Optimal Design of Hydraulic System Parameters for Vector Propeller in Underwater Robot

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Abstract. Vector Propeller can increase the steering force and oscillation ability for anti-wind and anti-wave of underwater machinery at any speed. The device uses three parallel hydraulic circuits to drive the lifting, rotating and locking operations. In order to make the hydraulic system control vector propeller precisely, the hydraulic parameters need to be optimized. Genetic algorithm is used to optimize the hydraulic system components' parameters, which can optimize multi-parameters and multi-objectives at the same time; the parameters of hydraulic PID control is optimized by Kriging method, which can get the optimal value flexibly and quickly. Finally, the correctness of the optimization results is verified by the software simulation of the whole system.

Keywords: Vector Propeller, Hydraulic Parameters, Genetic Algorithm, Kriging Method.
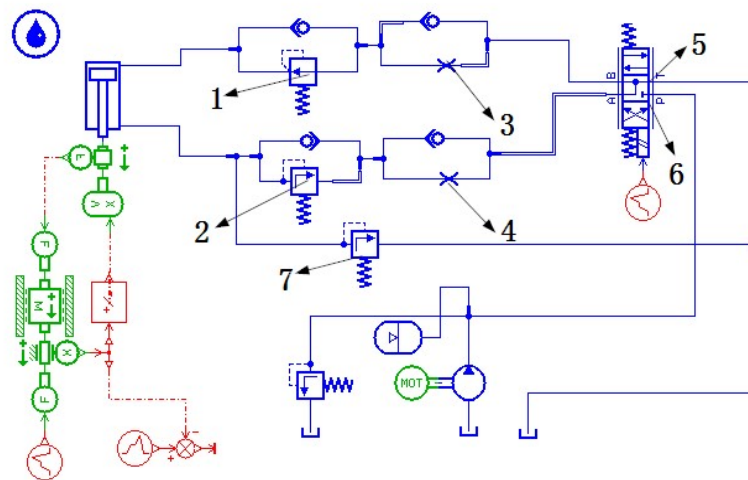
1. Introduction

Underwater robots are widely used in marine engineering and deep-sea exploration. However, the underwater robot lacks the steering force and the ability to resist the waves and waves, and it is not easy to maintain the navigation direction and attitude stability. Vector propulsion to the underwater robot was added, and controlled the hydraulic-driving vector propulsion device through the algorithm, so that hull posture can be adjusted as required. In order to improve the response speed, accuracy and other performance indicators of the whole system, the parameters of hydraulic systems need to be optimized. Due to the efficiency loss of the hydraulic system, it will cause the movement and expected error of the mechanical system. These losses vary with the hydraulic pump, hydraulic motor, hydraulic cylinder displacement, hydraulic component parameters, and hydraulic system pressure and the control effects of different parameters are different. The genetic algorithm is effective in solving NP problems, nonlinear, multi-objective and multi-peak problems. Keriging method can quickly simulate the response surface when the parameters are closely linked and the number is determined, and then get the optimized value. Therefore, the parameters of hydraulic system can be optimized by genetic algorithm and Kelijin method [1-2].

2. Underwater robot vector propulsion hydraulic drive system

In order to analyze the effect of hydraulic parameters on vector propulsion device, the motion process of the vector propulsion device and its hydraulic drive loop should be considered firstly. Using vector propulsion device, the lifting, turning and locking three actions can be finished. Three hydraulic drive systems are connected in parallel, so they can be divided into three parts for optimization design.

If all hydraulic parameters of each circuit are optimized, it takes time and effort, and it is not easy to find the role of key parameters. Therefore, the parameters of key components in hydraulic system can be selected for optimization design. The key component parameters are selected as shown in Figure 1-3.

1-Open pressure of Pressure relief valve 2-Open pressure of balance valve 3-Diameter of throttle valve 4-Diameter of throttle valve 5-Stretching traffic 6-Zoom flow

Figure 1. Hydraulic circuit of elevation and movement.

