Automatic Design for Pipe Arrangement using Multi-objective Genetic Algorithms

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Background

Reduce labor requirements

- efficiency improvement
- labor saving

Advances in CAD

Automation of pipe arrangement design has not yet achieved.

Objective

Design pipe arrangement automatically

1. Formulating pipe arrangement design problem

Large-scale multi-objective optimization problem

2. Designing multi-objective genetic algorithms
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Designing Pipe Arrangement

When both origin and endpoint coordinates and direction vectors are provided, piping route is automatically designed.

Considering interference with pipes and obstacles.

An infinite number of piping route.

A limit is imposed on the degrees-of-freedom for the route.
Generation pattern

1. According to direction vectors
   - Opposite
   - Right-angled
   - Same

2. According to the number of nodes
   - Mode-1: 3
   - Mode-2: 5
   - Mode-3: 2
   - Mode-4: 3
   - Mode-5: 4
   - Mode-6: 3

The number of nodes increases

Degrees-of freedom expands

The number of nodes should be minimized while avoiding interference with other pipes and obstacles.
A pipe is characterized uniquely.

The number of combination: 14
The number of variables: 3
The number of combination: 6
The number of variables: 2

The number of combination: 2
The number of variables: 1
Evaluation function for obstacle (1)

A space set aside to allow for maintenance people to pass

This space is considered as an obstacle.

Need not completely avoid the obstacle

Avoid the obstacle as much as possible

Evaluation function

Minimize the evaluation value

Optimization problem
Evaluation value for obstacle (2)

\[ f_{\text{obstacle}} = \sum_{l=1}^{n_o} \sum_{k=1}^{n_p} (b_{kl} - \bar{a}_{kl} + A_l) \]

- \( b_{kl} \): The length of intersection when the pipe \( k \) intersects the obstacle \( l \)
- \( \bar{a}_{kl} \): The averaged length between the center of the gravity of the obstacle \( k \) and the part divided by each node of the pipe \( l \)
- \( A_l \): The length between the center of the gravity and the top of the obstacle \( l \)
- \( n_o \): The number of obstacles
- \( n_p \): The number of pipes

Minimum value = 0
(All pipes not interfering with obstacles)

Evaluation values are worse when a pipe passes through the center of an obstacle and the length of the intersection is long.
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Characteristic of this problem

This problem includes numerical optimization and combination optimization problems.

It is difficult to optimize this problem using usual optimization techniques.

- Annealing method
- Downhill simplex method, etc.

The length of pipe

Trade-off

The Evaluation value for obstacle

Using GA, which is direct search method

Multi-objective optimization problem

Multi-objective GA
Multi-objective genetic algorithms

Parents → Crossover → Children
Parents → Mutation → Children

Selection for reproduction

Cost-1
Cost-2
Generation t

Selection for survival

Generation t+1

Pareto optimal selection strategy

(Kobayashi, Tokyo Institute of Technology)

Pareto solutions selected

Pareto solution: A solution that is superior to all other solutions in at least one criterion.
A pipe is characterized by them.

A combination of them are used as the solution representation.

<table>
<thead>
<tr>
<th>Pattern of generation</th>
<th>Numerical parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{pattern}_1 )</td>
<td>( \text{pattern}_2 )</td>
</tr>
<tr>
<td>( x_{10} )</td>
<td>( x_{20} )</td>
</tr>
<tr>
<td>( x_{11} )</td>
<td>( x_{21} )</td>
</tr>
<tr>
<td>( x_{12} )</td>
<td>( x_{22} )</td>
</tr>
</tbody>
</table>

pipe 1  pipe 2  pipe \( n \)
Crossover with Two Gene: XTG

Index of pipe ① ② ③

Parent-1 3 0 9
Parent-2 6 5 4

Uniform Crossover

When a pipe not interfering with obstacles: 0
When a pipe interfering with obstacles: 1

The evaluation value for obstacle can be expected to be improved.
The gene to which the mutation is applied is generated at random.
Modification operator on Contact: MOC

- Pipes interfere with each other. Infeasible solution
- Pipes do not interfere with each other. Feasible solution
- Pipes having a lot of interferences are modified
- Change the properties of the original solution candidates as little as possible
- Not changed
Multi-objective genetic algorithms

Pareto optimal selection strategy

Crossover
Mutation

Parents
Children

Selection for reproduction
Selection for survival

Cost-1
Cost-2

Generation t
Generation t+1

Pareto solution:
A solution that is superior to all other solutions in at least one criterion.

(Kobayashi, Tokyo Institute of Technology)
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## Experiments

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<thead>
<tr>
<th></th>
<th>Mode-1</th>
<th>Mode-2</th>
<th>Mode-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>The number of pipes</td>
<td>5</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>The number of variables</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>The number of combinations</td>
<td>14</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>The total number of variables</td>
<td>15</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>The total number of combinations</td>
<td>537,824</td>
<td>279,936</td>
<td>8</td>
</tr>
<tr>
<td>The number of all variables</td>
<td></td>
<td></td>
<td>32</td>
</tr>
<tr>
<td>The number of all combinations</td>
<td></td>
<td></td>
<td>Approximately 1.2 trillion</td>
</tr>
</tbody>
</table>

The space where a obstacle exists

Large-scale optimization problems

We set the problem where many pipes exist closely and a big obstacle exists.
Initial Pareto solutions

The sum total of the length of pipe

Better!!

The evaluation value for obstacle

Calculation environment
Pentium 4 2.40GHz
512MB
Windows XP
Java
Pareto solutions in 100\textsuperscript{th} generation (1.0 \times 10^4 solution candidates evaluated.)

About 10 minutes for searching
Pareto solutions in 1000\textsuperscript{th} generation (1.0 \times 10^5 solution candidates evaluated.)

About 60 minutes for searching
Results

Programming language: Java3D

The number of pipes: 15
The number of obstacles: 2

The number of pipes: 20
The number of obstacles: 1

The number of pipes: 20
The number of obstacles: 3
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Conclusions

- A design problem for pipe arrangement was formulated.
- A multi-objective Genetic Algorithms suitable for this problem was developed.
- The effectiveness of the proposed method was verified through several experiments.

Future works

- Applying this methodology to a practical design
- Improvements to the proposed algorithms