# Motion Planning for a Manipulator Equipped on an Underwater Robot

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**Abstract**

In this paper, an approach for motion planning of an underwater manipulator is described. The approach generates the secure path of the tip of the manipulator in its workspace, which includes several obstacles, using a genetic algorithm. This approach also decides the manipulator's posture to avoid obstacles using an evaluation function considering the drag force. Several experiments are made in order to confirm the effectiveness of this approach.

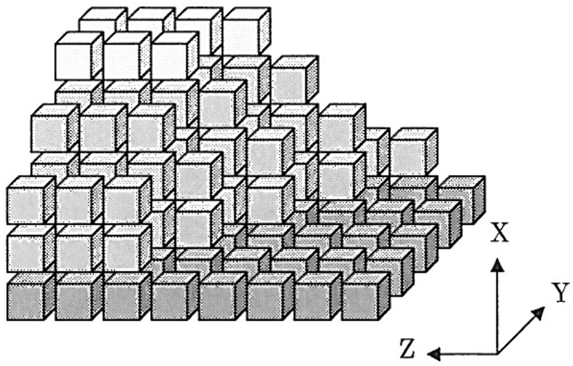



Fig. 1 Work space divided into cubes.

## 1. Introduction

At present, underwater robots, which work in the deep sea, are developed and put a thing to practical use [1][2]. With the increase of ocean development, a sea disaster and an investigation of a sunken ship, they are more needed in the future.

Base on this background, we have been considering a working system for a manipulator which is equipped on an Autonomous Underwater Vehicle [3][4]. This system operates manipulators autonomously using visual data from CCD camera. As part of the system constructing scheme, we propose an approach for motion planning of an underwater manipulator in this paper.

This approach executes a path planning of a tip of the manipulator and a collision avoidance of it. Genetic Algorithm (GA) is used as a method for the path planning. Researches using this method are reported by some papers. A path planning of cars, ships and underwater vehicles are representative example using this method [5][6]. Based on these results, GA is used to generate the path of the tip of the manipulator. The workspace is divided into cubes. And some cubes are selected by GA to generate a quasi-optimum path in the workspace. Namely, each position of selected cubes is the path.

Since manipulator's motion is influenced from various resistances in the water, it is very difficult that manipulators perform tasks smoothly. Therefore we give attention to drag force. The manipulator's posture to avoid obstacles is decided to decrease in the total drag force to the manipulator.

The effectiveness of this approach is confirmed in several experiments using a manipulator which has a 7dof.

## 2. Workspace of a Manipulator

The workspace is divided into cubes. Fig. 1 shows an image of the workspace. Each obstacle domain can be distinguished precisely by the image. All of cubes, which

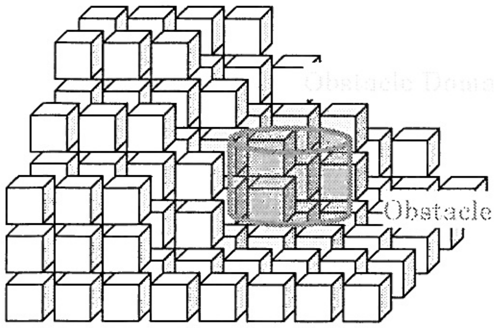



Fig. 2 Obstacle domain in the workspace image.

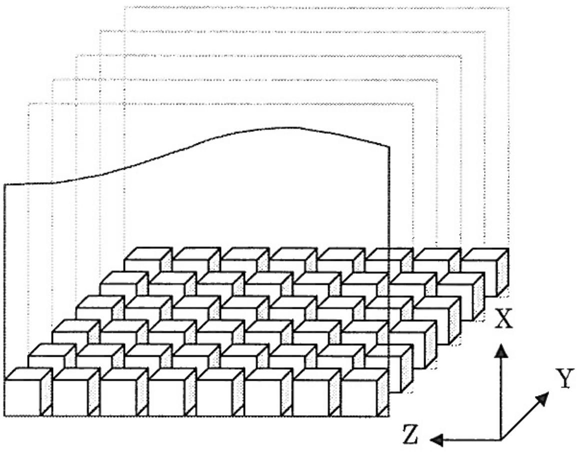



Fig. 3 X-Y plane in the workspace.