3. Theoretical bases

The main parameters of the hydraulic system need to be coordinated while ensuring the completion of the planned operation to make the system have good performance, reliability and high efficiency. Therefore, it is necessary to optimize the parameters of the hydraulic system. Genetic algorithm does not need to solve the approximate model of the system compared to experimental statistical methods, the selection of test points should not be considered and it is possible to give a wide range of values for each factor. Keriging method can predict the model quickly and flexibly when the number of parameters is determined. Therefore, the hydraulic parameters are optimized by genetic algorithm. Keriging algorithm is used for the PID parameter of hydraulic control module.
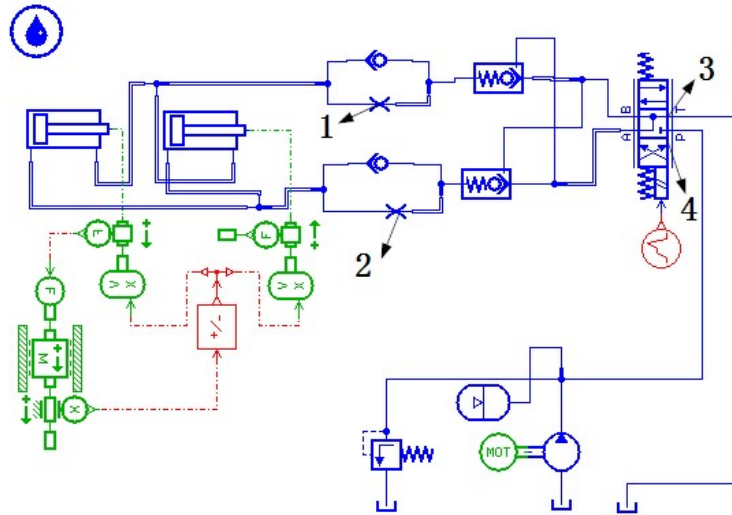
3.1. Genetic Algorithm

Genetic Algorithm is an efficient global search algorithm, which is based on natural selection and genetic theory, combining the survival rule of fittest and the random information exchange mechanism of the internal chromosomes in the process of biological evolution. The genetic algorithm toolbox uses the Sheffield genetic algorithm toolbox [3-4]. The specific steps are as follows.

Step1: Encoding and Decoding. Determine the range of hydraulic parameters to be optimized and the number of digits required to write them in binary form. Binary encoding of parameters is generated by generating random numbers. And connect all binary codes to a "chromosome" at the beginning and end. It is an individual, multiple individuals form a population. The binary decoding formula is as follows.
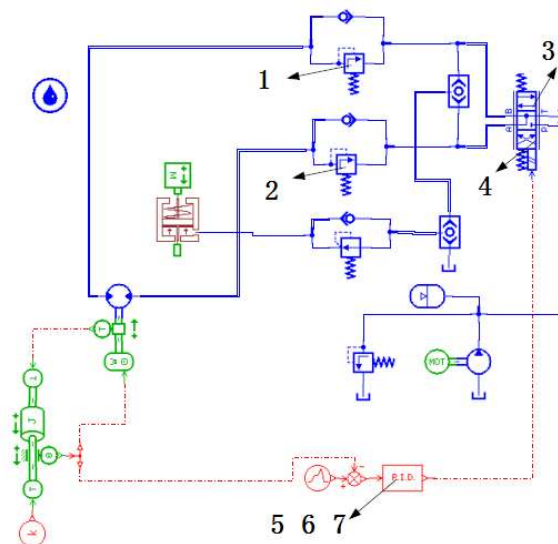
$$x = L + \left(\sum_{i=1}^{k} b_i 2^{i-1} \right) \frac{U - L}{2^{k-1}} \tag{1}$$

Where x is decimal decoding value, L and U is hydraulic parameters upper and lower limits, respectively. k is binary number and b is binary bit i.

1-Containment valve diameter 2-Diameter of throttle valve 3-Diameter of throttle valve 4- Outflow of T 5-Flow of P

Figure 2. Hydraulic circuit of lock movement.

1-Open pressur of pressure relief valve 2-Open pressure of pressure relief valve 3-Flow of T 4-Flow of P 5- Proportional constant 6- Integral constant 7-Differential constant

Figure 3. Rotary hydraulic circuit.

Step2: Adaptability calculation. The hydraulic parameters generated by random number are introduced into the model and simulated. Make the minimum square root of difference between actual displacement curve and desired displacement surface as control target. That is, the fitness function is as follows.

$$f_i = 1 - \frac{RMS_i}{\sum_{k=1}^{N} RMS_k} \tag{2}$$

Where RMSi is the ith square root of the body.

Step3: Set initial parameters such as iterative steps, population values, selection operators, and crossover and mutation operators. The parameter optimization value is obtained by using the Sheffield tool box template.

