Performance Analysis of Multi-step GA for Real-time 3D Model-Based Recognition for Underwater Vehicle

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Nowadays, underwater vehicle has become essential tool such applications environmental survey, cable or pipeline tracking, unstructured undersea ocean exploration which is hazardous area. We have developed visual based underwater vehicle using dual-eyes cameras and three-dimensional marker. In this system,(position and orientation) pose between vehicle and target is estimated by means of 3D model-based recognition utilizing Multi-step GA. This paper analyses the performance of Multi-step GA for 3D recognition for underwater vehicle effectively based on the variations and modification in GA parameters. The recognition accuracy using Multi-step GA is evaluated by using offline full search. The indoor experimental results show that the proposed system can provide promising real-time 3D recognition accuracy.

***Key Words*:** Multi-step Genetic Algorithm, Performance analysis, Model-based Recognition, Accuracy, Dual-eyes cameras

1 Introduction

In today world, visual servo based underwater vehicle have being conducted for many purposes. It becomes essential for sea exploration and exploitation such as inspection, repair oil and gas, docking task, scientific studies of the deep ocean, etc. Visual servoing controls the operation of the robot by performing feedback control based on visual information. The studies on visual servoing based underwater vehicle have been conducted all over the world in recent year. Almost references are based on single eye camera to estimate the pose of the target object[4][5]. However, the visual servoing performance using single camera is often gauged inaccurately especially in term of 3D depth information. To solve this problem, visual servo type underwater vehicle using dual-eyes cameras and 3D marker has been developed using real-time pose tracking by means of visual servoing. To the best of author knowledge, visual servoing using stereo vision with two cameras is initiated by our group research.

In proposed system, the vehicle's pose with respect to the target is estimated in real-time by using model-based matching and genetic algorithm. To recognize the pose of the target object with respect to the vehicle, it is needed to utilize optimum searching for real-time. There are many typical optimization techniques such as linear programming, iterations, simple heuristic functions, depth first search and breadth first search. To the best author, there is no related works in which advanced optimization techniques are apply in applications where real time performance is dominant. Therefore, instead of getting the best accuracy with limitation for real-time application, an approach that is simple, be able to converge for real-time performance with repeatable ability is considered in proposed system. Therefore, the proposed system is performed by applying the GA for optimization problem of searching for the optimum solution. However, the configuration of GA effects the recognition performance. Therefore, performance analysis of GA for real-time 3D model-based recognition for underwater vehicle is conducted and reported in this paper. There are many research that the analysis of GA performance based on modification of GA parameter[2] [6]. GA is selected because of its simplicity, effectiveness and repeatability for real time application. Multi-step GA is utilized to evaluate on real time recognition of the target object based on variation parameter of GA. The aim of this case is to analyse the parameters value of GA that generate the maximum population size, the optimum selection rate, the optimum mutation rate that improve the performance searching for real time operation.

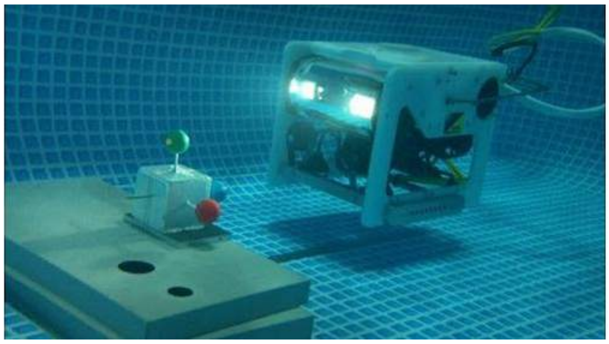

Fig.1 Underwater Vehicle and 3D Marker

2 Proposed System

2.1 ROV Description and Specification

A commercially available ROV robot is used for demonstration that is manufactured by KOWA corporation. The ROV mechanical structure is shown in Fig.1, has length width and height of 380[mm], 280[mm], 310[mm] respectively and dry weight is 15 kilogram. Two fixed cameras (binocular camera) and four thrusters (traverse, vertical and horizontal direction) are installed in ROV. The four thruster enable roll, pitch and yaw. Maximum thrust force is 9.8 N in horizontal and 4.9 N in vertical. It can operate in maximum water depth is 50[m].

