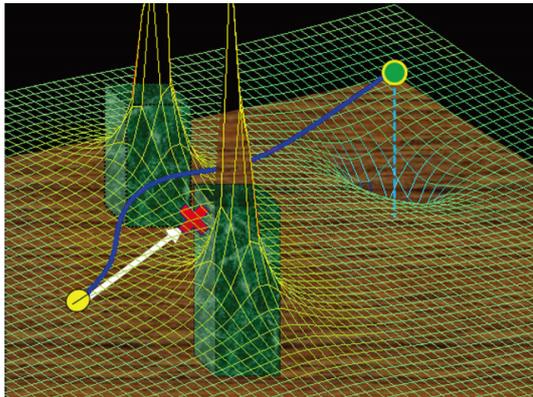


Development of Obstacle Avoidance Control for Robotic Products Using Potential Method



YUSUKE YASHIRO*1

KAZUKI EGUCHI*1

SATOSHI IWASAKI*2

YOSHIAKI YAMAUCHI*3

MASAHIRO NAKATA*4

In the field of robot development used in areas into which human beings have difficulty entering such as deep water, space and irradiated areas, the need for autonomous products that can operate without being remotely control by a human being has increased. Considering application to more general issues, it is important for autonomous operation to have the capability to avoid unknown obstacles in three dimensional space. Accordingly, Mitsubishi Heavy Industries, Ltd. (MHI) has used the potential method to establish control logic and verified the effectiveness of the logic through simulation. Specifically, the capability to improve the efficiency of avoidance operations in three dimensional space by finding obstacle avoidance paths in horizontal and vertical directions based only on the coordinates of the obstacle was confirmed.

1. Introduction

In the past, MHI developed several robotic products used for operations in harsh environments into which human beings have difficulty entering such as deep water, space, nuclear power plants, etc. In recent years, due to improvements in the performance of computers and sensors, the development of autonomous products has been made possible. Technology for the autonomous operation of robots is also in demand in the market as a customer need because it allows the extension of the operational range of autonomous robots and the reduction of fatigue in human beings caused by many hours of control operation.

In areas where robotic products are used, there may be obstacles that are not indicated by information on a prepared map because of unexpected events such as disasters, etc. In such cases, a robot with the capability to avoid obstacles switches its operational mode to obstacle avoidance. However, if the obstacle avoidance operation is based on a preset sequence, some obstacle shapes cause repeating and/or exaggerated operation, resulting in a loss of efficiency.

Accordingly, to improve the efficiency of avoidance operation of robots, a method to find avoidance paths depending on the shape of obstacles is needed. Considering the application of robots to more general issues, it is favorable that the method is applicable to operations in three dimensional space.

One of the methods to find avoidance paths is the potential method⁽¹⁾. This method defines potential functions on a destination position and obstacle positions and determines the moving direction based on the gradients of the functions in order to find a path for moving to the destination position while avoiding the obstacles. The calculation of potential functions can be extended three-dimensionally. This method can also deal with unknown obstacles because the route can be changed in real time based on observation data up to the point of time.

*1 Nagasaki Research & Development Center, Technology & Innovation Headquarters

*2 Chief Staff Manager, Nagasaki Research & Development Center, Technology & Innovation Headquarters

*3 Ship & Ocean Engineering Department, Shipbuilding & Ocean Development Division, Commercial Aviation & Transportation Systems

*4 Submarine Department, Naval Ship Division, Integrated Defense & Space Systems

This paper presents the use of the potential method for the establishment of control logic for finding an obstacle avoidance path of a robotic product and the results of its effectiveness verification through simulation. This control logic stores and updates a certain number of obstacle coordinates detected by the sensor, and calculates potential functions and the gradients based on the coordinates of the obstacles and the destination position to determine a moving direction. A weighting coefficient is used for the potential function and increased or decreased depending on conditions in order to improve the efficiency of avoidance paths and to resolve the issue where the robot stops at a certain position in some cases (deadlock) because a moving direction cannot be successfully determined. In the verification of the control logic through a simulation using different shapes of obstacles without changing the parameters, it was confirmed that an appropriate path could be derived based only on sensor detection results, and efficient obstacle avoidance was realized.