3.2. Kriging method

Kriging method is a functional space estimation technique. It consists of a parameter model and a non-parametric random process. Kriging method is more flexible and predictive than a single parameterized model. At the same time, it overcomes the limitation of processing high dimensional data by non-parametric model. The Kriging model generally consists of two parts: polynomials and random distributions. The specific model is as follows.

$$y(x) = F(\beta, x) + z(x) = f^T(x)\beta + z(x) \tag{3}$$

Where β is regression coefficient and f(x) is polynomial of variable x. In design space, f(x) provides a global approximation of the simulation that is the mathematical expectation of X. z(x) provides an approximation of simulated local deviations that is local change of z(x). Under normal circumstances, f(x) form does not play a decisive role in simulation accuracy that is f(x) can be a fixed constant. z(x) obeys normal distribution $N(0, \sigma^2)$ and the covariance is not zero. z(x) is not independent, but as the same distribution. The covariance matrix of z(x) is as follows.

$$\text{cov}[z(x_i), z(x_j)] = \sigma^2 R[R(x_i, x_i)] \tag{4}$$

$R(x_i, x_j)$ is any two of the sample points xi and xj in ns sample points, which determines the accuracy of the simulation. The general form is EXP, EXPG and GAUSS etc. Among them, Gaussian related equations have a good calculation effect and are widely used.

Latin supercube sampling can avoid sampling points overlapping in small neighboring areas. The basic principles are as follows. If N times sampling are done, the M random variables are divided into N intervals of equal probability, thus the entire sampling space is divided into nm small squares of equal probability. The N sampling must fall in each small interval, so the actual sampling point is equally distributed throughout the random space. The specific steps are as follows.

Step1: The sample points are selected and the Latin supercube sampling is used. The design space is the range of the parameters of each hydraulic element.

Step2: System response calculation. After selecting ns sample points, the hydraulic element is set to the sample point parameter value for simulation calculation. The mean square root value of the difference between the desired displacement and the actual displacement is taken as the response of the system.

$$RMS = \sqrt{\frac{\sum_{i=1}^{n_s} \Delta y_i^2}{n_s}} \tag{5}$$

Where Δy_i is difference between expected and actual displacement.

Step3: Use sample points and response values as known information, which is $X_{sampling}, Y_{sampling}$. Select quadratic function as fitting function and Gaussian correlation equation. The range of variables to be optimized is evenly divided into grids, and each variable crosses to form a node. The Kriging interpolation method is used to predict the response values of each node. And the minimum value function is used to find the minimum square root value, that is, the optimal value.

4. Experiments of optimized design

4.1. Optimization design of hydraulic parameters in lift loop

The movement of the lifting part is open loop control, the anti-interference ability is weak, the control accuracy is low, the automatic correction capability is lack. Because the levation and movement process is constant, the pressure flow of each hydraulic element can be calculated according to the actual requirements. However, there are many parameters of the components, thus the calculation is complex. The movement of the lifting part can be matched by the matching of the parameters of the hydraulic element so that the movement of the lifting part meets the expected movement.

Optimization design of parameters is done by selecting hydraulic parameters of 4 components in Figure 1, as shown in table 1. Optimization algorithm adopts genetic algorithm. The desired motion curve and the optimized curve are shown in Figure 4. It can be seen from the figure that the actual displacement curve of the lifting part is in good agreement with the desired curve. The maximum error between the above two is less than 2mm, which should be controlled within the allowed range of motion errors.
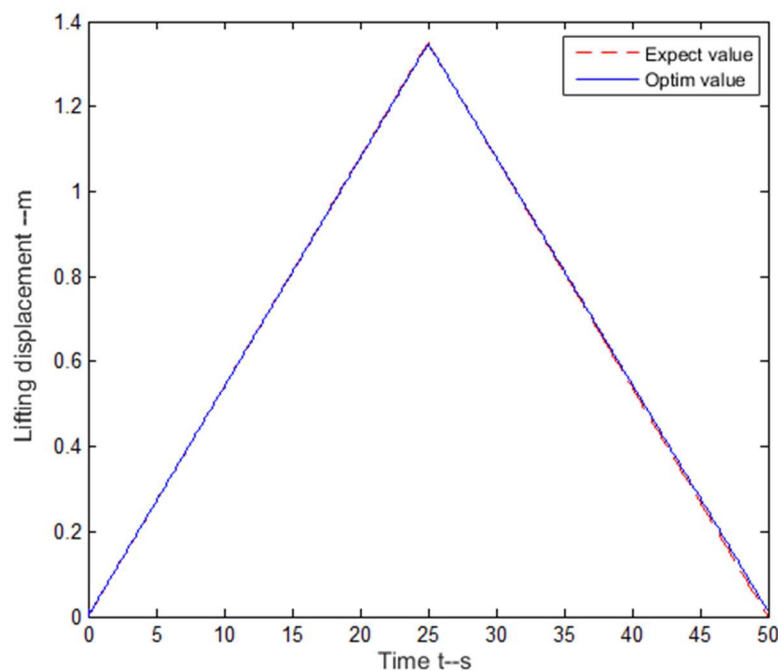

