An application of genetic algorithm to optimize the 3-Joint carangiform fish robot' s links to get the desired straight velocity

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ABSTRACT:

Biomimetic robot is a new branch of researched field which is developing quickly in recent years. Some of the popular biomimetic robots are fish robot, snake robot, dog robot, dragonfly robot, etc. Among the biomimetic underwater robots, fish robot and snake robot are mostly concerned. In this paper, we study about an optimization method to find the design parameters of fish robot. First, we analyze the dynamic model of the 3-joint Carangiform fish robot by using Lagrange method. Then the Genetic Algorithm (GA) is used to find the optimal lengths' values of fish robot's links. The constraint of this optimization problem is that the values of fish robot's links are chosen that they can make fish robot swim with the desired straight velocity. Finally, some simulation results are presented to prove the effectiveness of the proposed method.

Keywords: *Biomimetic robot, Carangiform, Fish robot, Lagrange, Genetic Algorithm (GA), Singular Value Decomposition (SVD), Straight velocity, Links.*

1. INTRODUCTION

Fish has been passing over millions years of evolution throughout many generations to adapt to the harsh of underwater environment. So more and more types of fish with diversity movements were born to be able to exist in natural environment. Many kinds of fish move by using the change of their body shape for generating the movement. This changing shape generates propulsion force to make fish moves forward effectively. Carangiform fish type also uses this changing shape to move itself in the underwater environment.

Based on the motion mechanism of Carangiform fish, there are some researches about this type of motion. Koichi Hirata et al. discussed turning modes for the fish robot that uses tail swing [1]. Qin Yan et al. have experiments to investigate the influences of characteristic parameters such as the frequency, the amplitude, the wave length, the phase difference and the coefficient on forward velocity of robot fish [2]. And, Yeffry Handoko et al. also designed three types of body constructions of robot fish to gain optimal thrust speed [3]. Besides, in our previous research, we used GA and HCA to optimize parameters of input torques including amplitude, frequency and phase angle to gain maximum velocity [4].

In this paper, we consider a 3-joint (4 links) Carangiform fish robot. We also pay much attention to the motion of fish robot's head in analyzing the dynamics system of fish robot. Then, the dynamics system of fish robot are derived by using Lagrange method. The influences of fluid force to the motion of fish robot are also considered which is based on Nakashima's study on the propulsive mechanism of a double jointed fish robot [5]. Then, the SVD (Singular Value Decomposition) algorithm is also used in our simulation program to minimize the divergence of fish robot's linkage system when simulating fish robot's operation in underwater environment.

The main goal of this paper introduces about the application of GA to optimize the length of fish robot's linkage system in order to make the fish robot swim with the desired straight velocity. And, the dynamics system of fish robot and some other related constrains are also considered when we carry on the optimization problem.

2. DYNAMICS ANALYSIS

In our fish robot, we focus mainly on the Carangiform fish's type because of fast swimming characteristics which resemble to tuna or mackerel. The movement of this Carngiform fish type requires powerful muscles that generate side to side motion of the posterior part (vertebral column and flexible tail) while the anterior part of the body remains relatively in motionless state as seen in Fig. 1.

We design 3-joint (4 links) fish robot in order to get smoother and more natural motion. As expressed in Fig. 2, the total length limitation of fish robot is about 400mm which includes 4 links. The head and body of fish robot are supposed to be one rigid part (link0) which is connected to link1 by active RC motor1 (joint1). Then, link1 and link2 are connected by active RC motor2 (joint2). Lastly, link3 (lunate shape tail fin) is jointed into link2 (joint3) by two extension flexible springs in order to imitate the smooth motion of real fish. The stiffness value of each spring is about 100Nm. Total weight of the fish robot (in air) is about 5 kg.

