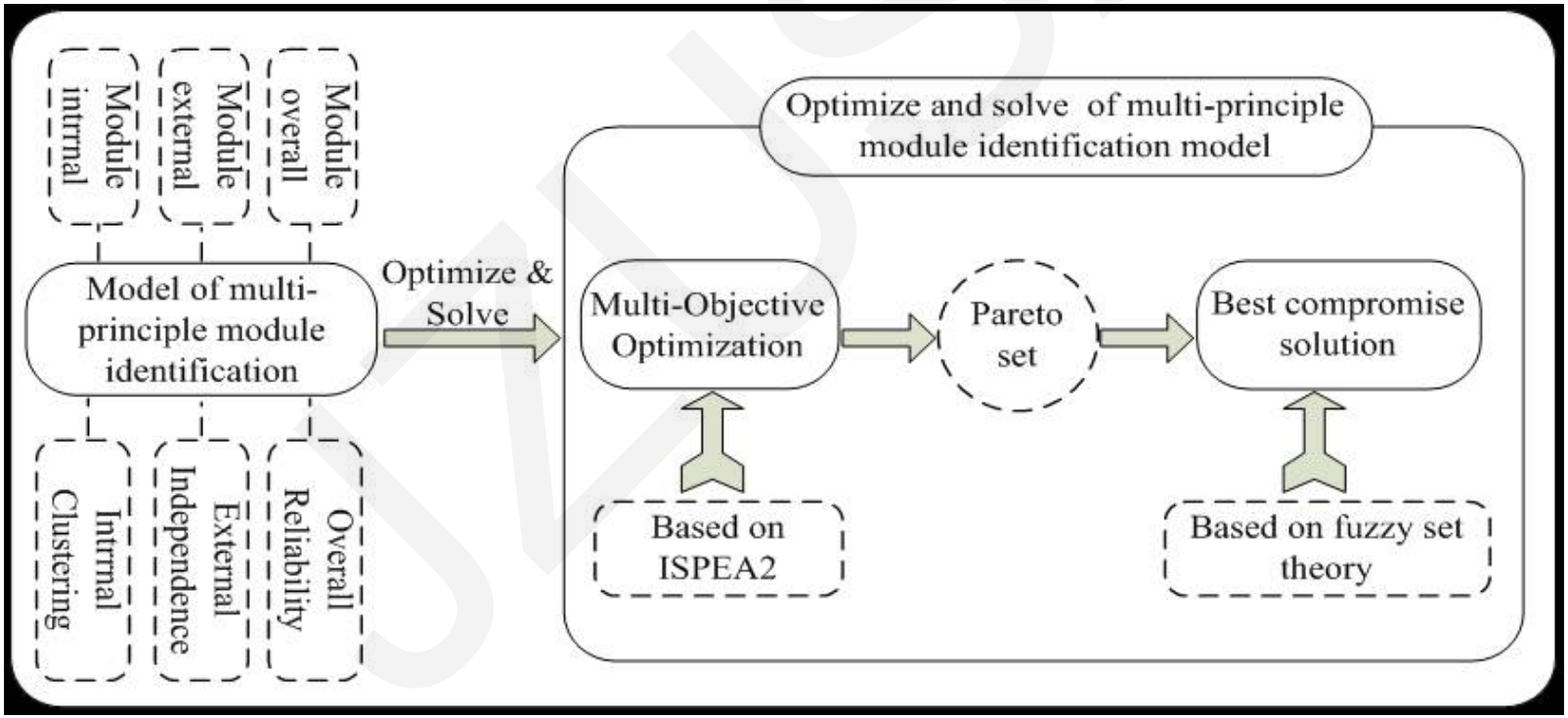


Fig. 1: Conceptual modeling of the multi-principle module identification method

Optimization based on ISPEA2

- a Multi-Objective Optimization Problem (MOOP) with *n* objective functions can be loosely posed as the following:

  minimize/maximize $F(x) = (f_1(x),...,f_n(x))$

  subject to

  $g_j(x) \leq 0$, $h_k(x) = 0$, $j = 1;2;...;J$, $k = 1; 2;...; K$.

- ISPEA2 is a new model of Multi-Objective Genetic Algorithm (MOGA) that features more effective crossover, and it will result in diverse solutions in both objective and variable spaces

- ISPEA2 can be regarded as a particular type of SPEA2 with three additional mechanisms: (i) neighborhood crossover that allows crossing over individuals located near each other in the objective space; (ii) mating selection that reflects all good solutions within the archive; (iii) application of two archives to maintain diverse solutions in both objective and variable spaces.

