Automatic Design for Pipe Arrangement Considering Valve Operationality

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Shipbuilding ICCAS 2009
Overview

1. Motivation and Purpose

2. Evaluation Algorithm for Pipe Operationality
   - Accessibility
   - Possibility of Valve Handling

3. Multi-Objective Optimization Algorithm
   - Coding for Genetic Algorithm (Only Valves)
   - Multi-Objective Genetic Algorithm: NSGA-Ⅱ
   - Routing Pipes and Making Branches

4. Experiments

5. Conclusion and Future Works
A Ballast Pump Room

Pump

Valve
A handle for valve operation

It is operated using a rod from upper pathway.
From upper pathway
Motivation

Pipe Arrangement

3D-CAD contributes designing efficiency

But...

Needs sophisticated skills

Automatic design

Why?

[Reason 1] Obscurity of the design evaluation

Not only to arrange shortest pipes between equipments!

ex.) Easy to operate valves, easy for maintenance, etc.

Answer →

1) Define numerical evaluation for all items
2) Formulate as a multi-objective optimization

[Reason 2] A Problem in designing algorithms

It is no use that the algorithm gives only one solution!

Answer →

Show plural solutions
Designer selects one of them as he needs.

But…

Genetic algorithm
Motivation

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Genetic algorithm
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Valve Operationality

Evaluation of the space from pathways to valves

Good Arrangement

Accessible,

But…

(1) The valve can be operated by some tools

(2) Crew needs to get down to go through the narrow place

The valve can be operated by hands
Valve Operationality

Evaluation of the space from pathways to valves

**Good Arrangement**

The valve can be operated by hands.

**Fair Arrangement**

(1) The valve can be operated by a rod.

(2) Crew needs to get down to pass through the narrow place.

Accessible, But…

The valve can be operated by hands.
Valve Operationality

Evaluation of the space from pathways to valves

All pipes and valves must be arranged not only to put without interference each other but also to make space from pathways to valves so that crew can access the valves.

Implicit and Obscure so far!

To apply optimization algorithms, **Numerical evaluation for the valve operationality** is needed.
Evaluation Algorithm for Valve Operationality

Accessibility
Crew can move to a position where the valve can be operated by hands or by some tools.

Possibility of Valve Handling
The valve can be operated by hands.

The design space is partitioned into regular grids, and recognize accessible segments.

Evaluation
Valve operationality is calculated in this grid space by summing up the minimum distance from each valve to accessible segments that are located in the direction of the axis of the valve’s handle or four directions perpendicular to that axis.

Recursive Fill Algorithm
Finding Accessible Segments: Recursive Fill Algorithm

Worker segment Matrix:
Imitating shape of the crew (worker)

Obstacles:
Pipes, hull, pump, etc.

Sweep

Valves

Pathway
Finding Accessible Segments: Recursive Fill Algorithm

Worker segment Matrix:
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Pathway

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Valves
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Pathway

Obstacles: Pipes, hull, pump, etc.
Finding Accessible Segments: Recursive Fill Algorithm

Obstacles:
- Pipes, hull, pump, etc.

- Able to handle by hand

- Crew can move this swept area

- Able to handle by a rod

Distance (cost) = 3 segments
Find inaccessible segments using the **recursive fill algorithm**

Divide into regular grids, and judge all segments.

Evaluate all valves, and sum up.
## Features of the Evaluation Algorithm

### Accessible
1. Crew can move to a position where the valve can be operated by hands.
2. Crew can move to a position where the valve can be operated by a rod, but cannot be operated by hands.

### Inaccessible
Crew cannot move to a position where the valve can be operated because obstacles surround valves.

**Expert’s Obscure or Implicit Criterion of Valve-Operationality** is clearly numerically defined.

<table>
<thead>
<tr>
<th>Accessible</th>
<th>Good</th>
<th>Cost = 0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inaccessible</th>
<th>Bad</th>
<th>Cost = 10000</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
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</table>

Summing over all valves
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Multi-Objective Genetic Algorithm (MOGA)

Pareto optimum solutions: Suited for showing plural solutions!
NSGA-II

NSGA-II: Nondominated Sorting Genetic Algorithms II

Multi-objective Genetic algorithm

1. Efficient calculation in Nondominated Sorting
2. Crowding distance
3. Elite strategy

Reference
Problem Formulation

Given

Pipe diagram

P&ID

Pipeline FROM – TO List

Plot Plan

Equipment Dim. & Loc.

Equipment arrangement list

Search Space

Parameters for VALVES

locations

directions

Parameters for PIPES

locations

directions

branches

patterns

locations

Minimize

Valve Operationality (cost)

and

Cost of Materials
Material Cost

Material Cost Function

\[ f_{\text{material}} = \sum_{k=1}^{n_p} W_k L_k D_k \]

- \( W_k \) : **Weight** of the kth pipe
- \( L_k \) : **Length** of the kth pipe
- \( D_k \) : **Diameter** of the kth pipe
- \( n_p \) : Number of pipes
The parameters of valves are dominant to the parameters of pipes, because the pipes are routed between valves.

