AUTOMATIC PIPING ARRANGEMENT DESIGN CONSIDERING PIPING SUPPORTS AND CURVED SURFACES OF BUILDING BLOCKS

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SUMMARY

In this paper, a new piping path planning system is proposed in order to automate piping design corresponding to pipe supports and curved hulls. In the proposed system, candidates for positions and directions to which pipes should be passed are given in advance as 'candidate points' from the circumstances of pipe racks and support. Then, the system selects the appropriate candidate points automatically to generate piping paths keeping constraint of many factors, e.g., gravitational flow, or geometrical limitation of the pipe-bending machine, etc. Therefore, it is quite practical. The proposed system is implemented to a computer program, and the performance of the system is demonstrated through several simulations.

1. INTRODUCTION

Pipe arrangement is considered one of the most time-consuming works in the production of vessels, buildings and plants. In recent years the advancement of 3D-CAD systems has helped designers to arrange pipes. Especially, they can grasp the pipe location visually and check the interference between pipes and structures by using the system. Designers have to make right decisions in order to generate optimum piping routes and suitable positions for equipment during the process. However, the most part of the pipe routing problem, which is to design the best routes of the pipeline, demands veteran designer's experiences because the problem involves many regulations or requirements to be concerned. It has become increasingly difficult to secure skilled designers and problems of technology transferring to young engineers are also occurring. Automation of piping design is one promising method for solving these problems.

Many previous works of automatic piping design have been done in many approaches. Some of these studies, such as Ito [1], Park et al.[2], Asmara et al.[3,4], Paulo et al.[5], and Lin et al.[6] applied for Cell Decomposition approach that is composed to divide the design area into meshes and connect them from the start point to the goal point. There are two main advantages in applying this approach. The first is possible to apply maze solving algorithms to find solutions. In the maze algorithms, there exist methods to assure to find optimum solutions such as the Dijkstra's method. The second is possible to set different cost values in each cell. From this feature, the algorithm can draw pipelines near to a ship's hull, while avoiding aisle spaces as possible. In previous works that used Cell Decomposing approach, the mesh size was restricted to be larger than the pipe diameter.

Ando et.al[7, 8] presents a new pipe arrangement algorithm of which mesh sizes are not restricted by the pipe diameter, but it cannot cope with the pipes along the curved structures. In piping design, consideration must be given to the position and direction in which pipes are passed, in order to properly support pipes from pipe racks or structural members with support. In this paper, a new piping path planning system is proposed in order to automate piping design corresponding to pipe supports and curved hulls.

2. ASSUMPRIONS AND PURPOSE

The following assumptions are given in the pipe routing problem:

[Topology of target pipelines]

All pipelines are represented by a tree structure, that is, all pipelines are composed of one root (start) point and multiple leaf (goal) points. If the number of the leaf point is one in a pipeline, no branch exists in it. The piping route in the same pipeline is represented by multiple routes from the common root point to the leaf points. As a result, the piping routes are overlapped from the root point to the branches in the same pipelines. The position and the shape of the branches in the pipeline are given by analyzing the multiple routes.

[Pipes' diameter]

The pipes' diameter is invariable in the same pipeline. You may feel that this assumption is not practical, however, we can easily modify the pipes after the routing.

[Design points]

In advance, we put design points which indicate possible positions and directions of the way of pipes for each pipeline. That is, the design points are candidates of the waypoints of the pipes. In actual piping design, the pipes are put at the position that is certain distance away from structures. Also directions of the pipes on the pipe-supports are along the (curved) structures, especially in ships. For the automatic pipe routing, putting the design points is a promising approach to cope with these situations.

[Obstacles]

Structures or equipments are regarded as obstacles. The geometric information of obstacles is represented by several primitive shapes, that is, triangles, boxes, spheres or cylinders. It is not allowed that arranged pipes interfere with these obstacles.

The algorithm searches pipe routes with following design objectives:
1) To connect the pipes from start points to goal points without interference between obstacles or the other pipelines.
2) To minimize the total length of pipes,
3) To minimize the number of elbows and bends,
4) To maximize the length of the overlapping pipes in the same pipelines. The overlapping pipes in the same pipelines contribute to cut material costs.

In order to regard the pipe arrangement as a single purpose optimization, a routing cost which is proportional to the total length of routes is provided. Costs elbows and bends are given in advance. The proposed algorithm tries to find optimal routes with minimized sum of these costs.

