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A study on path optimization method of an unmanned surface vehicle under environmental loads using genetic algorithm

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ABSTRACT

Setting a path is essential for reaching a target point and avoiding obstacles in the autonomous navigation system for an unmanned surface vehicle (USV). Accordingly, a decision algorithm for determining an optimized path, considering ocean environmental loads, is necessary. In this study, a genetic algorithm was used to determine the optimized path with the minimum travel time for a USV under environmental loads. The optimized paths were determined using numerical simulations. First, the path of the vessel under environmental loads was expressed using chromosomes consisting of the turning angle of the vessel per unit time. In the configuration of the decision algorithm, the following three objective functions were derived: avoiding obstacles, reaching a target point, and minimizing travel time. By integrating the three objective functions, a new fitness function was proposed. In addition, to determine the optimized path, the fitness evaluation of each chromosome was repeated for all generations using the fitness function. Using the proposed algorithm, the optimized paths were determined considering environmental loads and the allowed minimum distance of approach to an obstacle, and validated using numerical simulations.

1. Introduction

Determining the route of an unmanned surface vehicle (USV) is an important problem associated with its safety and efficiency. According to the trends in ship automation systems and unmanned technology, an electronic navigation chart (ENC) has been introduced, and research on its application is being conducted actively. Accordingly, research is required to determine the route of a ship on an ENC. Lee et al. (2000) have discussed the necessity of this research. In addition, finding the best route autonomously is necessary to manage a USV effectively in a wide area. The necessity of the research is described by Kim et al. (2012).

However, autonomous path planning should consider overcoming environmental loads in real ocean environments, and minimizing energy consumption to maximize the capability of a USV's operations. This is why, even though the shortest path that avoids obstacles is planned, a USV cannot follow this path owing to a thrust limit.

A genetic algorithm, which is also referred to as an optimization algorithm, can search for an optimal solution robustly even if a problem is complex or if additional information is not provided. When various environmental loads are considered, the following difficulties are encountered while solving problems: lack of advanced information and limitations of functions in conjunction with a large search space. Thus, genetic algorithms could be suitable for searching for an optimized path and finding a valid solution. Lee et al. (2000) discussed the suitability of genetic algorithms for searching for an optimized path.

In this study, the optimized path of a USV, considering environmental loads, is found using a genetic algorithm. The following three objective functions are derived: avoiding obstacles, reaching a target point, and minimizing travel time. A new fitness function is proposed by integrating the three objective functions. An optimized path is found using evolutionary processes and repeating fitness evaluations of each chromosome over all generations using the fitness function. If the proposed algorithm is applied to search for paths, the optimized paths that have the minimum travel distance or time can be obtained. The proposed algorithm is verified using numerical simulations for several conditions of environmental loads and obstacles.

2. Genetic algorithm

A genetic algorithm is a stochastic searching method, which obtained its idea from the evolution of organisms. The algorithm is modeled using natural phenomena including genetic inheritance and Darwin's survival of the fittest. The structure of a genetic algorithm is shown in Fig. 1.

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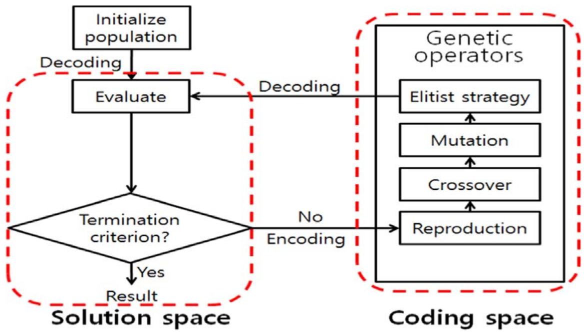

Fig. 1. Structure of genetic algorithm.

2.1. Initialization

In the initialization process, an initial population is generated, and a simulated evolution occurs. Random initialization, i.e., generating a population randomly, is used in this study. The process of random initialization is shown in Fig. 2. Random initialization is described by Jin (2010).

2.2. Fitness function evaluation

The fitness of every individual is evaluated over all newly generated populations in each generation. The fitness function is derived from the objective function, which is required for appropriate mapping, as follows:

$$f(s) = \frac{1}{F(x) + \gamma} \quad (1)$$

where $F(x)$ is the objective function, $f(s)$ is the fitness function, x is a multi-dimensional vector, s is a string vector or chromosome, and γ is a constant. The equation always satisfies $f(s) \geq 0$ (Jin, 2010).