Figure 4. Optimization results of lift loop circuit.

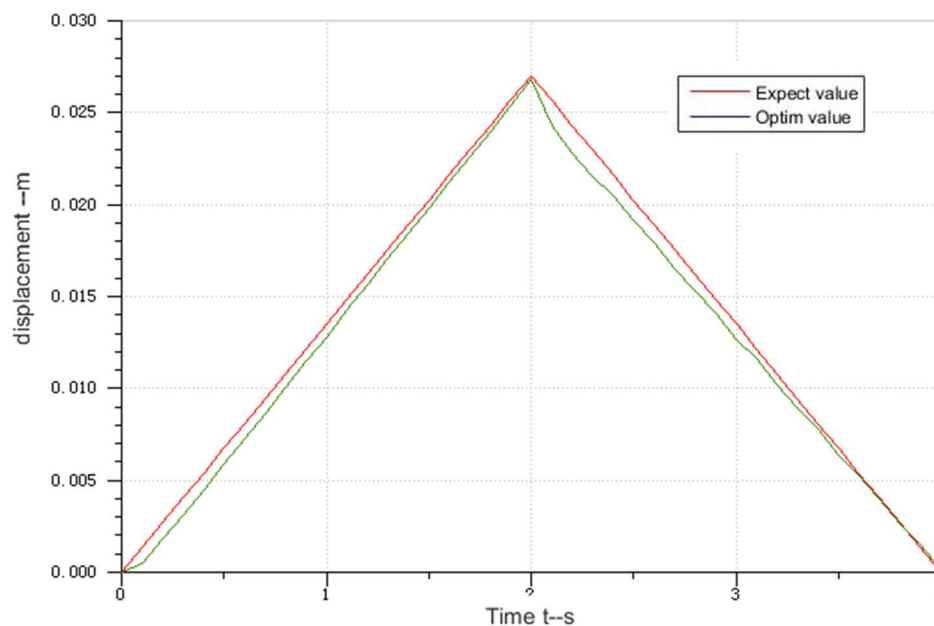**Table 1.** Optimization range and results of hydraulic parameters in lift and motion.

	1 Opening pressure (bar)	2 Opening pressure (bar)	5 Stretching flow (L/min)	6 Zooming flow (L/min)
Min	170	60	15	15
Max	200	90	25	25
Opt	192.69	64.50	20.85	15.70

4.2. Optimization design of hydraulic parameters in locking loop
The motion of the locking loop is also an open-loop control. Select 4 Hydraulic components in Figure 2, as shown in table. Optimization algorithm adopts genetic algorithm, the desired and optimized motion curves are shown in Figure 5.

Table 2. Optimization range and results of locking motion hydraulic parameters.

	1 Valve diameter (mm)	2 Valve diameter (mm)	3 Stretching flow (L/mm)	4 Zooming flow (L/mm)
Min	2	2	10	12
Max	4	4	12	14
Opt	4	4	10.5	12

Figure 5. Optimization results of locking loop.

It can be seen from the figure that the actual displacement curve does not completely coincide with the desired curve. It is because the initial range of optimization parameters is not reasonable. The optimal value is obtained on the initial boundary. Better optimization values can be obtained by adjusting the optimization range.

4.3. Optimization Design of Hydraulic Parameters in Rotary Loop
PID closed loop control is used for rotary part. Four hydraulic components are choosed in hydraulic parameters selection of figure 3, as shown in table 3. Optimization algorithm adopts genetic algorithm. The desired motion curve and the optimized curve are shown in Figure 6.