3. PIPING PATH SEARCH ALGORITHM

3.1 PREPARATION FOR PIPING

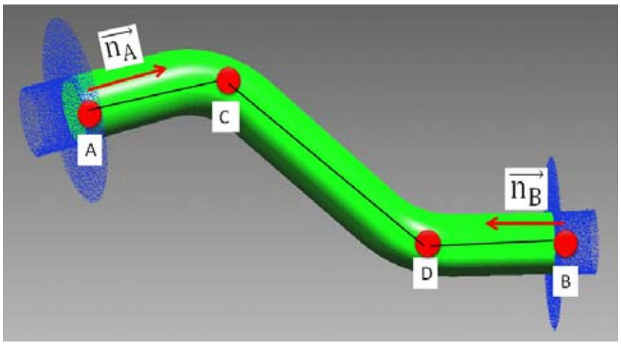

Figure 1: An example of a pipe unit connecting two design points (A and B) with two bends. The centre lines of the straight pipes are put along the AC, CD and DB.

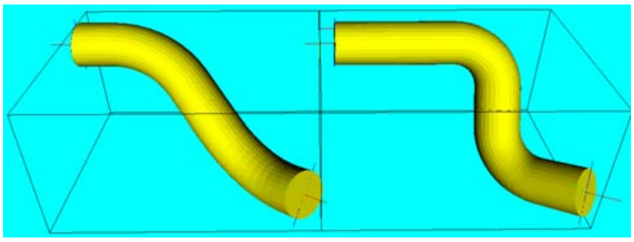

Figure 2: Left side: A piping example between two waypoints with two bends. Right side: A piping example in the same waypoints with two 90-degree elbows.

A pipe in Figure 1 shows a sample that connects two design points which have arbitrary positions and directions. Notice that geometrically, all the pipes with two bends can connect arbitrary two design points which have any positions and directions. Two pipes shown in Figure2 are examples which have the same start and goal positions and directions. In the left pipe in Figure 2, the bends have certain angles, but the position of the bend is given in advance such as AC:CD:DP=1:2:1. In the right pipe in Figure 2, bends are constrained to use only 90 degree elbows, and the position of the bends are derived from mathematical calculations.

Shapes of real pipes are constrained by the limitations of the pipe bending machines. Pipes are bent with arbitrary angles, but there exists a limit of the maximum angle. The radius of the bend is constrained by the pipe bender's moulds. When pipes are bent, straight parts between the bend are required to grasp the pipes.