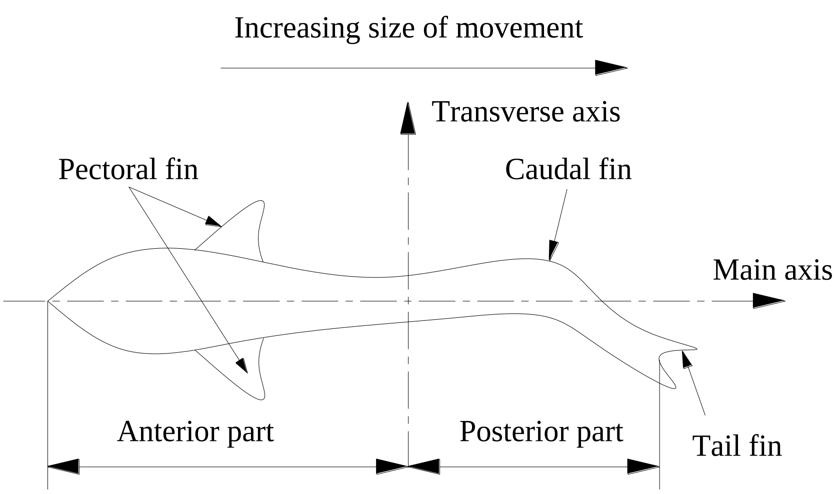

Figure 1. Carangiform fish locomotion type.

In Fig. 2, T_1 and T_2 are the input torques at joint1 and joint2 which are generated by two active RC motors. We assume that inertial fluid force F_V and lift force F_J act on tail fin only (link 3) which is similar to the concept of Motomu Nakashima et al [5].

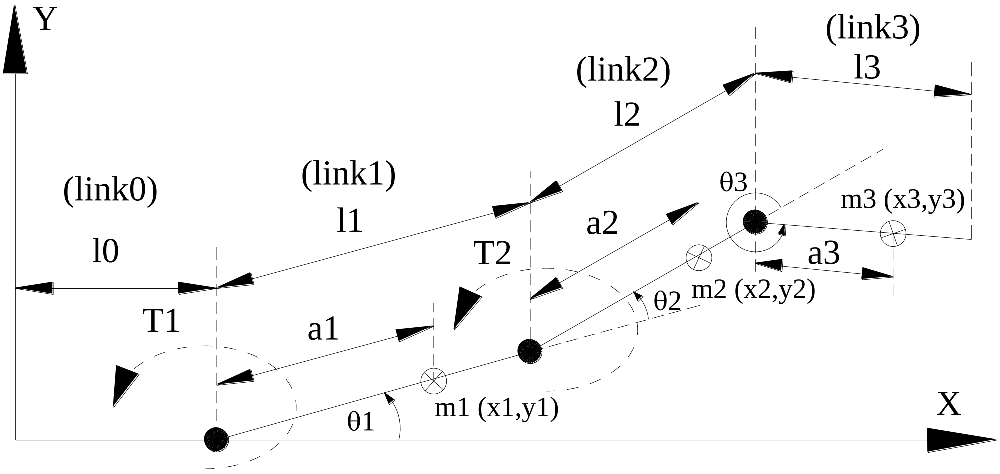

Figure 2. Fish robot analytical model.

The expression of forces distribution on fish robot is presented in Fig. 3 below. F_F is the thrust force component at tail fin, F_C is lateral force component and F_D is the drag force effecting to the motion of fish robot. The calculations of these forces are similar to Motomu Nakashima et al method for their 2-joint fish robot [5].