2.2 Model-based Matching System using Dual-eyes Cameras and 3D Marker

Model-based matching approach has been developed to recognize and determine the pose of the target object with respect to the vehicle. The solid model of the target is predefined relative to the pose of the ROV and projected to 2D image. The multiple models are located in the searching area with different pose. The relative pose difference is calculated by comparing the projected solid model image with the captured 2D image by dual-eyes camera. In this experiment, 3D marker is used as the target object that composes of three spheres (40[mm] in diameter) whose colors are red, green and blue. The best model is generated by collecting the maximum fitness value. Fig.2 shows model-base matching system by using dual-eyes vision system. The effectiveness of model-based matching system is less time consuming than other system.

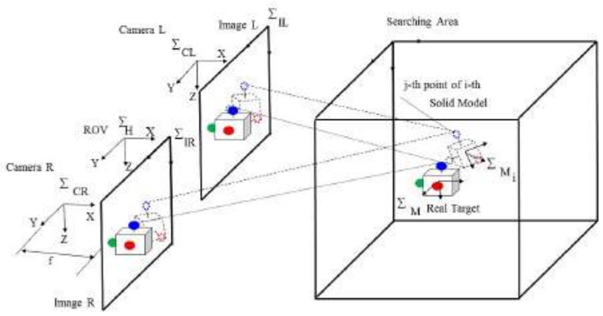

Fig.2 Model-based Matching System with Dual-eyes Camera

2.3 Optimum Solution Search Method using GA

Genetic algorithm is the optimization method which generates the random population of GA individual. The 3D marker that consist of three sphere color and shape information are used in this experiment. The position of the individual represents the position of the three dimensional model in the Model-based matching method, the upper 36 bits of 1 by 12 bits represent the position coordinate of the three dimensional model of the gene. The remaining 36 bits of 1 by 12 bits describe the orientation of the model bit number to be use for reducing the search time shortening.

$$\underbrace{\overbrace{011000100111}^{x}}_{12bits}\underbrace{\overbrace{000011000111}^{y}}_{12bits}\underbrace{\overbrace{001100111101}^{z}}_{12bits}$$

$$\underbrace{\overbrace{110101001001}^{\epsilon_1}}_{12bits}\underbrace{\overbrace{000101111001}^{\epsilon_2}}_{12bits}\underbrace{\overbrace{001101111001}^{\epsilon_3}}_{12bits}$$

Genetic algorithm generates a population of chromosome. A population is composed of a set of chromosome that contains the several genes. Then, each individual get its orientation information from the fitness function shown in equation (3) based on the maximum fitness value. This evolution process carried out the maximum fitness value of each generation

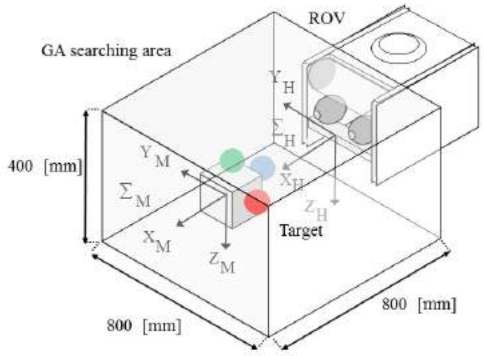

Fig.3 GA searching Area

of every individual model to form the next generation. At this time the set of generation have higher position and orientation with good fitness value than the previous generation, that is closer toward the maximum value near the fitness function that represent the object. These possible models reproduce

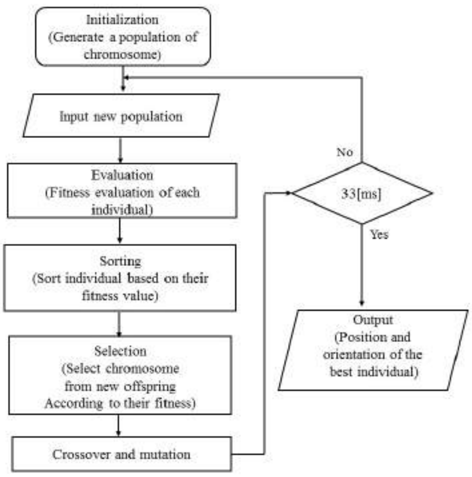

Fig.4 Flow chart of Genetic Algorithm

new generation by selection and recombination method which represents a better solution to the real target pose estimation. Then again a new generations are formed from mutation or crossover. By performing this process repeatedly, GA searched the optimum value that indicate the position of the object. However, it is necessary to wait for a certain convergence time for completing the recognition of the object. The gene sufficient for 9 times by the sampling rate (video rate) of 33ms in the experiment. Fig.3 shows the GA searching area and Fig.4 shows the GA flow chart.