3.2 PATH PLANNING FOR SINGLE PIPE

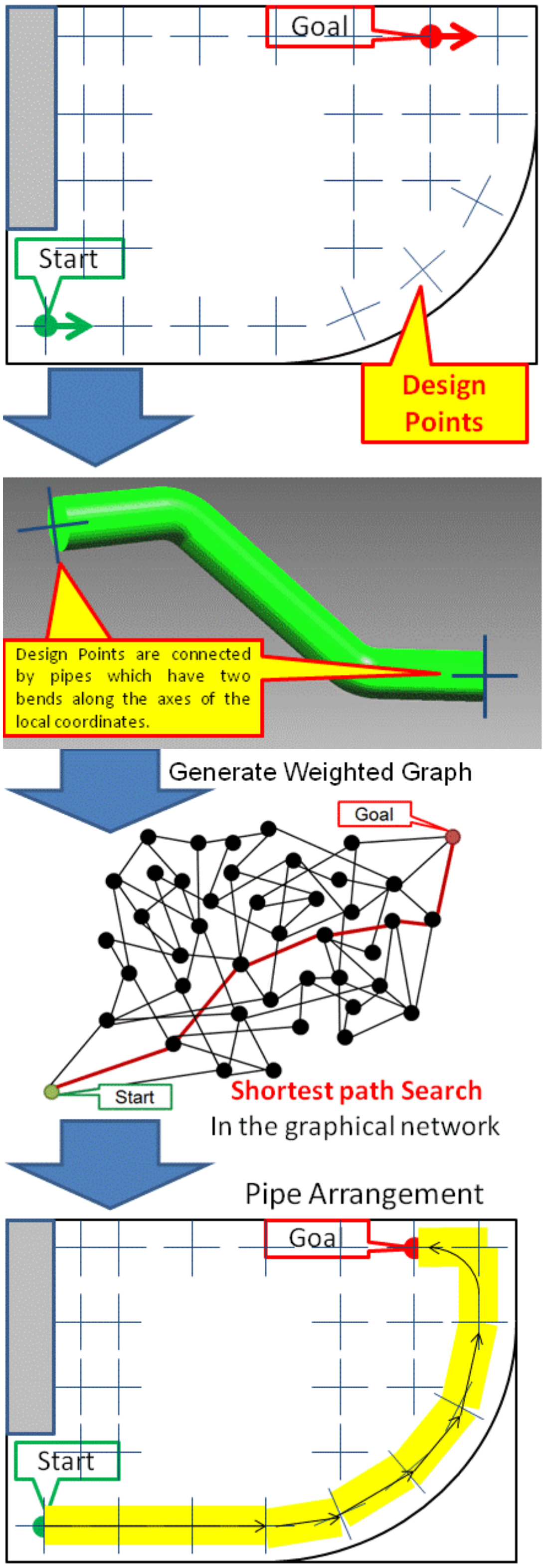

Figure3: Process of the routing algorithm for single pipe.

Figure 3 shows an overview of the proposed algorithm for single pipe arrangement. First, we put design points which indicate possible positions and directions of the way of pipes for each pipeline considering pipe supports, pipe racks or structures. The design points are given manually in advance, however, it is easy to generate it automatically. In the next step, the system tries to generate weighted and directed graph by judging that arbitrary two design points (and directions) can be physically connectable or not. Conditions of the construction constraints or gravitational flow or pockets of the pipe is also considered in the judgement of the edges. When the weighted graph is generated, the system applies a shortest path search algorithm, e.g., Dijkstra's method or A* search method. Note that both the graph generation and the path search can be executed concurrently. The calculation result in the directed graph is converted to the path of the single pipe.

3.3 STANBLE BLOCKS IN PATH PLANNING FOR MULTIPLE PIPELINES

Usually there exist multiple pipelines in practical pipe arrangement problems. However, when we apply the path planning algorithm presented in the previous section to the pipes one by one, we would get largely different piping arrangement design depending on the following two reasons.

3.3 (a) Influence on the Arrangement By Search Order

In practice of piping design, a route search is generally performed in order of expensive pipes. When the material is equivalent, it is arranged from a pipe with a large diameter. However, when there are multiple pipes of the same diameter, arbitrariness arises in the order of processing, and the final route plan changes dramatically depending on the order.

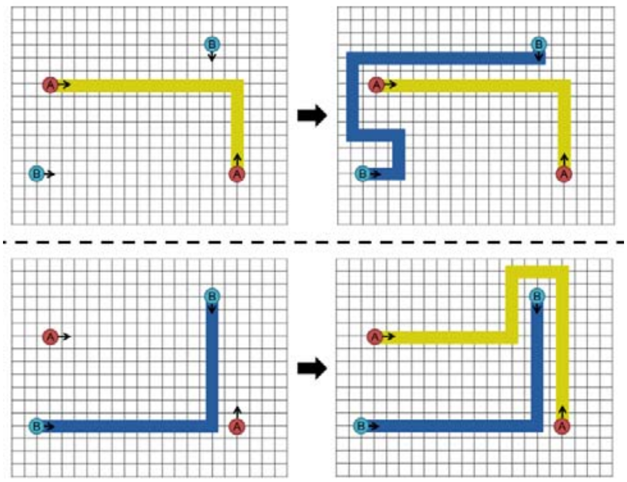

Figure 4: Influence of routing search order.

Figure 4 shows an example in which the piping route acquired by the search order is different whereas the route of two pipelines (pipe A, pipe B) have the same diameter. For the sake of clarity, the route search within a two-dimensional plane is performed. In this case, since the diameters of the two pipes are equal, there are two possible search order, one from the search from pipe A as shown in the upper part of Figure 3, and the other from pipe B. The resulted route plan is completely different depending on the pipe search order.

3.3 (a) Influence on the Arrangement by Selection from Multiple Optimum Solutions

In one piping route search, there are cases where there are multiple solutions as optimal solutions of routes. In this case, depending on which route is selected from among the optimum route candidates, the arrangement finally obtained may be greatly changed in some cases.

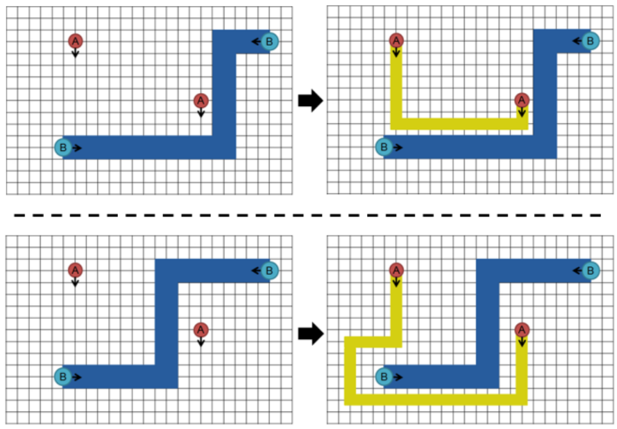

Figure 5: Influence of selection from optimum routes.