2. Potential method

The potential method defines potential functions on a destination position and obstacle positions and determines the moving direction based on the gradients (partial differentiation of each coordinate component) of the functions. **Figure 1** shows an image of a potential field (superposition of potential functions) designed on a two-dimensional plane. Smooth potential functions are defined so that those of the obstacles diverge in the direction of positive infinity and that of the destination position diverges in the direction of negative infinity. The gradient of the functions defined for obstacles are in a direction away from the obstacle. On the contrary, the gradient of the function defined for the destination position is in a direction approaching the destination position. The potential field is the superposition of these functions. The gradient (differentiation) of the potential field is in a direction away from obstacles and approaching the destination position. A robot can move to the destination position while avoiding obstacles, using this gradient as the moving direction at that time. The potential method has the following three features.

- Prior information such as a topographic map is unnecessary because the moving direction is derived according to the information available at that time.
- The moving path can be changed in real time because the potential field changes when an obstacle is found.
- Application to three-dimensional space is easy because gradients are derived separately for each of the coordinate components (x, y, \dots).

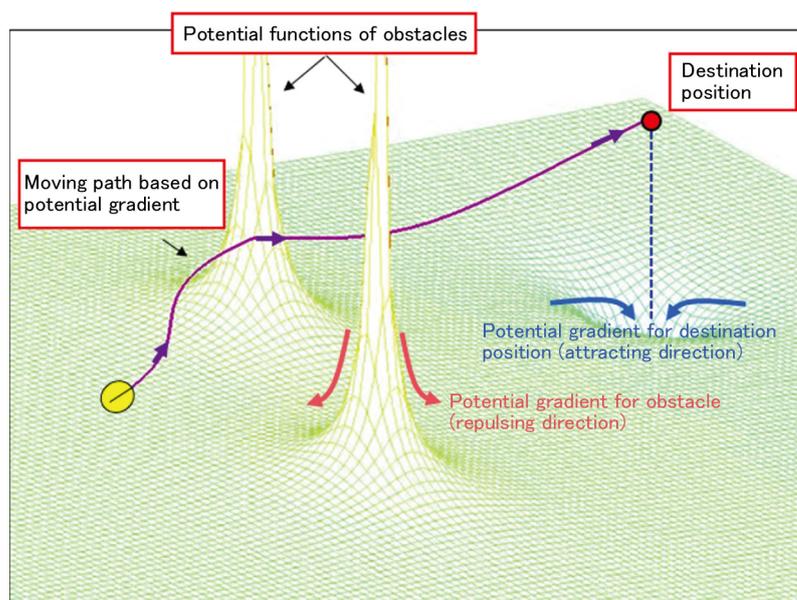


Figure 1 Example of deriving path based on potential method (two-dimensional plane)

This figure shows the derivation flow of the moving direction and path from the gradients of potential functions defined on a two-dimensional plane.

The following formulas (1) and (2) show potential functions, formula (3) shows the calculation of a potential field, and formula (4) shows the calculation of a gradient.

$$P_o(x, y, z) = \frac{1}{\sqrt{(x - x_o)^2 + (y - y_o)^2 + (z - z_o)^2}} \quad (1)$$

$$P_d(x, y, z) = -\frac{1}{\sqrt{(x - x_d)^2 + (y - y_d)^2 + (z - z_d)^2}} \quad (2)$$

$$P(x, y, z) = \sum w_o P_o + w_d P_d \quad (3)$$

$$-\text{grad}P(x, y, z) = -\left[\frac{\partial P}{\partial x}, \frac{\partial P}{\partial y}, \frac{\partial P}{\partial z}\right] \quad (4)$$

(x, y, z) : Robot position (x_o, y_o, z_o) : Obstacle position (x_d, y_d, z_d) : Destination position
 (w_o, w_d) : Weighting coefficient

3. Establishment of control logic

Figure 2 shows the control logic based on the potential method. The movement of the robot depends on the actuators controlled according to the direction derived by the logic.