It can be seen from the figure that the optimal motion curve and the desired curve of the rotary loop are high. Maximum error angle does not exceed 0.9°. Movement control meets actual requirements.

Table 3. Optimization range and results of hydraulic parameters in rotary motion.

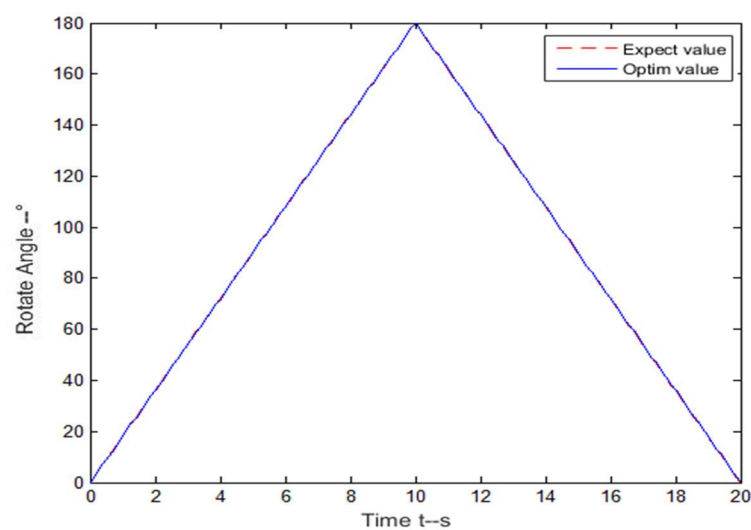|	1 Opening pressure (bar)	2 Opening pressure (bar)	3 Flow (L/min)	4 Flow (L/min)
Min	60	60	15	15
Max	90	90	25	25
Opt	74.51	72.74	18.91	15.44

Figure 6. Rotary loop optimization results.

4.4. Optimized design of PID control parameters for rotary loop
The number of PID parameters in the rotary loop is small and close to each other. Keriging method can be used for the optimization. The parameters range and results of the optimization are shown in table 4.

Table 4. Optimization range and results of PID parameters for rotary loop.

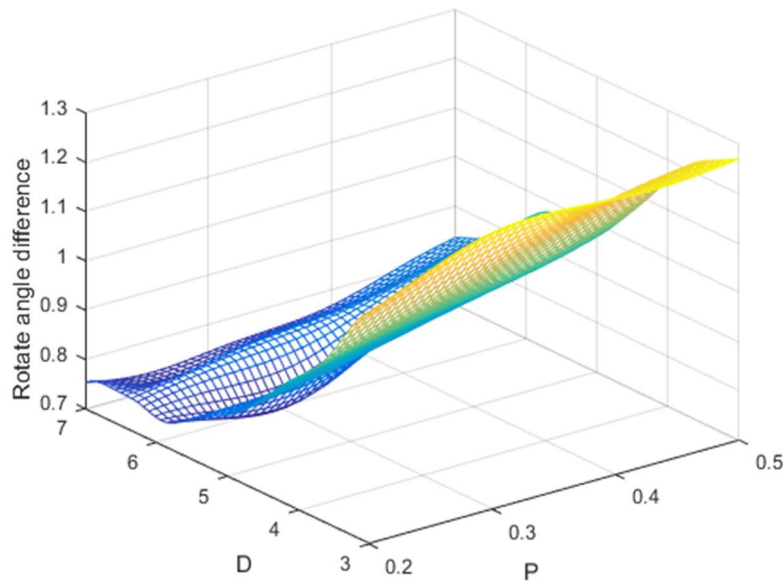|	P	I	D
Min	0.1	0	4
Max	0.5	0.004	7
Opt	0.1429	0.003	6.0204

Figure 7. Optimization results.

It can be seen that the changing range of I is less than P and D ranges. P and D are selecting to make Keriging curved surface as shown in Figure 7. It can be seen from the figure, in the D=6.0204, P=0.1429, the surface has a recess. That is to get the best value there.

5. Conclusion

The steering force and the ability to resist wind wave swing under any condition of underwater robot can be increased by the vector propulsion device, which can help maintain steady navigation and posture. By optimizing the parameters of hydraulic system of vector propulsion device, the response speed, accuracy and other performance indicators of the entire system can be improved, and the working state of some components is improved.

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