Figure 5 shows the case of searching the route of the large diameter pipe B and the small diameter pipe A on the 2-dimensional plane. Here, as the optimum path candidate for pipe B, the upper route in the figure and the lower route are considered. In the figure below, due to the influence of the route of the pipe B, the pipe A greatly bypasses. Since there are few obstacles in the design target space at the beginning of the route search, there are more optimum route proposals. However, depending on which one of these route proposals is chosen, it can be seen that the result of the subsequent pipe arrangement change drastically.

3.4 PATH PLANNING FOR MULTIPLE PIPELINES: TOUCH AND CROSS METHOD

Touch and cross method is known as a heuristics for wire-routing in electric circuits. The basic idea of this algorithm is that the arrangement of shortest paths without considering interferences has important information to avoid the other pipelines (or to overlap the same pipelines). Here shows the process of the Touch and Cross method:

1) Find optimum paths ignoring interference between the pipelines.

2) Redraw all pipes one by one, adding penalties of interference between the other pipelines to the costs. The penalties are proportional to the interfered volumes. Also in the cost calculation of the piping, when the target pipe is overlapped with pipes which are the same pipelines, the cost in the overlapped section is discounted as $Cost \times 1/\sqrt{N_{dup}}$, where N_{dup} is the number of overlapped pipes.
3) If all the pipelines do not interfere with each other, then finish. Else, increase the rate of the penalties of interference and go to the step 2).

The proposed path-planning method for single pipe shown in the Section 3.2 is applied to search piping paths in the step 1) and 2). Figure 6 and 7 are examples of the piping path searching process using the Touch and Cross method on the two dimensional space. In the early stage of the process in Figure 6, all the pipes are interfered, but it is gradually solved by redrawing the pipes in order of A, C and B. In contrast, the length of the overlapped section is gradually increased by redrawing the pipes in order A, B, (C), A and B in the same pipeline as shown in Figure 7.

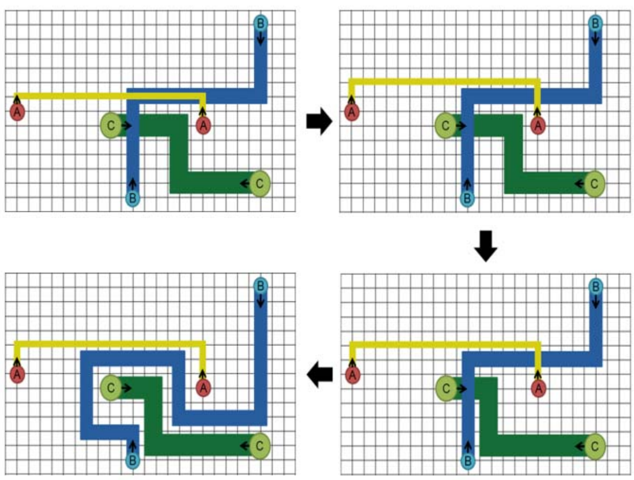

Figure 6 Process of Touch and Cross method to avoid interfering pipes.

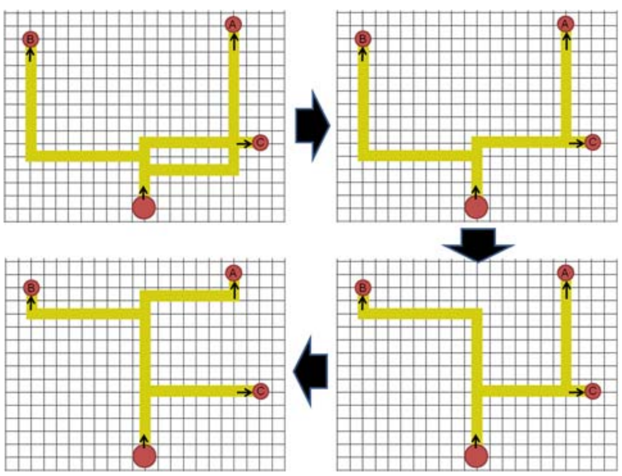

Figure 7 Process of Touch and Cross method to arrange low-cost branched paths in the same pipeline.

