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Research On Dynamic Motioning System For Virtual Reality System of Human Occupied Vehicle

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***Abstract*—Dynamic motioning system is one of the key sub-system for virtual reality system of human occupied vehicle, positioning data of the virtual reality system is calculated by the dynamic motioning system. The present research is to establish the dynamic motioning system of the VR system of human occupied vehicle. Based on the six-degree-of-freedom maneuverable space motion equation, the research object establishes the dynamic simulation model of the manned submersible. On this basis, the hydrodynamic coefficients obtained from the tank test and the actual sea test data are introduced to establish the dynamic simulation model. The present research provide reliable space positioning information for the VR system.**

Keywords- Human occupied vehicle; Virual reality; Dynamic motioning system

I. INTRODUCTION

In recent years, VR (virtual reality) is widely used in engineering applications such as automobile, aeronautics, astronautics, et al. The application of VR technology in design, manufacturing, evaluation and teaching & training of manned submersibles, provide immersive experiences for engineers and pilots. Thus, VR technology would be an effective way to improve the design, manufacturing and training efficiency [1].

There are plenty of successful engineering applications of VR technology on the manned submersibles. For instance, JAMSTEC established a VR system for pilots training of the deep-sea human occupied vehicle "SHINKAI 6500" [2], simulator of the manned submersible "ALVIN" provided sailing training and mission rehearsal services for the pilots [1], Huang BY [2] proposed an operation simulation training system for ROV based on the commercial software "Vega" and "Creator", China ship scientific research center proposed a VR system for sailing simulation of the human occupied vehicle "Jiao Long" [3].

The present research is to establish the dynamic motioning system of the VR system of human occupied vehicle (HOV). Dynamic motioning system is one of the most important sub-system for virtual reality system of human occupied vehicle, positioning data of the VR system is calculated by the dynamic motioning system. Based on the six-degree-of-freedom maneuverable space motion equation, the research object establishes the dynamic simulation model of the manned submersible. On this basis, the hydrodynamic coefficients obtained from the water tank test and the actual sea test data are introduced to establish the dynamic simulation model.

II. DYNAMIC MOTIONING SIMULATION PROCESS

The aim of the dynamic motioning system is to calculate the dynamic motioning characteristics for the virtual reality system. As shown in Figure 1, based on the input data of commands from the pilot, the motioning characteristics are calculated by the transfer function, then the calculated results are output to the VR system. Meanwhile, the calculated results are the input data for next numerical calculation step. The details are listed below:

(1) Initial parameters set-up. Parameters including dimensions, mass, moment of inertia, initial coordinate, initial velocity, etc. should be defined firstly. These parameters are the basis for dynamic motioning simulation of VR system.

(2) Thruster calculation. As soon as receiving the command from the pilot, navigation controller would carry out the thruster parameters, such as voltage, current, rotational speed immediately. By then, the control signal is sent to each electronic propeller.

(3) Dynamic motioning calculation. The hydrodynamic coefficients were carried out by model test in the water tank, firstly. Then based on these coefficients, a dynamic model has been established. The displacement and velocity of the vehicle would be calculated by the transfer function based on the input data. Furthermore, the influence of random disturbances such as wave, current and wind also have been considered in the dynamic motioning model.

(4) Data output. The output data would be sent to the VR system, then the displacement, the velocity would be refreshed in the user interface. Meanwhile, the output data would be sent back to the control circuit as the input data for next numerical calculating step.

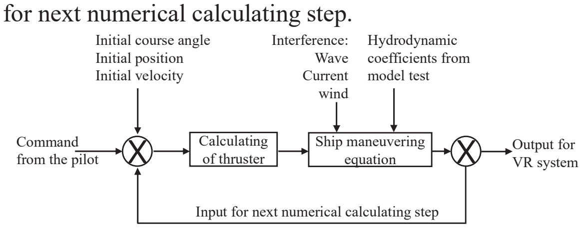

Figure 1 Schematic diagram of the dynamic motion system

III. PROPELLING MODEL

The thruster model is a medium between the control signal and the dynamic reaction of the HOV. Once receiving the control signal, the thruster model, the propelling system realizes thruster output by adjusting

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voltage and current, theoretical model of the thruster is shown in Figure 2.