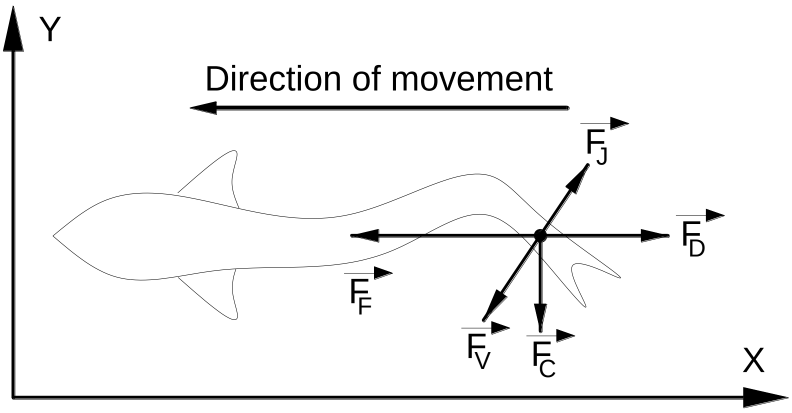

Figure 3. Forces distribution on fish robot

We suppose that the tail fin of fish robot is in a constant flow U_m so we can derive the inertial fluid force and the lift force act on the tail fin of fish robot. Then we can calculate their thrust component F_F and lateral component F_C from the inertial fluid force and lift force. We also suppose that the experiment condition of testing our fish robot is in tank so that the value of U_m is chosen as 0.08m/s. F_v is a force proportional to an acceleration acting in the opposite direction of the acceleration [5]. The calculation of F_V is expressed in Eq. (1). The lift force F_J acts in the perpendicular direction to the flow and its calculation as in Eq. (2). In these two equations, chord length is 2C, the span of the tail fin is L and ρ is water's density.

$$F_V = \pi\rho LC^2 \dot{U} \sin\alpha + \pi\rho LC^2 \dot{\alpha} U \cos\alpha \qquad (1)[5]$$

$$F_J = 2\pi\rho LCU^2 \sin\alpha \cos\alpha \qquad (2)[5]$$

These fluid force and lift force are divided into thrust component F_F in x direction and lateral force component F_C in y direction as presented in Fig. 4.

In Fig. 4, U is the relative velocity at the center of the tail fin, α is the attack angle.

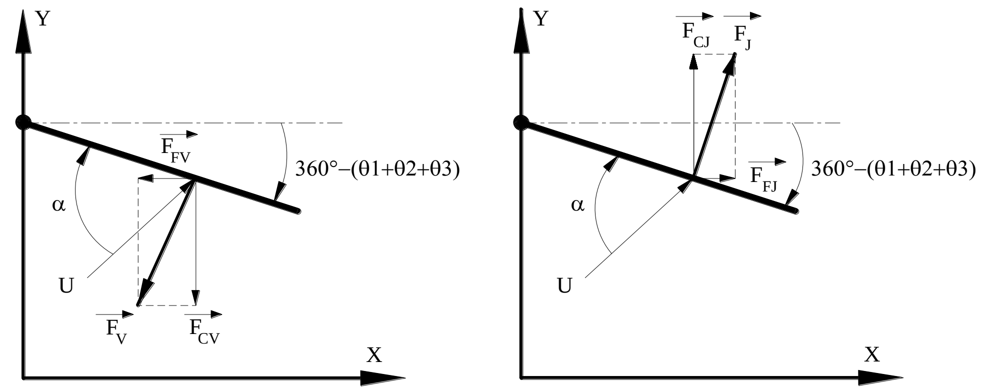

Figure 4. Model of inertial fluid force and lift force

Based on Fig. 4, the value of F_F and F_C can be calculated by these two Eqs. (3)-(4):

$$F_F = -F_V \sin(\theta_1+\theta_2+\theta_3) + F_J \sin(\theta_1+\theta_2+\theta_3) \quad (3)$$

$$F_C = F_V \cos(\theta_1+\theta_2+\theta_3) - F_J \cos(\theta_1+\theta_2+\theta_3) \quad (4)$$

If we just consider the movement of fish robot in x direction, so the relative velocity in y direction at the center of tail fin is calculated by Eq. (5).

$$u = \dot{\theta}_1 l_1 \cos\theta_1 + (\dot{\theta}_1+\dot{\theta}_2) l_2 \cos(\theta_1+\theta_2) + (\dot{\theta}_1+\dot{\theta}_2+\dot{\theta}_3) a_3 \cos(\theta_1+\theta_2+\theta_3) \quad (5)$$