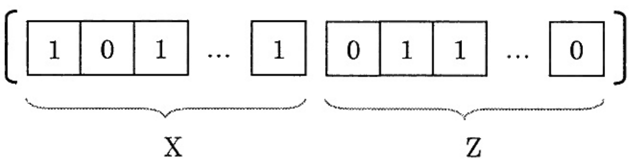



Fig. 4 Genotype of a chromosome.

include obstacles, become obstacle domain. Fig. 2 shows the obstacle domain in the workspace image.

## 3. Path Planning

In order to generate the path using GA, a chromosome of an individual must be established. In this approach, GA is used in all X-Z planes on the Y-axis shown in Fig.3. Therefore a genotype is a set of the X-value and the Z-value of a cube position. And the genotype is expressed by the binary notation. Fig. 4 shows an

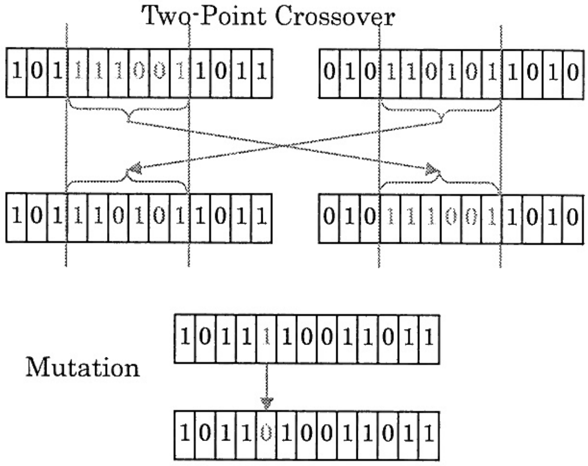



Fig. 5 GA manipulations.

example of the genotype. Plural individuals, which are formed by such genotype, are a population. The population is manipulated by GA in each X-Z plane. GA manipulations in this approach are a reproduction, a crossover and a mutation. The reproduction is composed of a selection and a multiplication. They are manipulated by a fitness value of each individual. A cost function $F$, which derives the fitness value of the individual, is described as a following equation.

$$F = \alpha_1 \cdot f_1 + \alpha_2 \cdot f_2 + \alpha_3 \cdot f_3 \tag{1}$$

where

$f_1$ : Distance between a cube position and a goal position.

$f_2$ : Sum of distance between a cube position and each obstacle domain.

$f_3$ : Distance between a cube position and its former cube position.

$_1$, $_2$ and $_3$ are a constant weight. As the fitness value of the individual is small, there is much probability that the individual is selected in next generation. However if the $f_2$ is less than some threshold, the $F$ isn't considered. Methods of the reproduction and the crossover in this paper are the Roulette-method and Two-point Crossover respectively. Fig. 5 shows images

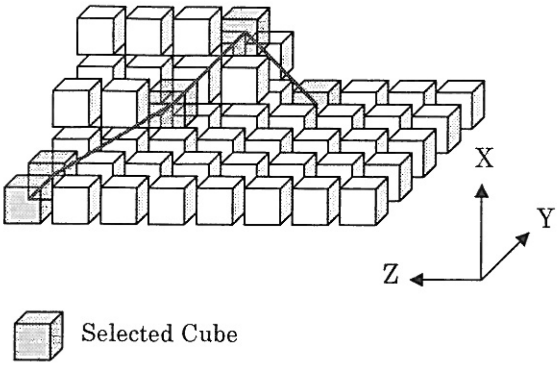



Fig. 6 Image of generated path using GA.

of the crossover and the mutation. GA manipulation mentioned above is executed over and over in each X-Z plane. The manipulation is finished if either the number of time of it exceeds an upper limit or the average of the fitness value in the generation is less than some threshold. Then a cube, which has smallest fitness value in the generation, is selected. A line, which links selected cubes to direction of Y-axis, become the path, namely, each position of these cubes is the position of the tip of the manipulator. Fig. 6 shows the relation between the path and the position of selected cubes. The position of the tip of the manipulator is the center of these cubes.