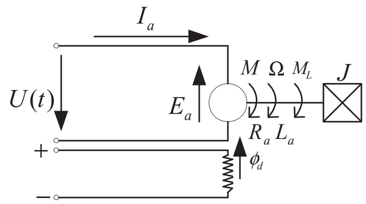


Figure 2 Theoretical model of the thruster

In electromagnetism, the DC electromotor equation would be expressed as:

$$U - E_a = L_a \frac{dL_a}{dt} + R_a I_a \tag{1}$$

Where U represents applied voltage, E_a represents voltage on the armature, I_a represents the current, L_a and R_a represents the inductance and resistance respectively.

In mechanical view, relationship between the moment and angular velocity would be expressed as:

$$M - M_L = J \frac{d\Omega}{dt} \tag{2}$$

Where, M means moment on the armature, M_L means output moment on the axis, J means of rotating inertia of the whole thruster, Ω means angular velocity of the axis.

By combining Equation (1) and Equation (2), with ignorance of higher-order infinitesimal quantities, the theoretical model of the thruster could be expressed as:

$$T_m \frac{d\Omega}{dt} + \Omega = \frac{1}{k_d} U - \frac{R_a}{k_d{}^2} M_L \tag{3}$$

Where, $T_m = \frac{JR_a}{k_d{}^2}$, k_d is an empirical coefficient of the electromotor.

Meanwhile, relationship between thrust T and angular velocity Ω would be expressed as:

$$T = (1-t) K_t \rho (\frac{\Omega}{N})^2 D^4 \tag{4}$$

In which, t represents thrust deduction, K_t represents dimensionless thrust factor of the propeller, ρ represents density of the water, N means reduction ratio of the reducer, D means diameter of the propeller. By combining Equation (3) and Equation (4), the theoretical model of the thruster would be established finally.

IV. MANEUVERING MODEL OF HOV

Dynamic motioning characteristics of the HOV would be calculated by the maneuvering model. The coordinates vector and velocity vector calculated by the maneuvering equation are the basic information of dynamic motioning parameters for VR system of HOV. The present chapter is to establish the maneuvering equation.

The velocity of HOV relative to the current would be defined as U_R= (u, v, w)^T, angular velocity would be defined as Ω= (p, q, r)^T, the current velocity would be defined as U_W= (ux, uy, uz)^T. Thus, absolute velocity of HOV would be defined as $U=U_R+U_W$. Based on the ideal fluid assumption, the dynamic motioning equation would be written as:

$$\begin{gathered} M_T\dot{U} + A_T\dot{U}_R + (M_{RT}^T + A_{RT}^T)\dot{\Omega} + \\ \Omega\times[M_T U + A_T U_R + (M_{RT}^T + A_{RT}^T)\Omega] = F \end{gathered} \tag{5}$$

$$\begin{gathered} M_{RT}\dot{U} + A_{RT}\dot{U}_R + (M_R + A_R)\dot{\Omega} + \\ \Omega\times[M_{RT}U + A_{RT}U_R + (M_R + A_R)\Omega] + \\ U\times(M_T U + M_{RT}^T\Omega) + U_R\times(A_T U_R + A_{RT}^T\Omega) = L \end{gathered} \tag{6}$$

Where:

$$M_T = \begin{bmatrix} m & 0 & 0 \\ 0 & m & 0 \\ 0 & 0 & m \end{bmatrix}, \quad M_R = \begin{bmatrix} I_x & J_{xy} & J_{xz} \\ J_{xy} & I_y & J_{yz} \\ J_{xz} & J_{yz} & I_z \end{bmatrix}$$

$$M_{RT} = \begin{bmatrix} 0 & -mz_g & -my_g \\ -mz_g & 0 & -mx_g \\ -my_g & -mx_g & 0 \end{bmatrix}$$

$$A_T = -\begin{bmatrix} X_{\dot{u}} & X_{\dot{v}} & X_{\dot{w}} \\ Y_{\dot{u}} & Y_{\dot{v}} & Y_{\dot{w}} \\ Z_{\dot{u}} & Z_{\dot{v}} & Z_{\dot{w}} \end{bmatrix}, \quad A_R = -\begin{bmatrix} K_{\dot{p}} & K_{\dot{q}} & K_{\dot{r}} \\ M_{\dot{p}} & M_{\dot{q}} & M_{\dot{r}} \\ N_{\dot{p}} & N_{\dot{q}} & N_{\dot{r}} \end{bmatrix}$$

$$A_{RT} = -\begin{bmatrix} K_{\dot{u}} & K_{\dot{v}} & K_{\dot{w}} \\ M_{\dot{u}} & M_{\dot{v}} & M_{\dot{w}} \\ N_{\dot{u}} & N_{\dot{v}} & N_{\dot{w}} \end{bmatrix} = -\begin{bmatrix} X_{\dot{p}} & X_{\dot{q}} & X_{\dot{r}} \\ Y_{\dot{p}} & Y_{\dot{q}} & Y_{\dot{r}} \\ Z_{\dot{p}} & Z_{\dot{q}} & Z_{\dot{r}} \end{bmatrix}$$