4. EXPERIMENTS

4.1 PIPING ALONG CURVED STRUCTURE

Using the proposed algorithms, pipes of ϕ 100 (orange), ϕ 400 (yellow), ϕ 600 (green) are placed along a wall-like structure consisting of a half cylinder with a radius of 3000 and a flat part with a length of 2000. Arrangement of the design points are: at 400 intervals in the height direction, and in the direction of radius of the cylinder, away 200 from the wall, the points are put at 400 intervals, and in the circumferential direction, divided 180 degrees into 20 (at 9 degrees intervals), then the total number of the design points are 870. The pipes have constraints of the bends that radius of the bend is 2400 or 1200 at the ϕ 600 pipe, 1600 or 1200 at the ϕ 400 pipe and 300 or 150 at the ϕ 100 pipe. Note that the angle of the bend is only 90 degrees in the ϕ 100 pipe, and the others are arbitrary degrees of pipes. The minimum length of the straight pipe section between the bends (or elbows) is 200 in the ϕ 600 or ϕ 400 pipes and 100 in the ϕ 100 pipe. Figure 8 shows a result by a standard PC with 64bit Microsoft Windows7, IntelCOREi7-2.7GHz processor, 16GB memories and the proposed system is developed on Java-1.8.0 environment. It takes about 1 or 2 minutes for the calculation, but it was sometimes failed to obtain piping paths without interfering pipes depending on the initial paths of the Touch-and-Cross method. Notice that the orange pipe is arranged along the curved wall despite using only the 90 degrees' elbows.

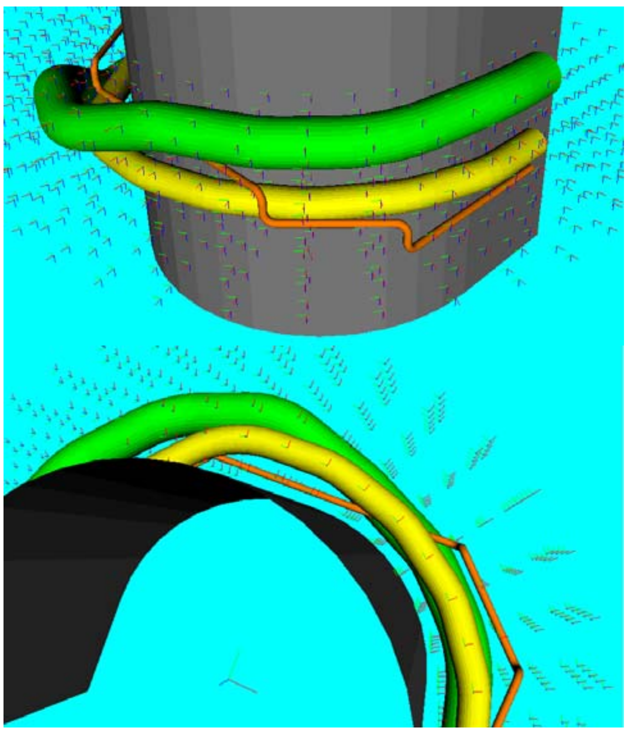

Figure 8 A result of the path-planning along curved structure.

4.2 PIPING CONSIDERING SUPPORTS

Two pipes of ϕ 200, one pipe of ϕ 150 and two pipes of ϕ 100 are arranged in a cage lining side by side along a wall on the side inside a passage shaped space of width 1500 depth 4000 height 2000. Assuming that pipe supports of two positions in the horizontal position of 100 and 400 from the ceiling and pipe supports of two stages in the vertical direction of 100 and 400 from one wall side are installed at 500 intervals in the depth direction, the design points are placed in advance assuming use of these pipe supports. A rectangular parallelepiped of width 800, height 1300 from the floor and depth 4000 was set as aisle space opposite the wall with supports, and invasion of pipes is prohibited there.

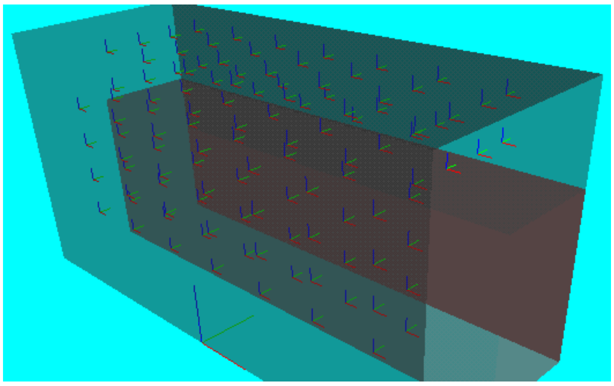

Figure 9 Candidates of design points for the ϕ 200 pipes.