2.4 Fitness Function

The fitness function is very important role to obtain the best solutions within a searching area. In each generation, the recognition accuracy of individual model is based on the fitness function. The fitness function of a chromosome expressed by the following equation [1]-[3] is used to determine the fitness value of an individual model. ρ is the huge value of the points.

$$F_R(\varphi) = \sum_{IR_{ri} \in F_{R,in(\varphi)}} \rho(IR_{ri}) - \sum_{IR_{ri} \in F_{R,out(\varphi)}} \rho(IR_{ri}) \quad (1)$$

$$F_L(\varphi) = \sum_{IL_{ri} \in F_{L,in(\varphi)}} \rho(IL_{ri}) - \sum_{IL_{ri} \in F_{L,out(\varphi)}} \rho(IL_{ri}) \quad (2)$$

$$F(\varphi) = (F_R(\varphi) + F_L(\varphi))/2 \quad (3)$$

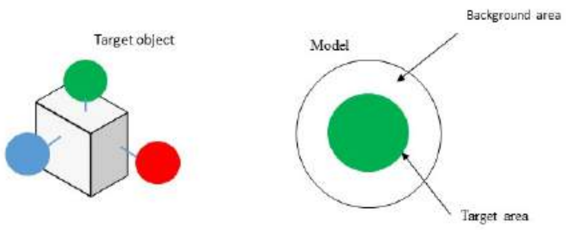

Fig.5 Target Object and Model

There are two portions, the first portion is the inner one which is the same size with the target and the second is outer portion which is the background area. The capture portion situated in the inner one the fitness value will increase and it situated in the background area the fitness value will decrease. Good fitness value will be identical the target and the model object.

2.5 Experiment Layout

The experiment was tested in indoor pool(length 750[mm]× width 570[mm] × height 490[mm]) in a laboratory room where the light conditions could be varied. The distance between the static 3D model object with respect to the vehicle is [350mm]. ROV receives the image information through the tether cable connected to PC. The GA searching area is fixed between the underwater vehicle and the object as shown in Fig.6

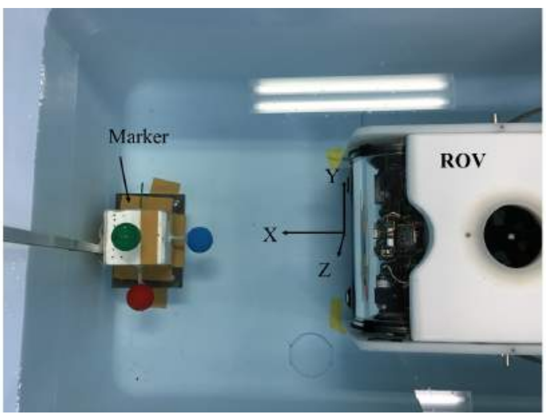

Fig.6 Experiment Layout

2.6 Genetic Operators

In Genetic algorithm, strings of bits are used to represent the candidate as chromosomes. A population comprises a set of chromosome that contained of genes. Every gene of chromosome is expressed as the two possible values 0 and 1. Initial population of GA is generated in random and GA candidates are evaluated by the operators; selection, crossover and mutation. The selection operator chooses the chromosome in the

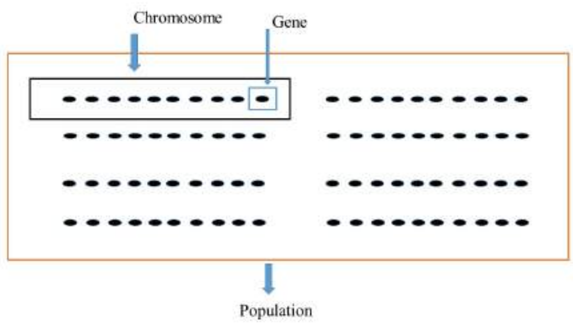

Fig.7 Population, Chromosome and Gene

population based on fitness function and selected the better chromosome for reproduction. In this paper, the process of ranking based selection is considered. The probability of selection operator is responsible for the convergence of GA, if the GA is run many times. The crossover operator generates and creates the new chromosome from the current string. The simplest way of crossover is to exchange the position between the strings randomly. After the crossover had performed the mutation will operate. This operator randomly changes one or some bits in the result from crossover process within the population.

3 Performance Analysis of GA

In this experiment, we analysed the GA convergence for real time 3D recognition of underwater vehicle based on varying and modification of GA parameter. According to the analysis on experimental results, it is observed that the genetic parameter namely as selection, crossover, mutation, fitness function and population size are needed to obtain the optimum accuracy of the system. These parameters are considered as primary parameter.