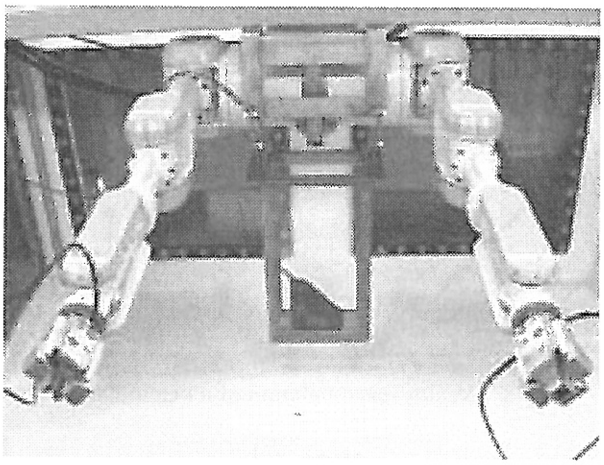
## 4. Collision Avoidance

The manipulator's posture, which avoids obstacle domains, must be decided. The manipulator used in this paper has a 7dof shown in Fig. 7. The position of the tip of the manipulator (x, y, z) is the position of the selected cube which is converted into the value in the manipulator's coordinates. Then the appropriate value is decided as the posture of the tip of the manipulator (yaw, pith, roll) in each time.

The vector of the angle of each joint, which satisfies the position and the posture, $J$ is expressed as:

$$J = [\theta_1, \theta_2, \theta_3, \theta_4, \theta_5, \theta_6, \theta_7] \ . \quad (2)$$

Since the manipulator has a redundant joint ($\theta_3$), the unique $J$ don't exist. Therefore, in order to decide the $J$, we put restrictions on the angle of the $\theta_3$. If the number of $\theta_3$ is fixed at $N$, $J_i$ ( i = 1 , ..... , $N$) exists.



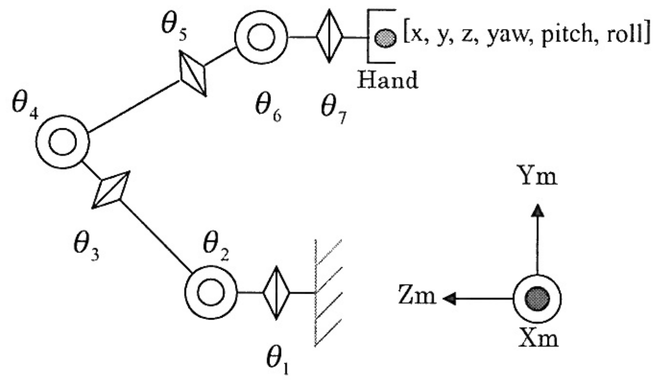



Fig. 7 Underwater manipulator with seven joints.

Therefore each $J_i$ is evaluated by an evaluation function $E$. And $J_i$ , which has the highest evaluation, is decided as the secure manipulator's posture. The $E$ is described as a following equation.

$$E = k_1 \cdot g_1 + k_2 \cdot g_2 + k_3 \cdot g_3 \quad (3)$$

where

$g_1$ :Degree of change between an estimated $J$ and its former $J$.

$g_2$ : Sum of distance between each link of the manipulator and each obstacle domain.

$g_3$ : Sum of the drag force to each link.

$k_1$, $k_2$ and $k_3$ are a constant weight. As a value of the $E$ is small, the $J$ has a high evaluation.

The $g_1$ is derived from the following formula,

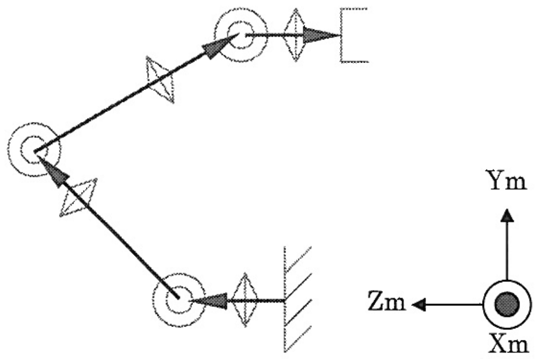



Fig. 8 Vector representation of a manipulator.