Only the parameters of the valves are encoded as the genes for the GA.

\[
\begin{bmatrix}
\theta_1 & \theta_2 & \cdots & \theta_n \\
x_1 & x_2 & \cdots & x_n \\
y_1 & y_2 & \cdots & y_n \\
z_1 & z_2 & \cdots & z_n 
\end{bmatrix}
\]

One point crossover

Pipes are arranged by local search algorithms after the parameters of valves are determined. (Routing and Branching)
Routing Pipes (1)

Valves, pumps, connections or branches. Each point has location and direction.

Pipe Routing between two points is limited to finite patterns.

Vectors at start point and end point are opposite.
Routing Pipes (2)

Modification for Interfered Pipes

Pipes are Interfered

Infeasible!
Routing Pipes (2)

Modification for Interfered Pipes

Pipes are Interfered

Infeasible!

Modification Operator

The green pipe is removed

The more interfered pipes, the higher priority to remove

Maintain the shape as similar as possible

Not Changed

Also the smaller diameter pipes have the higher priority.

All Pipes are Separated

Feasible!
Generating Branches of Pipes

Problems

How to Generate T-branch efficiently?

Increasing elbows  Infeasible elbow

Start point  End point 1

Start point

End point 2

Main route
Generating Branches of Pipes

**Problems**

- Increasing elbows
- Infeasible elbow

**How to Generate T-branch efficiently?**

**Answer:**
Generate a T-branch on an elbow on the main route of the pipeline.
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Experiments

Pipeline list

<table>
<thead>
<tr>
<th>LINE NO</th>
<th>FLUID</th>
<th>SIZE</th>
<th>CLASS</th>
<th>FROM-TO</th>
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</thead>
<tbody>
<tr>
<td>P-001</td>
<td>S</td>
<td>150</td>
<td>-</td>
<td>V1</td>
</tr>
<tr>
<td>P-002</td>
<td>S</td>
<td>150</td>
<td>-</td>
<td>V1</td>
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<tr>
<td>P-003</td>
<td>P</td>
<td>150</td>
<td>-</td>
<td>P1</td>
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<td>P-004</td>
<td>P</td>
<td>150</td>
<td>-</td>
<td>V2</td>
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<tr>
<td>P-005</td>
<td>D</td>
<td>150</td>
<td>-</td>
<td>V4</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>VALVE NO</th>
<th>SIZE L</th>
<th>SIZE D</th>
<th>SIZE H</th>
<th>CLASS</th>
<th>AFTER</th>
<th>FORWARD</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1</td>
<td>0.3</td>
<td>0.3</td>
<td>0.5</td>
<td>-</td>
<td>V5</td>
<td>CP3</td>
</tr>
<tr>
<td>V2</td>
<td>0.3</td>
<td>0.3</td>
<td>0.5</td>
<td>-</td>
<td>P1</td>
<td>V5</td>
</tr>
<tr>
<td>V3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.5</td>
<td>-</td>
<td>P1</td>
<td>V1</td>
</tr>
<tr>
<td>V4</td>
<td>0.5</td>
<td>0.5</td>
<td>0.8</td>
<td>-</td>
<td>CP2</td>
<td>-</td>
</tr>
<tr>
<td>V5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.8</td>
<td>-</td>
<td>P1</td>
<td>V2</td>
</tr>
</tbody>
</table>

Equipment arrangement list

<table>
<thead>
<tr>
<th>EQUIP NO</th>
<th>CATEGORY</th>
<th>TYPE</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>DIR</th>
<th>AFTER</th>
<th>FORWARD</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>PUMP</td>
<td>RK2</td>
<td>1.5</td>
<td>2.0</td>
<td>0.0</td>
<td>90</td>
<td>V1</td>
<td>V3</td>
</tr>
</tbody>
</table>

Total

- Valves: 5
- Equipments: 1
- Connections: 3
- Pipelines: 5
- Pipes: 10
- Parameters: 45
- Combination: over $10^{12}$
Results

Initial Population After 400 generations (calculation time: 60 minutes)

Valve Operationality

Material Cost

- One Point Crossover
- Randomly Generated

In the MOGA, children are generated by:

\[ \circ : \text{One Point Crossover} \]
\[ \times : \text{Randomly Generated} \]

Calculation Environment

- CPU: Pentium 4 2.40GHz
- Memory: 512MB
- OS: Windows XP
- Program Language: Java
Obtained 3D Models

Material Cost = 8.12
Cost of Valve Operationality = 0

Material Cost = 5.50
Cost of Valve Operationality = 10001

Multi-Objective Optimization algorithm enables us to show plural Pareto-Optimal solutions simultaneously.
The more improvement of the optimization algorithm is needed.
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Conclusions and Future Works

Conclusions

1. supposition in Automatic Pipe Arrangement

2. Valve Operationality Evaluation Algorithm is proposed.

3. An Implementation of Multi-objective GA for pipe arrangement is proposed.

Future Works

1. Algorithm Improvement taking in the expert’s designing procedure that the pipe routing is determined first, thereafter, valves are set in the arranged pipes.

2. Evaluation Algorithm for Easiness of Pipe Maintenance
Remarks

Proposed System

Multi-Objective Optimization Algorithm

Expert’s knowledge for generating plans is stored

Evaluation Algorithms

Expert’s knowledge for evaluating plans is stored

CAD System

• Pipe diagram
• Equipment Arrangement list
• From-To list (Pipeline list)
• Geometric shapes of Hull, Equipments, and pipes

Locations and directions of Pipes and Valves

Viewer

text file

text file

CAD Operator

Open Source