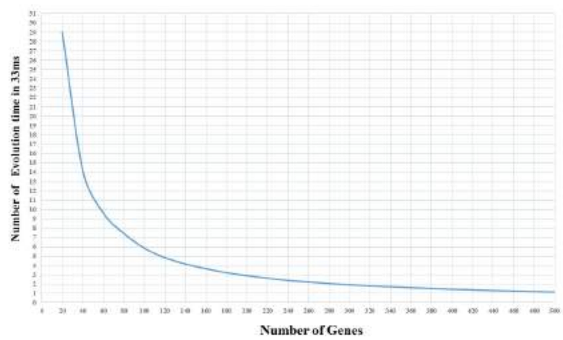

Fig.8 Repeatable ability of GA

We analysed recognition accuracy based on the fitness function. Firstly, according to the experiment result for differential configuration of GA, selection rate(0.6%)and the mutation rate(0.1%) based on the quick response of the fitness value and the least error of recognition. Analysis of repeatability of GA performance based on the different number of population sizes with the optimum selection rate and the mutation rate in 33 [ms](video rate) is done as shown in Fig.8. The number of population sizes evaluated from 20 to 500. The number of evolution times is decreased by increasing the number of population sizes. Our task is to choose the optimum number of population size with reasonable number of evolution time for optimum recognition accuracy.

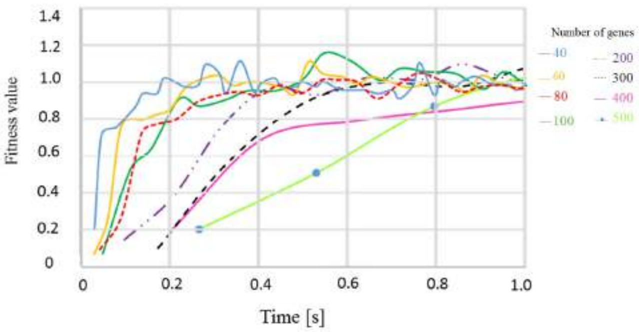

Fig.9 Convergence performance of GA

Fig.9. shows the time response of the convergence performance of GA based on the fitness value of different number of population sizes. It can be seen that the fitness value of the number of population sizes 40 is maintained above 0.8 within a few seconds. Even though the fitness value of the number of genes 60, 80 and 100 are maintained above 0.8 within a few second, the response time is delay comparing to time response for number of genes 40. In this experiment, GA recognition accuracy needed to have the value of 0.5 or more for good performance. According to the experiment, it is observed that the best population size is 40 for real time operation. Finally, the summary of the GA parameters are shown in Table.I.

Table 1 Best parameters for GA

Number of genes	40
Search area [mm]	$[x, y, z] = \pm 400 \pm 200 \pm 400$
Selection probability	0.6%
Mutation probability	0.1%
Number of Evolution	14
Control Period [ms]	33
Target variable	Position (x[mm])

Then, we evaluated the recognition accuracy by using GA. Fig.10. shows the recognition comparison of position Y-Z plane between the GA search and the full search process. The full search is a method to evaluate the result of multi-step GA by analysing the specific image where multi-step GA get the corresponding fitness value. The main idea of full search is to calculate the fitness of every points which are 1[mm] apart in the entire searching area. By using GA, the recognition accuracy of maximum fitness value is (1.213) and the position is 14.0625 [mm] in Y plane and -72.3711 [mm] in Z-plane. In full search process, the maximum fitness value is (1.3611) and the position of (Y,Z) plane are 15 [mm] and -72 [mm] respectively. It is obvious that the small error will be occur in (y,z) plane about 0.9[mm] and -0.3711[mm]).

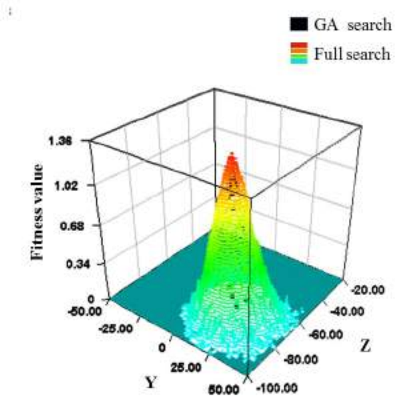

Fig.10 Full search of GA

4 Conclusion

In this study, performance analysis on GA for real time recognition for underwater vehicle by using 3D marker and dual-eyes camera has been presented. Population sizes, selection rate and mutation rate that influences on the recognition accuracy are analysed and selected for proposed system. Experimental results show that the recognition accuracy of the system is optimized with the error in [mm] level for real time recognition. In the future work, analysis on the performance of GA with dynamic target object for real time recognition will be done.

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