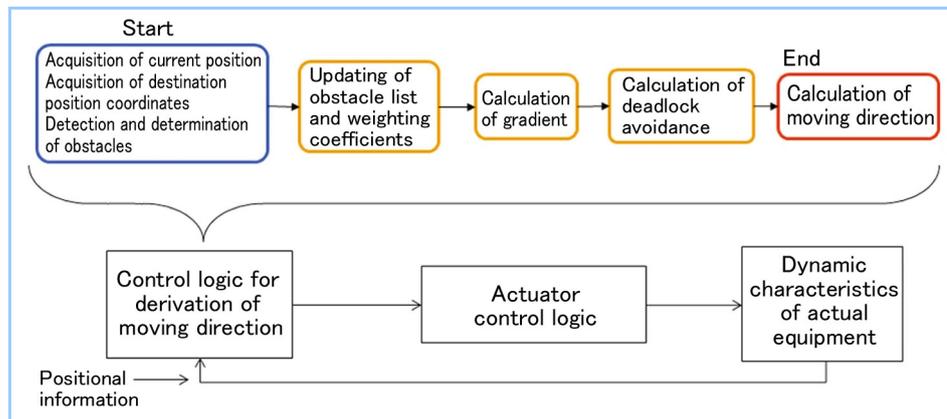


Figure 2 Obstacle avoidance logic based on potential method

This figure shows the logic flow using the potential method and its positional relationship to the actual equipment and the actuator.

The following capabilities are added to the logic in order to move the robot efficiently to the destination position while avoiding obstacles.

- Capability to update the list storing obstacle coordinates
- Capability to adjust the weighting coefficients of the potential field

Updating the obstacle coordinate list allows the elimination of obstacles already avoided and the creation of a potential field that covers only considerable obstacles. Adjusting the weighting coefficients allows more rapid obstacle avoidance and the reduction of the influence of obstacles having lower avoidance priority on the determination of a path.

Figure 3 shows the procedures for the prevention of deadlocks using capabilities to store obstacle coordinates and to adjust the weighting coefficients. In some cases, the potentials of the destination position and the obstacles reach equilibrium when the potential gradient is calculated from all potential functions. In such cases, a small value with the opposite sign in the moving direction is derived repeatedly, resulting in a path that makes the robot almost stop at that position. This is referred to as a deadlock, one of the issues with the use of the potential method. To resolve this issue, the reduction of the weighting coefficient of the destination position with the approaching obstacle kept stored allows the robot to move away from the obstacle temporarily. Then once again returning the weighting coefficient of the destination position to the original value makes the robot move to the destination position while avoiding the stored obstacle, resulting in a path that prevents deadlocks.

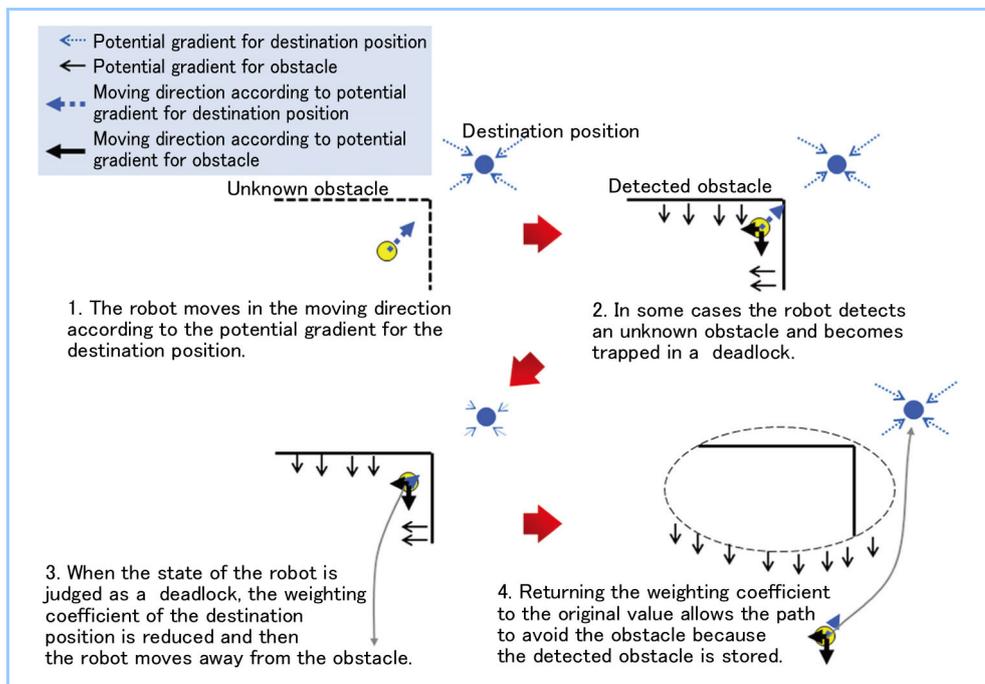


Figure 3 Deadlock avoidance logic

This figure shows the flow of the logic that changes weighting coefficients to prevent deadlocks, the equilibrium of the potential gradients of the obstacle and the destination position.