Since U_m and u are perpendicular as in Fig. 5(a), so the value of U can be calculated by Eq. (6):

$$U^2 = U_m^2 + u^2 \quad (6)$$

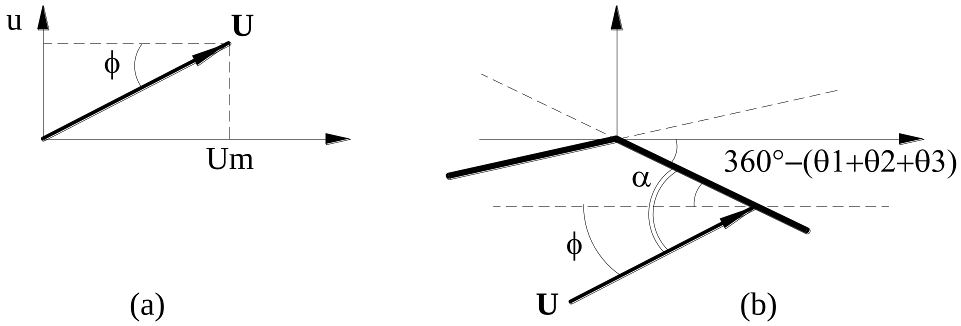

Figure 5. (a) Relationship between U and U_m.

(b) Diagram of attack angle α calculation.

By using Lagrange's method, the dynamic model of fish robot is described briefly as in Eq. (7).

$$\begin{bmatrix} M_{11} & M_{12} & M_{13} \\ M_{21} & M_{22} & M_{23} \\ M_{31} & M_{32} & M_{33} \end{bmatrix} \begin{bmatrix} \ddot{\theta}_1 \\ \ddot{\theta}_2 \\ \ddot{\theta}_3 \end{bmatrix} = \begin{bmatrix} N_1 \\ N_2 \\ N_3 \end{bmatrix} \quad (7)$$

By solving Eq. (7) above, we can get the value of θ_i, $\dot{\theta}_i$ (i = 1 ÷ 3). However, based on the dynamic model in Eq. (7), SVD (Singular Value Decomposition) algorithm is also used in our simulation program to minimize the divergence of the oscillation of fish robot's links when simulating the operation of fish robot in underwater environment. This divergence also cause the velocity of fish robot be diverged too.

The motion equation of fish robot is expressed in Eq. (8). $\ddot{x}_G$ is the acceleration of fish robot's centroid position. m is the total weight of fish robot in water. F_F is the propulsion force to push fish robot forward and F_D is drag force caused by the friction between fish robot and the surround environment when fish robot swims.

$$m\ddot{x}_G = \vec{F}_F - \vec{F}_D \quad (8)$$

The calculation of F_D is presented in Eq. (9)

$$F_D = \frac{1}{2}\rho V^2 C_D S \quad (9)$$

Where ρ is the mass density of water. V is the velocity of fish robot relative to the water flow. C_D is the drag coefficient which is assumed to be 0.5 in the simulation program. S is the area of the main body of fish robot which is projected on the perpendicular plane of the flow.

3. OPTIMIZING THE LENGTH OF FISH ROBOT LINKAGE SYSTEM BY USING GENETIC ALGORITHM

Genetic Algorithm [6], [7], [8] is an optimization method which is based on the Darwin's theory of evolution. Algorithm begins with a set of solutions (represented by chromosomes) called population. Each chromosome is a binary string including shorter strings that contain value of optimization variables. Chromosomes in population will be taken and used to form a new population which is hoped to be better than the old one. Some chromosomes that have the best value (offspring) according to their fitness will have chance to live in new population. The chromosomes evolve during several iterations called generations. In every generation, chromosomes are evaluated, crossover and mutated to create a new population.

In our research, the mainly problem is how to find the length of each fish robot's link. In this case, we don't concern about the cross-sectional area of the links. The optimization algorithm by GA is introduced in Fig. 6 below.