These coefficients are difficult to solve out analytically, thus they would be presented out by model test in the water tank.

Equation (5) and Equation (6) are non-linear, and there exists interactions between each freedom of the HOV, thus the equations seem to be difficult to solve. In order to get an approximate solution, a few simplification should be presented based on ignorance of interactions between the freedoms, the dynamic equation would be modified, written with matrix form as:

$$\begin{bmatrix} A_1 & 0 & 0 & 0 & C_1 & B_1 \\ 0 & A_2 & 0 & B_2 & 0 & C_2 \\ 0 & 0 & A_3 & C_3 & B_3 & 0 \\ 0 & D_4 & B_4 & A_4 & 0 & C_4 \\ B_5 & 0 & C_5 & 0 & A_5 & 0 \\ C_6 & B_6 & 0 & D_6 & 0 & A_6 \end{bmatrix} \begin{bmatrix} \dot{u} \\ \dot{v} \\ \dot{w} \\ \dot{p} \\ \dot{q} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \\ f_5 \\ f_6 \end{bmatrix} \tag{7}$$

Where, A_1-A_6, B_1-B_6 and C_1-C_6 are all hydrodynamic coefficients based on model test; $\dot{U} = [\dot{u}\ \ \dot{v}\ \ \dot{w}\ \ \dot{p}\ \ \dot{q}\ \ \dot{r}]^T$ stands for acceleration, $F = [f_1\ \ f_2\ \ f_3\ \ f_4\ \ f_5\ \ f_6]$ stands for forces, with consideration of propelling force, irregular interference force caused by wind, current and wave. For simplification, the matrix M would be defined as:

$$M = \begin{bmatrix} A_1 & 0 & 0 & 0 & C_1 & B_1 \\ 0 & A_2 & 0 & B_2 & 0 & C_2 \\ 0 & 0 & A_3 & C_3 & B_3 & 0 \\ 0 & D_4 & B_4 & A_4 & 0 & C_4 \\ B_5 & 0 & C_5 & 0 & A_5 & 0 \\ C_6 & B_6 & 0 & D_6 & 0 & A_6 \end{bmatrix} \tag{8}$$

Thus, Equation (7) would by simplified as:

$$M\dot{U} = F \tag{9}$$

The inverse form of Equation (9) would be given out:

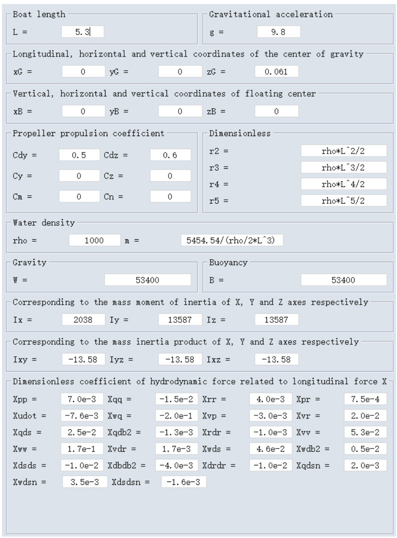
$$\dot{U} = M^{-1}F \tag{10}$$

By then, the numerical integration formula would be expressed as the following equation:

$$U_{T+1} = \Delta t \times \dot{U} + U_T \tag{11}$$

Where Δt represents the calculating step length in the numerical integration.