4. Simulation

The effectiveness of the control logic was confirmed using simulation. **Figure 4** shows the results of the functional confirmation of the control logic in two-dimensional space. The obstacle and destination position were set so that a deadlock would result. Because this was the verification of only the control logic, the sensor was defined to be able to detect the obstacle in all directions and the robot was defined to have no dynamic characteristics and be able to move in the moving direction without delay. As a result, the robot moved to the destination position while avoiding obstacles and deadlocks, thereby confirming the validity of the control logic.

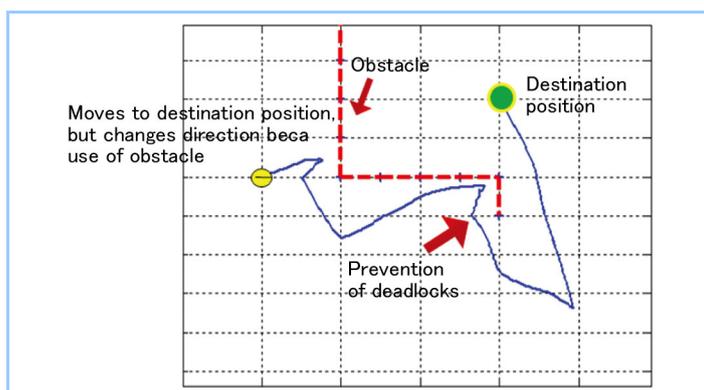


Figure 4 Result of simulation on two-dimensional plane

Next, simulation in three-dimensional space including vertical directional movement was performed. This simulation considers the dynamic characteristics of the robot and therefore the similar characteristics as an actual robot were reproduced. The sensor was defined as to be able to detect the obstacle only in three directions (to the front, and left and right obliquely downward).

Figure 5 and **Figure 6** show the results of horizontal and vertical directional obstacle avoidance simulation, respectively. The result of obstacle avoidance using sequential operation consisting of a change of direction, moving up, moving straight and moving down is shown together for a comparison of avoidance efficiency improvement. For both simulations, the design parameters of the control logic were the same. The obstacle positions were not given in advance and the robot could only acquire the obstacle positions that existed within the detection range of the sensor.

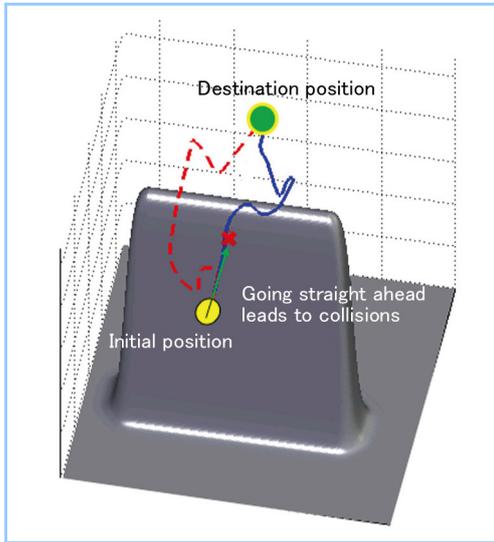


Figure 5 Result of vertical directional obstacle avoidance simulation in three-dimensional space (Red: Sequential operation, Blue: Operation according to potential method)