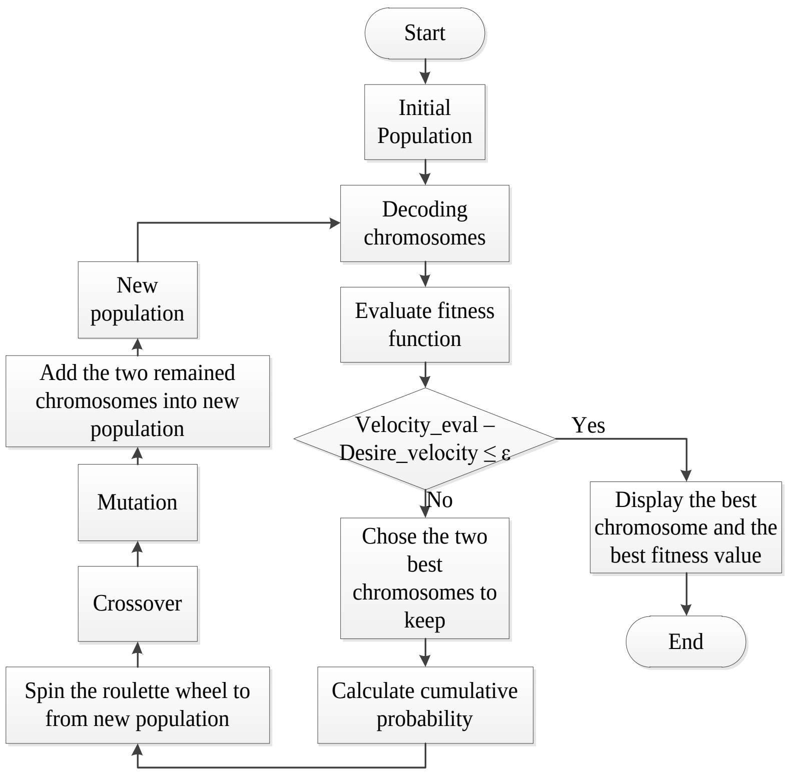

Figure 6. The optimization algorithm by GA

The Carngiform fish robot includes 4 links (link0, link1, link2 and link3) as seen in Fig.1. We assume the length of head of fish robot (link 0) is fixed and equal 200 mm. Therefore, the length of link 1, link 2 and link 3 must be calculated or chosen suitably. However, there are not much methods to choose the exact value of these parameters. So, in this paper, we use the Genetic Algorithm to find the optimal length values of three remain values of fish robot links as link1, link2 and link3. The fitness function includes the fish robot's dynamic model, the motion equation and also the desired straight velocity of fish robot. In these three parameters, the straight velocity is used as the stop condition for the GA. In this paper, the desired velocity of fish robot is chosen as 0.3 m/s and the total length of link1, link2 and link3 is around 400 mm. The constraints of the optimization problem by GA are as in Eq. (9):

$$50\text{ mm} \le l_1 \le 250\text{ mm}$$
$$50\text{ mm} \le l_2 \le 250\text{ mm} \quad (9)$$
$$50\text{ mm} \le l_3 \le 150\text{ mm}$$
$$395\text{ mm} \le l_1 + l_2 + l_3 \le 405\text{ mm}$$

4. SIMULATION RESULTS

By using GA, the optimal value of l1, l2, l3 will be generated simultaneously based on their constraints as seen in Eq. (9). The results of GA is calculated with two different desired straight velocity of fish robot. The first value of straight velocity is 0.3m/s and the second one is 0.15m/s. In every case, the GA will be run in 10 times to find 10 different values of optimal parameters sets. Then, based on the results of these, we will chose the parameters set that has the value which is the closet to the desired value of straight velocity. The range of straight velocity error that we use in our program is ± 0.01 m/s.

The table 1 below introduces about the result of GA when we use the desired straight velocity of fish robot is 0.3m/s.