2.3. Genetic operators

Genetic operators include reproduction, crossover, mutation, and elitist strategy. A reproduction operator selects individuals, which could be the source of a crossover, from the current population based on the fitness. A crossover operator creates a new chromosome by combining the characteristics of two other chromosomes. A mutation operator alters some genes in the chromosome from their initial state. In the elitist strategy, the best organism is carried over to the next generation, unaltered, by replacing the worst organism in the current generation (Jin, 2010).

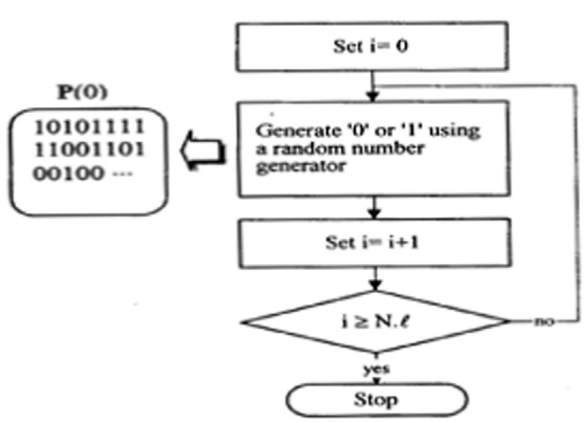

Fig. 2. Random initialization (Jin, 2010).

3. Genetic representation of a path of a ship

To apply the genetic algorithm to optimize the path of a ship, a genetic representation of the path is required. In addition, the fitness of the path must be evaluated using the fitness function.

Therefore, the turning angle of the ship per unit time is represented in the form of a chromosome, simplifying the motion of the ship. The moving distance of the ship per unit time is also calculated, considering the velocity induced by thrust, and the velocity variation induced by environmental loads. The path of the ship is expressed by combining the turning angle and the moving distance per unit time explained above.

3.1. Turning angle per unit time

The expression for the chromosome that represents the solution of a path, is

$$a^T = [a_1 a_2 a_3 \cdots a_n] \quad (2)$$

where a is turning angle, and n is the length of the chromosome. n is derived as follows:

$$n = \frac{t_0}{t_u} \quad (3)$$

where t_0 is the virtual operating time required to create the path of the ship, and t_u is the unit time during the turning movement. By following the notation of Lee et al. (2012), the path that is represented by the chromosome can be explained as shown in Fig. 3.

Here, $p_1, p_2, p_3, \cdots$ are the locations per unit time t_u, and p_n is the location at the final time t_0.

3.2. Moving distance per unit time

From Fig. 4, the velocity vector of the ship satisfies

$$\vec{U_i} = (\vec{V_t})_i + (\vec{V_e})_i \quad (4)$$

to move along the path line represented by the chromosome, where $\vec{U_i}$ is the velocity vector following the path line, $(\vec{V_t})_i$ is the velocity vector induced by the thrust of the ship, and $(\vec{V_e})_i$ is the velocity vector induced by the environmental loads on the ship. Hence, it follows that

$$(V_t)_i \sin(\theta_t)_i = (V_e)_i \sin(\theta_e)_i \quad (5)$$

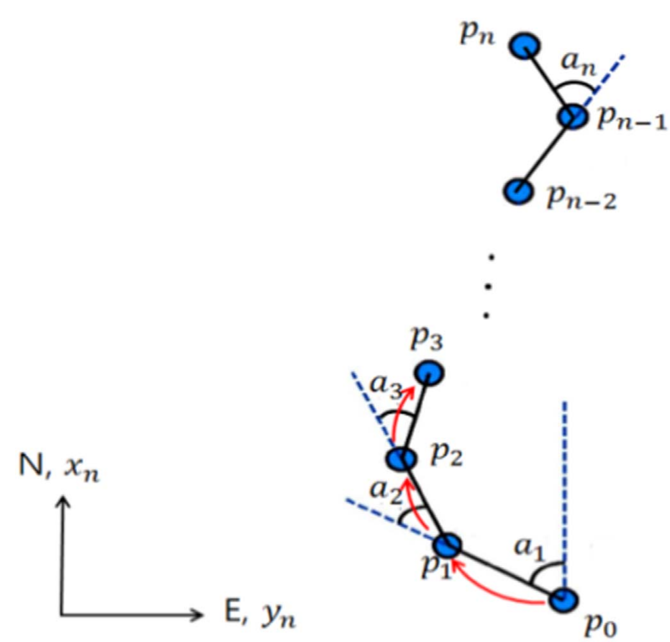

Fig. 3. Created path by a chromosome in North-East-Down coordinate system.