V. ENIGNEERING APPLICATIONS



As shown in

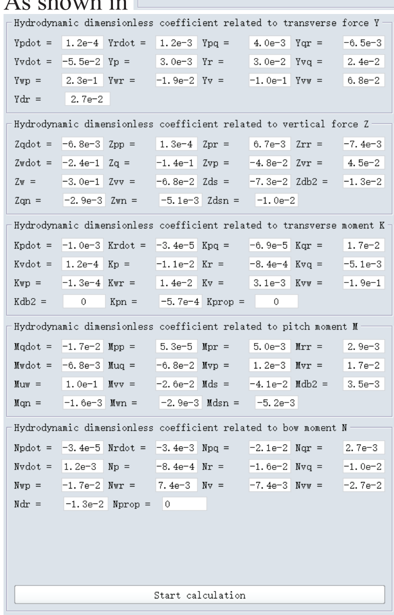


Figure 3, in engineering application of VR system, the pilot input the commands through the graphic user interface, then click the execute button to perform operation. Then the solver calculate the results by the transfer function, the results, including displacement vector, velocity vector, etc, are written into a "json" file, as shown in Figure 4.

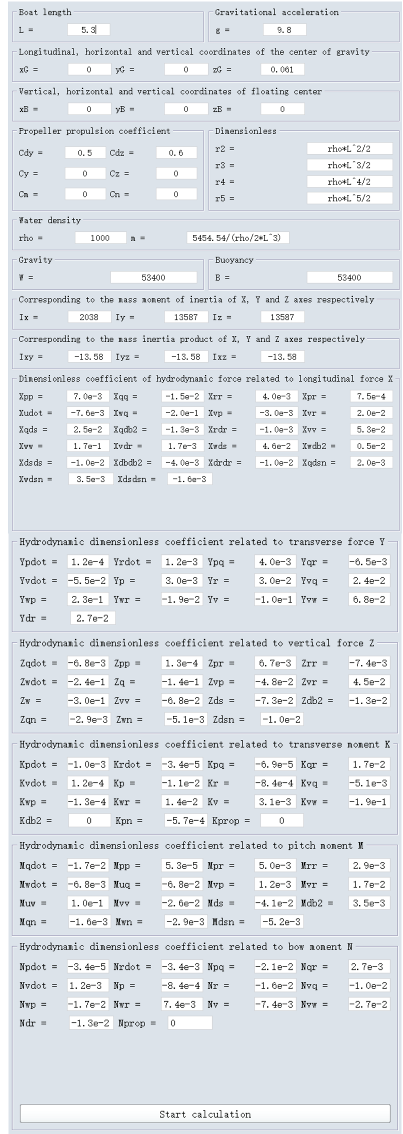


Figure 3 Graphical user interface of the motion system

data_npsauv.json


```
{
    "hovMove": [
        {
            "time": 0,
            "SurgeVelocity": 1.2,
            "SwayVelocity": 0,
            "HeaveVelocity": 0,
            "RollVelocity": 0,
            "PitchVelocity": 0,
            "YawVelocity": 0,
            "X": 0,
            "Y": 0,
            "Z": 0,
            "RollAngle": 0,
            "PitchAngle": 0,
            "YawAngle": 0
        },
        {
            "time": 0.5,
            "SurgeVelocity": 1.193059309,
            "SwayVelocity": 0.005054586145,
            "HeaveVelocity": -8.642620409e-06,
            "RollVelocity": 0.0004865794122,
            "PitchVelocity": 4.113646099e-05,
            "YawVelocity": -0.005270073366,
            "X": 0.5982622056,
            "Y": 0.0009636884414,
            "Z": -4.017207538e-06,
            "RollAngle": 0.0001271365452,
            "PitchAngle": 1.100716013e-05,
            "YawAngle": -0.001358159673
        },
        {
            "time": 1,
            "SurgeVelocity": 1.186187534,
            "SwayVelocity": 0.01060591746,
            "HeaveVelocity": -2.736720318e-05,
            "RollVelocity": 0.0008348374579,
            "PitchVelocity": 6.778572064e-05,
            "YawVelocity": -0.009654951316,
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            "Y": 0.003045092571,
            "Z": -2.570520877e-05,
            "RollAngle": 0.0004629820097,
            "PitchAngle": 3.99349734e-05,
            "YawAngle": -0.005123038153
        },
```


Figure 4 results generation of the motion system

VI. CONCLUSION

Dynamic motioning subsystem of the VR system of HOV have been conducted in the present research. The general architecture and information flow of the dynamic motion simulation system has been investigated firstly. By then, the functional modules, the main program execution flow of the software have been proposed out. Finally, development of the dynamic motioning simulation system have been carried out. The present research provide dynamic motioning simulation for the VR system of the human occupied vehicle, directly provide useful supporting data for VR system, and would promote the engineering application of novel VR system for HOV.

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