Table 1. Optimal result by GA (Desired straight velocity = 0.3m/s)

N	Generations	Velocity	L1	L2	L3
1	35	0.2932	0.2359	0.0995	0.1127
2	27	0.2890	0.2181	0.0979	0.1283
3	64	0.2940	0.2260	0.0983	0.0949
4	12	0.2916	0.2465	0.0557	0.0456
5	18	0.2967	0.2324	0.0803	0.0775
6	5	0.3008	0.2242	0.1016	0.1199
7	23	0.3041	0.2217	0.0981	0.1231
8*	30	0.3002	0.2215	0.0866	0.1251
9	12	0.2972	0.2441	0.0662	0.0496
10	47	0.2978	0.2498	0.0969	0.0986

From the results in table 1, we chose the best result of running GA to apply to the dynamic model. As seen in table 1, the best result is N =8. The reason that we choose N = 8 as the best one because it has the value of the straight velocity is the closet to the desired straight velocity as 0.3m/s. This case is called the optimal case.

In the dynamic model, we use a fixed set of control parameters including amplitude (A_1 and A_2), frequency (f_1 and f_2) and phase angle β. In order to prove the effectiveness of the GA results, we compare the result of GA with the result of an arbitrary value of l1, l2 and l3. The arbitrary value of these parameters are chosen randomly by manual with respect to the constrain as in Eq. (9) above. This case is called the non-optimal case. The results of fish robot straight velocity when we apply the results from GA and the arbitrary values are introduced in Fig. 7 and Fig. 8 below.

When we apply arbitrary set of l_1, l_2, l_3 which are satisfy according to constraints mentioned in Eq. (9) (with l_1 = 0.1995m, l_2 = 0.2352m, l_3 = 0.13m), the straight velocity of fish robot cannot reach to the desired value as 0.3m/s. As in Fig 7 below, after 20 second, the straight velocity of fish robot is about 0.25m/s and it will take long time to reach to the desired value or it cannot reach to the desired velocity.

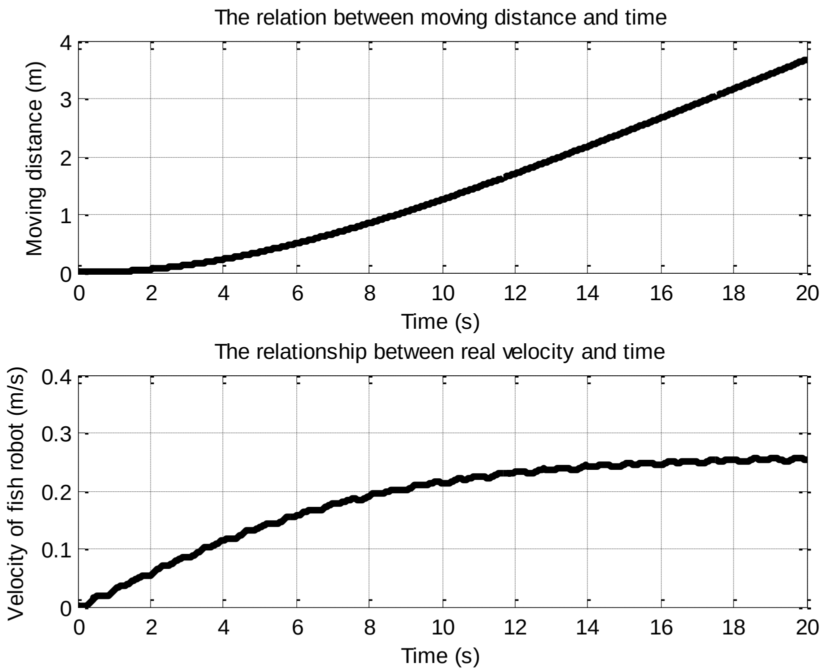

Figure 7. The velocity and the moving distance of fish robot in non-optimal case.

The result of fish robot straight velocity when we apply the result from GA is introduced in Fig. 8 below. In this figure, the fish robot take about 14 seconds to reach to the desired velocity. And, the value of fish robot straight velocity is also kept during the concerning time as shown in Fig. 8.