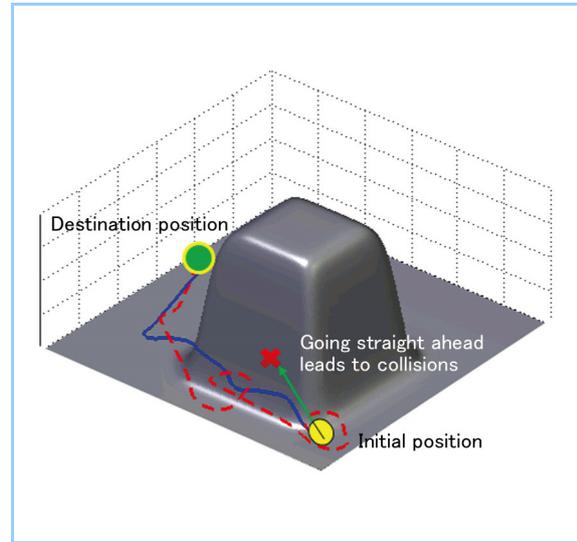


Figure 6 Result of horizontal directional obstacle avoidance simulation in three-dimensional space (Red: Sequential operation, Blue: Operation according to potential method)

In vertical directional obstacle avoidance using sequential operation, the robot moved up to avoid the obstacle and then moved down to the destination position. When the control logic based on the potential method was used, the robot moved up while turning to avoid the obstacle and then moved down to the destination position.

In horizontal directional obstacle avoidance using sequential operation, the robot moved to the destination position through a path including unnecessary turning. This was because the acting time of each operation was tuned for vertical directional obstacle avoidance. This result indicates that sequential operation causes unnecessary avoidance for different obstacles. On the other hand, the avoidance path that was made according to the potential method included no unnecessary turning. This result indicates that the potential method can derive an appropriate avoidance path even with the same parameters because potential functions were made depending on the shape of obstacles. The undulating shape of the path that was made based on the potential method was caused by the fact that the robot could not change the moving direction instantaneously due to its dynamic characteristics.

Figures 7 and 8 compare the efficiency of avoidance operation numerically. For both the vertical and horizontal directions, the control logic based on the potential method resulted in a shorter required time and the further reduction of the energy consumption index determined from the actuator travel. In this way, it can be said that the control logic based on the potential method improves the efficiency of obstacle avoidance operation.

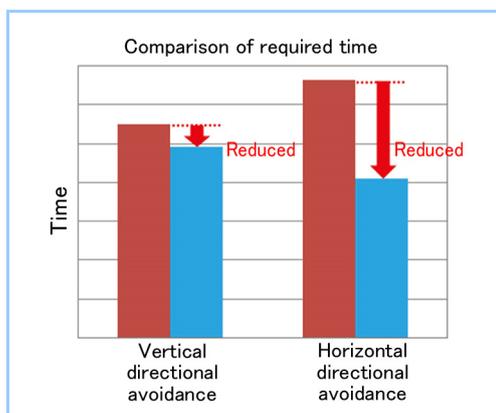


Figure 7 Comparison of time required for avoiding obstacles (Red: Sequential operation, Blue: Operation according to potential method)

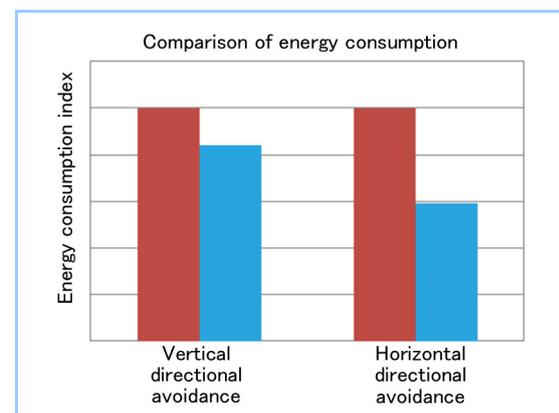


Figure 8 Comparison of energy consumption for avoiding obstacles (Red: Sequential operation, Blue: Operation according to potential method)

5. Conclusion

MHI used the potential method to establish logic for the avoidance of obstacles applicable to three-dimensional space and verified its capability to find a path depending on the shape of an obstacle and to improve the efficiency of avoidance operations through simulation. This method enables the efficient avoidance of unknown obstacles, resulting in the autonomous movement of robots in areas with complicated geography.

In the future, MHI will proceed with research of the elements necessary for application to actual equipment such as a weighting coefficients design method in consideration of the detection range of the sensor and the dynamic characteristics of the robot, and contribute to actual operation.

References

1. Jen-Hui Chuang et al., An Analytically Tractable Potential Field Model of Free Space and Its Application in Obstacle Avoidance, IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS-PART B: CYBERNETICS, Vol. 28 No. 5 (1998) pp. 729-736