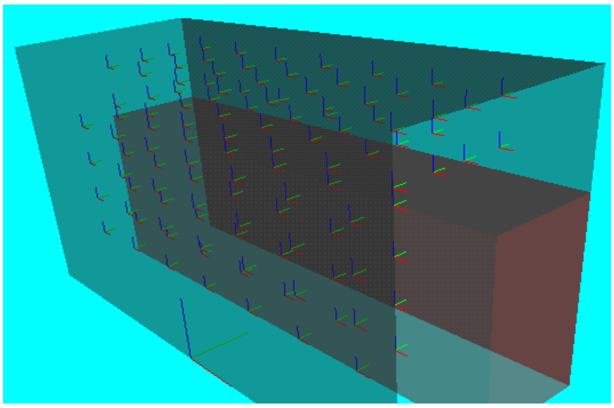

Figure 10 Candidates of design points for the ϕ 150 pipe.

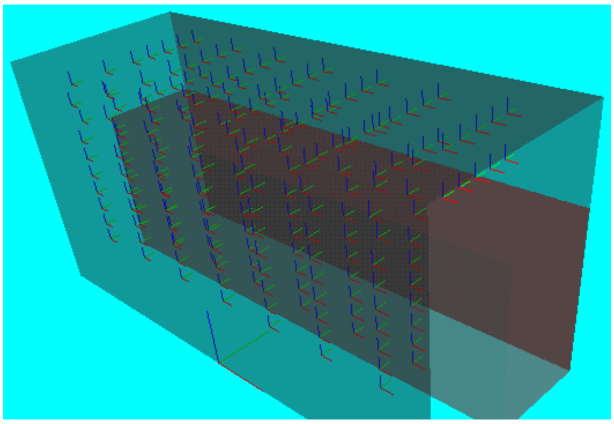

Figure 11 Candidates of design points for the ϕ 100 pipes.

All pipes' pieces are constrained to connect two design points placed at a distance of 2000 or less because of construction limitations. Figure 9, 10 and 11 shows the arrangements of design points for ϕ 200, 150 and 100 respectively. The number of the design points are 112 for ϕ 200 and ϕ 150, 210 for ϕ 100. The transparent dark-red box represents the aisle space. The pipes have constraints of the bends that radius of the bend is 400 or 300 at the ϕ 200 pipes, 300 or 150 at the ϕ 150 pipe, and 200 or 100 at the ϕ 100 pipes. The minimum length of the straight pipe section between the bends (or elbows) is 100 in all the pipes.

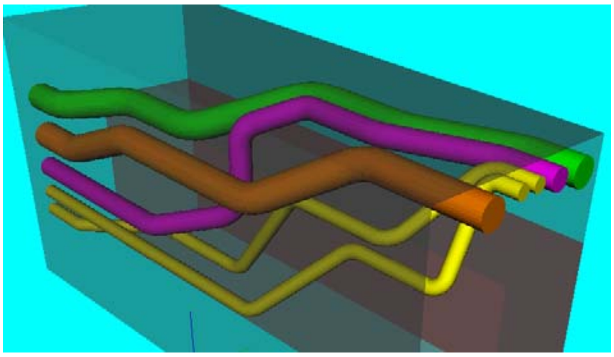

Figure 12 A result using free angle bends.

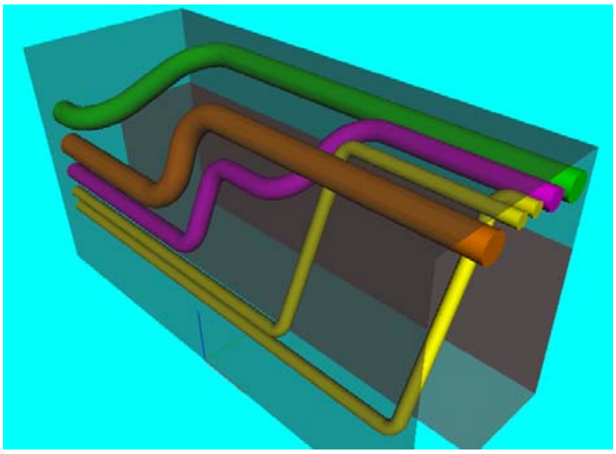

Figure 13 A result using only 90 degrees' elbows.