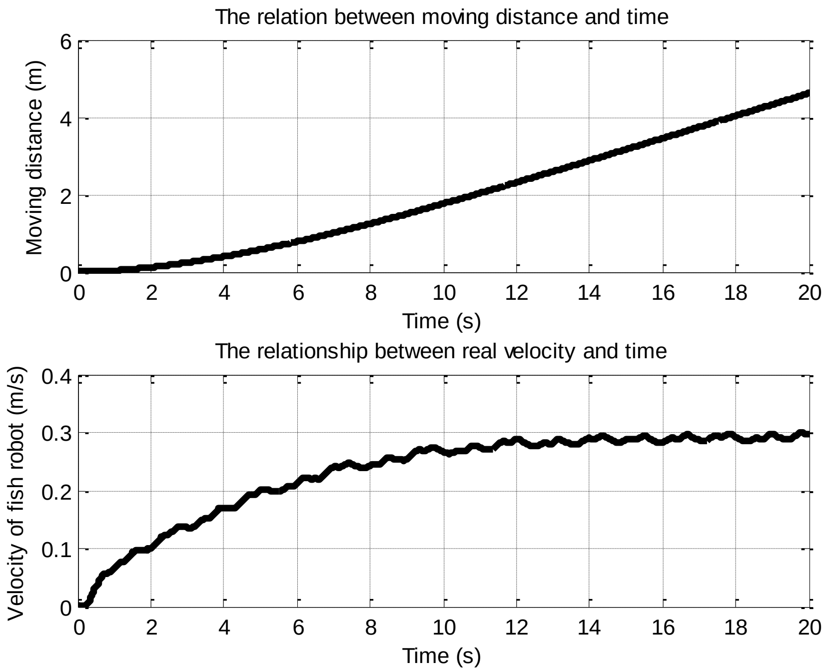

Figure 8. Velocity and moving distance of fish robot using the result of GA (N = 8) as in Table 1 – optimal case

Besides, by comparison between the oscillation of fish robot's linkage system in the caudal part , the values of l1, l2, l3 using by GA will also make fish robot's caudal part oscillate with bigger amplitude than the value of the l1, l2, l3 in arbitrary case. This reason also make the combination of fish robot better and they can help fish robot reach to the desired velocity faster.

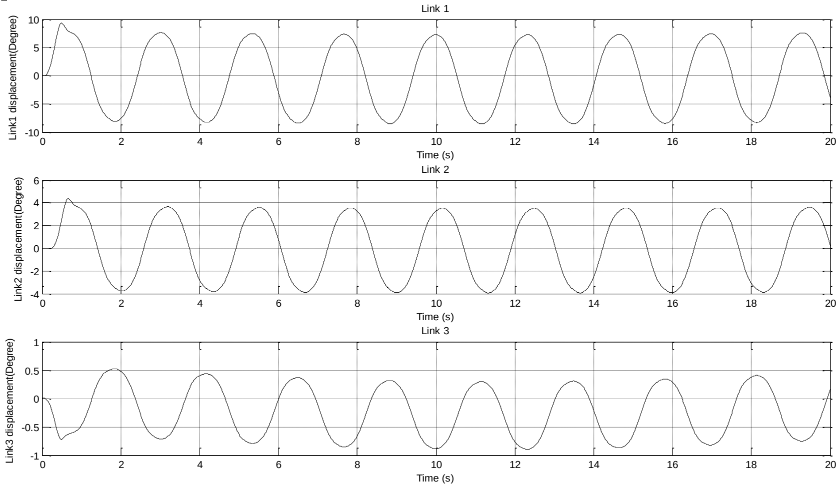

Figure 9. Fish robot linkage system's oscillation in optimal case by GA.

The oscillation of fish robot's linkage system in two cases (optimal and non-optimal case) are introduced in Fig. 9 and Fig. 10 below. And, if we consider about the oscillation of the third links in the non-optimal case, we can see that this link has the trend to be diverged by time as seen in Fig. 10.