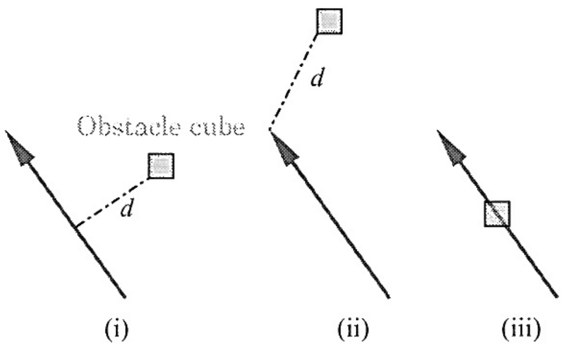



Fig. 9 Patterns of a relation between a vector and an obstacle.

$$g_1 = \sqrt{\sum_{j=1}^{7} w_j \cdot \Delta\theta_j^2} . \qquad (4)$$

This formula expresses the sum of error to two power of angle of each joint. $w_j$ ( $j$=1,…,7 ) is weight which is decided from the number of links moved by $\theta_j$.
The $g_2$ is derived from the following formula,

$$g_2 = \sum_{m=1}^{4} d_m . \qquad (5)$$

This formula expresses the sum of distance between each link of the manipulator and each obstacle domain. Each link is represented as a vector shown in Fig. 8. The $d_m$ ( $m$=1,...,4 ) is a distance between each vector and outer cubes in each obstacle domain. A relation between the vector and the cube is classified into three patterns. Fig. 9 shows each pattern. The $d$ is the length of a perpendicular line toward the vector from the cube like pattern (i). If the cube don't exist on the vector like pattern (ii), the $d$ is the length of a line which links the start or the end point of the vector to the cube. Pattern (iii), the cube contacts the vector, namely, the link contacts the obstacle. If there is such vector, the $J$ is excluded from the subject of the evaluation.
The $g_3$ is the total drag force to the estimated $J$. Since each link is hypothesized as a cylinder, the drag force to each link $D_j$ is given by

$$D_j = \frac{\rho}{2} \cdot C_{Dj} \cdot A_j \cdot V_j^2 \quad (j=1,\dots,7) . \qquad (6)$$

where
: Fluid density.
$C_D$ : Drag coefficient.
$A$ : Projected area to a perpendicular face at the fluid flow in the link's posture.
$V$ : Velocity of the link.

The $V^2$ is given by

$$V_j^2 = \int_0^l |\dot{p}_j + w_j \cdot x_j| \cdot (\dot{p}_j + w_j \cdot x_j) dx_j . \qquad (7)$$

where
$p_j$ : Position of the joint $j$.
$w_j$ : Velocity of the link $j$.
$x_j$ : Distance of a unit on link $j$.

The drag force of each link depends on the $A$ and the $V$. However it depends on only $A$ in this approach because it is hypothesized that the velocity of each link is fixed in order the tip of manipulator to move linear. The $A$ is given by

$$A_j = a_j \cdot \sin(\theta_j) \quad (j=1,\dots,7) . \qquad (8)$$

where
$\theta$ : Angle of the link's posture to the fluid flow.
$a$ : Projected area of the perpendicular link to fluid flow.

Therefore $g_3$ is replaced with following simple formula,

$$g_3 = \sum_{j=1}^{7} A_j . \qquad (9)$$

If all $J$ are excluded from the subject of the evaluation by the result of $g_2$ or all $E$ can't exceed some threshold, a cube, which has second fitness value, is decided as a new position of the tip of the manipulator. Fig. 10 shows the flow chart of this approach.

The manipulator's posture to avoid obstacle domains can be decided by this approach in each object position.