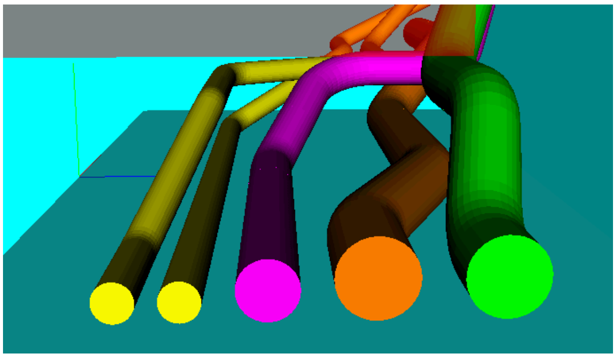

Figure 14 Another view of the solution in Fig.12.

Figure 12 shows a successful calculation result under the condition that all the pipes use free angle of bends. However, 18 out of 20 trials failed to explore. Figure 13 shows a result using only 90 degrees' elbows. Notice that although the bends are 90 degrees, some pipes are arranged diagonally. Thanks to the provision of different design points for each pipe diameter, pipes with different diameters can be fixed with the same pipe supports as shown in Figure 14. It takes about 3-5 minutes for the calculation under the same computational condition as the Section 4.1.

4.3 PIPING WITH BRANCHES

Two pipelines (green and yellow) which are composed of one root point and three leaf points are arranged behind the ceiling of a building as shown in Figure 15. The number of the design points is 1288, the number of the primitives of the obstacles is 28, and all pipes are restricted to use only 90 degrees elbows. It takes about 18 minutes for the calculation under the same computational conditions as the previous sections. The red sections in each pipeline represent branch pipe-parts which are detected by the path planning system. In this experiment, all ten trials resulted in quite similar piping paths.

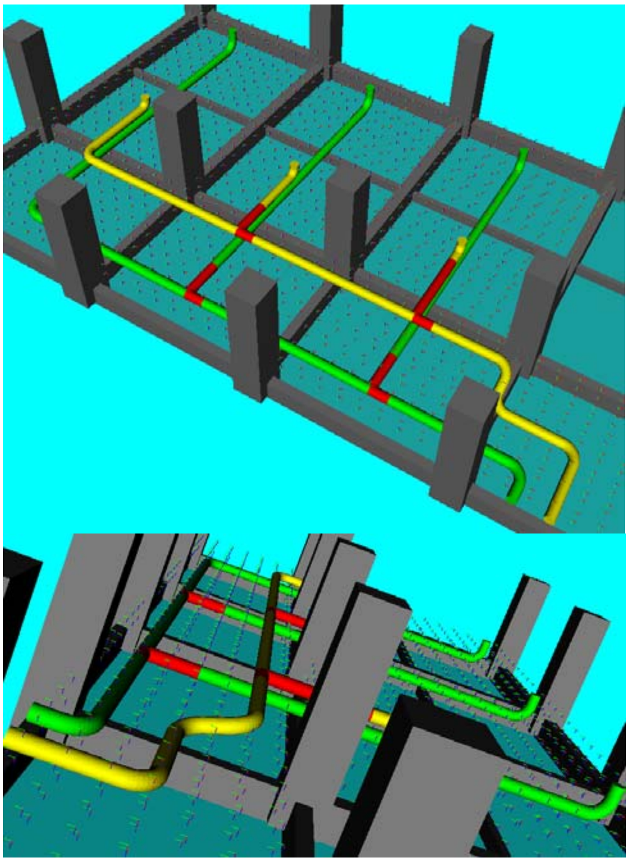

Figure 15 A simulation result for two branched pipelines.

The proposed system is also applied to a real practical problem that consists three pipelines with six leaf points (total 18 pipes), 108 primitives of the obstacles and 4002 design points for each pipeline, however, it takes 8 days for the calculation under the same computational environment as the previous sections.

4.4 PATH PLANNING OF MULTIPLE DRONES

The proposed system is applied to a path planning problem of multiple drones. Figure 16 and 17 represent a calculation result of the path planning of three drones. The number of the design points is 2000, and it takes about 25 minutes for the calculation. In order to generate short-cutting paths, the system makes a directed graph using long edges that are generated by connecting two distant design points. For this reason, the directed graph grows very large, and it takes a lot of time to solve it.