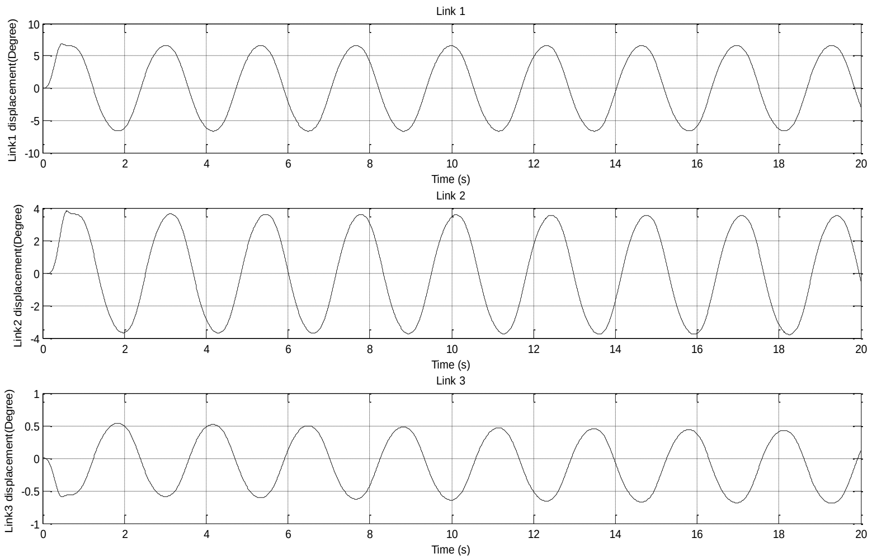

Figure 10. Fish robot linkage system's oscillation in non-optimal case.

Besides, there is not only the length of fish robot links, the Genetic Algorithm can also be used to find the optimal values of other design parameters or control parameters of fish robot. This is the strongest point of Genetic Algorithm in comparison to other optimal methods.

5. CONCLUSION

In our research, we considered the dynamic model of a 3-joint Carangiform fish robot. And, the influence of fluid forces which act on motion of fish robot in underwater environment are also considered. Besides, these SVD algorithm is used in the simulation program to reduce the divergence of fish robot links when solving the matrix of its dynamic model.

By using GA, we found the optimal length of fish robot links l_1, l_2 and l_3. And, these optimal design parameters will help fish robot reach the desired straight velocity as 0.3m/s in very short time. And, the results of this paper show that the lengths of robot fish linkage system also have great influence to its velocity. In the next step, some experiments will be carried out to check the agreement between the simulation results and the experimental results.

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Ứng dụng giải thuật di truyền trong tối ưu hóa kích thước dài các khâu của robot cá 3 khớp dạng carangiform để robot cá có thể di chuyển với vận tốc dài mong muốn

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TÓM TẮT:

Robot phỏng sinh học là một hướng nghiên cứu mới đang được phát triển mạnh trong những năm gần đây. Một số robot phỏng sinh học phổ biến là robot cá, robot rắn, robot chó, robot chuồn chuồn,…Trong những loại robot dưới nước này, robot cá và robot rắn được đặc biệt quan tâm nhiều. Bài báo này giới thiệu một phương pháp trong việc tối ưu hóa để tìm ra các thông số thiết kế của robot cá. Đầu tiên, phương pháp Larange được sử dụng để tìm ra bộ động lực học của robot cá 3 khớp dạng Carangiform. Sau đó, giải thuật di truyền được sử dụng để tìm các giá trị kích thước dài tối ưu các khâu của robot. Sự rang buộc của bài toán tối ưu là kích thước dài các khâu của robot được lựa chọn sao cho robot có thể di chuyển với một vận tốc dài mong muốn. Sau cùng, vài kết quả mô phỏng sẽ được giới thiệu để chứng minh tính hiệu quả của phương pháp này.

Từ khóa: *Robot phỏng sinh học, Carangiform, Robot cá, Larange, Giải thuật di truyền, SVD, Vận tốc thẳng, Các khâu.*

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