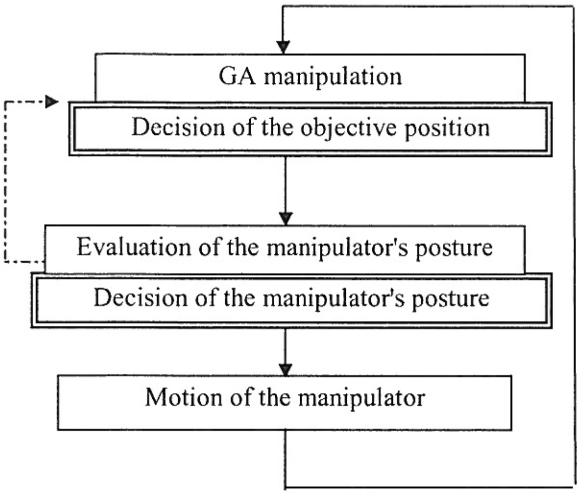



Fig. 10 Flow chart of the path planning and the collision avoidance.

And the collision avoidance between the present position and the next position is also expected because the evaluation function $E$ includes the $g_1$. Moreover, if the value of the $g_1$ is large, the $J$is excluded from the subject of the evaluation. Namely, compared with the former posture, the decided posture don't change extremely. Therefore decided posture is secure if the former posture has avoided obstacles.

## 5. Experimental Result

In order to confirm the effectiveness of this approach, several experiments are made. TABLE I shows parameters of the working environment and GA manipulation in one of experiments. In this experiment, the position of each obstacle domain is known in advance.

As the result of the experiment, a path, which avoids each obstacle domain, was generated by GA manipulation. Fig.11 shows the generated path in coordinate of Y-X, Y-Z and three dimensions. In the space, which didn't include obstacle domains, the path went toward the goal because the fitness function $F$ includes the $f_l$.

Each link didn't contact obstacle domains because all of the manipulator's postures on the path were secure shown in Fig. 12. When the value of Y was between –430 and –440, the degree of the change of the value of Z was comparatively large. Then manipulator's posture didn't change large because the posture, which could avoid obstacle domains, was found from among several $J$.

TABLE I Parameters of the experiment

| | |
|---|---|
| Size of a cube [mm] | 10 •10 •10 |
| START position | X:40 Y:-30 Z:60 |
| GOAL position | X:25 Y:-80 Z:15 |
| Number of obstacle cubes | 48 |
| Number of obstacle domains | 2 |
| Number of individuals in GA | 60 |
| Number of generations in GA | 60 |

## 6. Summary and Conclusions

In this paper, an approach for the motion planning of the underwater manipulator was described. This approach executed the path planning using GA and the collision avoidance using the evaluation function. And we confirmed the effectiveness of this approach with experiments. As the result, this approach could generate the path which avoids the obstacle, and decide the secure manipulator's posture.

The working time isn't considered so that fixed obstacles are set in the workspace. This approach executes path planning and collision avoidance in each objective position of the tip of the manipulator. Therefore we think that it can be applied to moving obstacles. However there are some problems. One of them is the decision of manipulator's posture and the calculating time for GA. All estimated $J$ contact obstacle domains exceptionally, and if good path can't be generated, the calculating time is very long because GA manipulation is continued to execute. As the next step of our research, we have considered an algorithm to decide $J$ certainly and GA manipulation, which can generate the path promptly.