Case Study

The focal product to be modularized is a turbo expander. Fig 2 illustrates a structure of a typical turbo expander, and Table 1 summarizes a list of its key components.

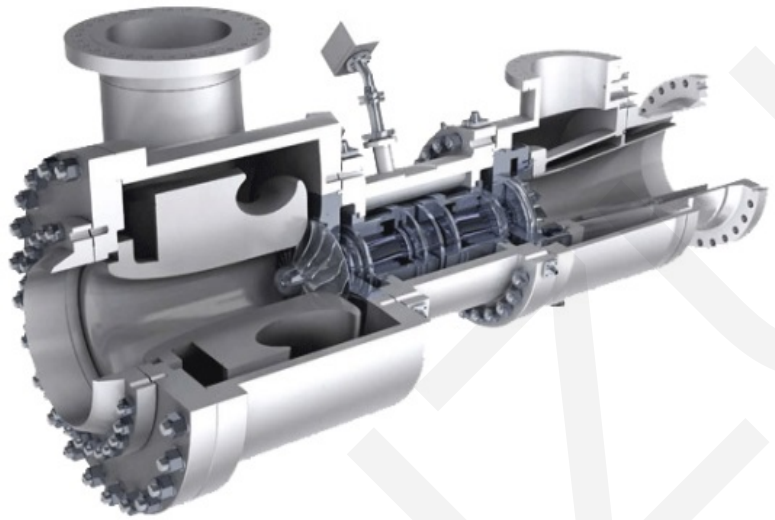


Fig 2: structure of the turbo expander

Table 1: List of key components of the turbo expander

No. Name	No. Name
1 Fuselage	22 Oil filter
2 Base	23 After cooler
3 Fan volute	24 Closures
4 Nozzle	25 Bladeless diffuser
5 Expander impeller	26 The inlet chamber
6 Rotor	27 Return pipe
7 Fan cover	28 Pneumatic membrane
8 Expander impeller	29 Sheet heat exchanger
9 Sensor holder	30 Tank
10 Operation panel	31 Three screw pump
11 Axis sensor	32 Thermostatic valve
12 Machine switches	33 Bladder Accumulators
13 Turbocharger impeller	34 Electric control box
14 Joint bearings	35 Anti-spill plug
15 Inlet pipe	36 Oil window parts
16 Gland	37 Cooling water valve
17 Cold box	38 Magnet sensor
18 Reducing Valve	39 Spindle
19 Exhaust Pipe	40 Intermediates
20 Support bracket	41 Bearing pedestal
21 Oil cooler	42 Nameplate

Case Study

- According to the multi-principle module identification method, six modules are identified: the final modularity scheme of the turbo expander is:
  (1) frame module {1, 2, 3, 7, 10, 20, 40, 42};
  (2) expander module {4, 6, 8, 18, 19, 28, 39, 41};
  (3) turbo module {13, 14, 25, 26};
  (4) lubrication module {15, 16, 22, 24, 27, 30, 31, 35, 36};
  (5) cooler module {17, 21, 23, 29, 32, 37};
  (6) control module {9, 11, 12, 33, 34, 38}.

- The ISPEA2 demonstrated an evidently better performance than the NSGA-II and SPEA2 in terms of both computing efficiency and accuracy.

Table2 comparison of different algorithms

Algorithms	ISPEA2	NSGA-II	SPEA2
Computing Time	54.37s	86.42s	72.68s
Quantity of non-dominated Solutions	37.6%	28.3%	34.1%
Crossover Probability	86%	81%	74%

Conclusions

- This paper abstracted three principles in the module identification, Both conceptual and mathematical modeling of the proposed multi-principle modularization method is presented. The ISPEA2 is used to find an optimal solution. The fuzzy-based selection mechanism is used to extract a Pareto-optimal solution as the best compromise.
- The Improved Strength Pareto Evolutionary Algorithm is compared with two other established multi-objective optimization methods. The result reveals that the ISPEA2 demonstrated a better performance.
- It is also expected that the proposed new method will help deepen the understanding of modularization, and to enhance modularization effectiveness in practice. Future research will include recent hybrid heuristics for optimization and the application of the proposed method in a more complex product, for instance from the automotive or aerospace domain.