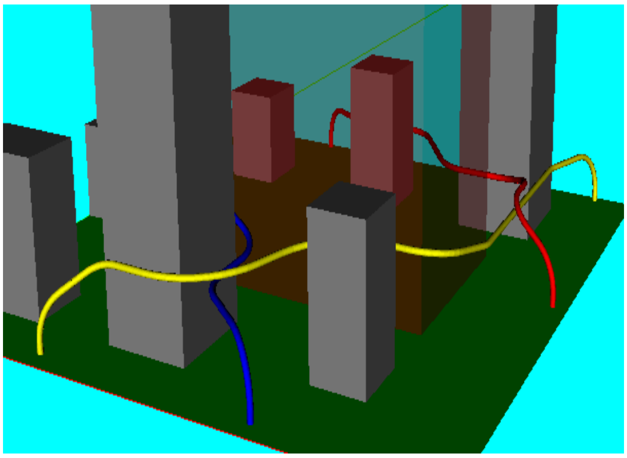

Figure 16 A path planning result of 3 drones.

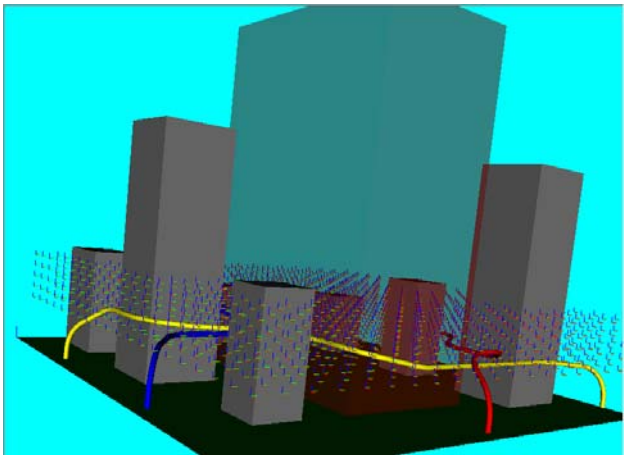

Figure 17 The obtained drones' paths with design points.

5. DISCUSSIONS

5.1 ARRANGEMENT OF THE DESIGN POINTS

In this system, design points are assumed to be arranged appropriately in advance, and the quality of the piping routes obtained by the system and the calculation time are largely affected by it. If it is too many, the computation time and required memory dramatically increase, and if it is too few, the quality of the solution goes down, or in the worst case the route cannot be found. In piping design where gravity flow is considered often, it is better to narrow the vertical direction of the pitch between the design points than the pitch of the horizontal direction.

It is troublesome to input if manually assigning via design points, and if it is arranged uniformly in the design target space, it becomes a piping route passing through a place where it is difficult to install support. We are currently developing a system that automatically generates via design points to positions where the installation of pipes becomes easier from the position and shape of structural members and supports.

5.2 CHOICE OF THE INITIAL SOLUTION IN THE TOUCH AND CROSS METHOD

In the first step of the touch and cross method, all pipes are arranged with the shortest (i.e., the lowest cost) paths ignoring interfering each other. In this time, when a pipe has several shortest paths, the system must choose one from the paths. The choice of the initial paths would affect the quality of the final solution of the touch and cross method.

5.3 REDRAWING PIPE ORDER IN THE TOUCH AND CROSS METHOD

In the touch and cross method, redrawing order of the pipes also largely affects the quality of the final solution. In our experiences, following the order of the pipes' length is a good strategy, because the longer piping path tends to have the more number of shortest paths which would avoid the other piping paths. However, when this strategy fails, repetition of the same strategy no longer passes. The proposed system takes mixture strategy of the pipes' length order and a random order. Research of the appropriate strategy is an important future work.

5.4 DEALING WITH BRANCHES IN THE TOUCH AND CROSS METHOD

The touch and cross method for branching pipes seems working well in the experiments, however, it would be biased easily to wrong solutions depending on the initial paths of the touch and cross method.
In practical piping design, there exist unfavourable shapes of the branch-pipe parts, e.g., the branch forces the main stream to strike on the wall, etc., however, the proposed system does not consider it. Also in the branch, the diameters of the pipes at the entrance and the exit of the branch are different, but currently the proposed system cannot deal with it because considering it in the automatic piping arrangement is too complicated. Modification of the pipes' diameters in post-processing is a promising way.

6. CONCLUSIONS

On the routing problem for one pipe, a new algorithm to deal with supports and arrangement along curved structure is proposed. It is assumed that design points that represent directions and positions for the candidates of the piping waypoints of the pipe are arranged in advance, and the system generates weighted graph checking whether two design points can connect by a pipe which satisfies the constraint of the pipe bender. After that, the system generates piping path from a shortest path search in the weighted graph. For arrangements of multiple pipelines with branches, a new approach that is composed of the proposed routing algorithm and the touch and cross method is also presented. Experimental results show the proposed system can withstand practical use.

7. ACKNOWLEDGEMENTS

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