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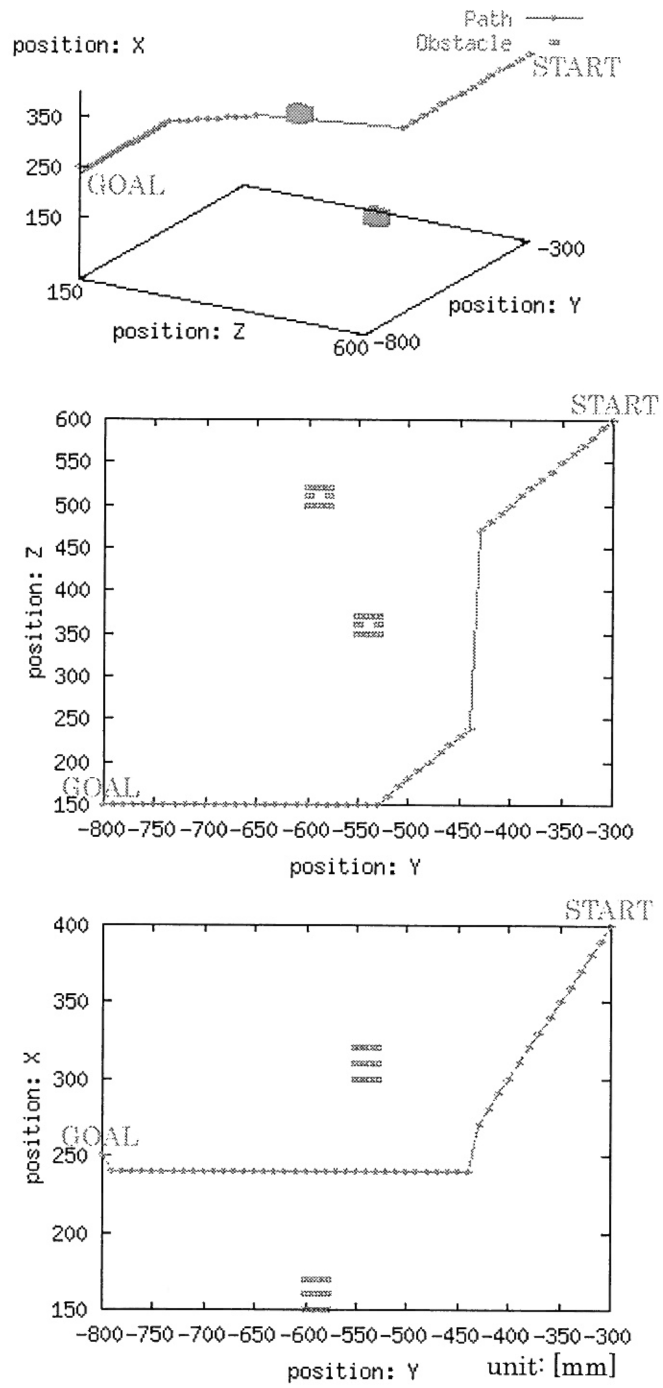


Fig. 11 Generated path and obstacle domains.

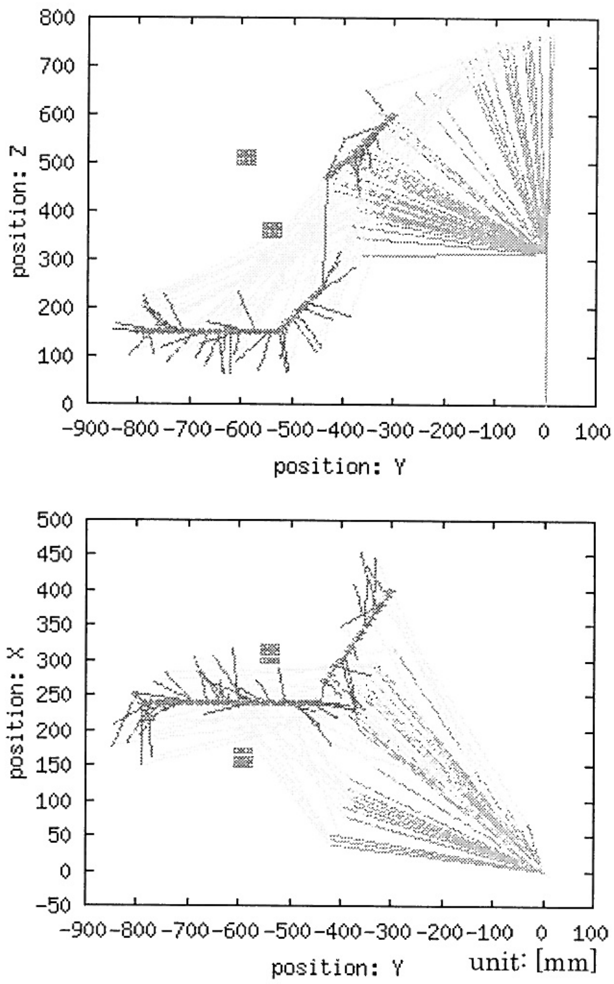


Fig. 12 Decided postures of the manipulation.


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