Development of Ship Maneuvering Simulator based on VR Technology

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Abstract: With the increase of the volume of world-wide trade, the continuous improvement of tonnage and dynamic performance of ships, and the density of ships on sea routes, the operation level of ship navigator has been challenged seriously. Therefore, it is imminent to improve the operation level of seafarers. Virtual reality technology can be used for navigator training. Environment and motion simulation, using virtual reality technology, has great application potential. In this paper, based on virtual reality technology and three-dimensional simulation software, a ship simulation platform is built, and the motion model are introduced in detail. The three-dimensional modeling of the vessels have been completed in the three-dimensional software 3DS MAX. In this paper, the work of motion simulation is accomplished by solving the motion equation of hull maneuvering, while visualization is realized by using VR toolbox. After ignoring the influence of ship oscillation on its hydrodynamic coefficients, and the vibration factor of propeller when establishing the power system model, the MMG equation has been established. In order to verify the correctness of the model, Simulink simulation is used to verify the model. For the reason of easy to use, low cost, powerful modeling function and good scalability and so on, XNA, a game development environment based on Direct X developed by Microsoft, has been chosen as the driver platform.

1. Introduction
In the 21st century, the globalization of economic is becoming more and more obvious. Large multinational corporations distribute their industrial chains in various countries in the world wild. The production process of a commodity even needs to be processed by factories in many countries. On the one hand, the development of economic globalization has promoted the improvement of commodity trade and production quality, on the other hand, it has also played an obvious role in promoting the development of transportation system. At present, almost 90% of the bulk industrial commodities reach their destinations by sea transportation, mainly because, comparing with land and air transportation, the sea transportation will be more economy, safety and cargo carrying capacity.

With the increasing number of ships transported by sea, the intensity of sea routes has gradually increased, even for ship pilots. The level of driving automation has made considerable progress, but the close degree of the route and the rapid development of ships put forward very high requirements for the driver's technology. Traditional ship driving training mainly focuses on real ship operation, which has obvious shortcomings: it can’t simulate extreme sailing conditions, once an accident occurs, it will lead to serious economic losses, high training costs and so on. The research content of this paper is aimed at this problem. This paper develops a virtual ship driving environment combining virtual reality technology, electronic communication technology, computer technology and so on. It can...
realize the interactive function between trainees and virtual platform simulator. It can not only build different marine navigation scenarios under different working conditions, but also provide a realistic driving environment for operators. Ship power system, steering system and so on have great application potential.

2. Research and Development of Virtual Reality Technology

Virtual reality technology was first proposed in the 1980s. According to the definition of American scholars, virtual reality technology can be divided into different modules. The principle of virtual reality technology is shown in Figure 1.

![Figure 1. Principle diagram of virtual reality technology.](image)

In the development process of virtual reality technology, scholars all over the world have done a lot of research. For example, industrial design and British Aerospace, which is engaged in VR technology research, successfully applied virtual reality technology to the virtual design of advanced fighter bridge, and developed fighter simulation bridge. Japan is the main body of research on virtual reality technology. Now in the field of virtual reality games, American scholars have developed a clinical medical system with interactive function based on virtual reality technology, which has very important application value.

The research in the field of virtual reality technology in China is still in its infancy. The Computer Department of Beijing University of Aeronautics and Astronautics first developed the research of virtual reality technology, mainly developed the interface program of the application of virtual reality technology, the simulation system of driving training, etc.

3. Development of Ship Driving Simulation System Based on VR Technology

3.1 Modeling of Ship Motion

The design of ship driving simulation system must satisfy the basic characteristics of ship motion. Therefore, it is necessary to establish a general function model of ship motion in virtual software platform[1].

In this paper, it is assumed that the ship motion function model is established.

- Consider the hydrodynamic force of ship and propeller separately and simplify it to a certain extent;
- Ignore the influence of ship oscillation on its hydrodynamic coefficients, and ignore the vibration factor of propeller when establishing the power system model.

The establishment of ship motion coordinate system is shown in Figure 2.
Based on the MMG equation, this paper adds the rolling motion equation and considers the transverse velocity \( v = V_m + x_G \beta_r \) at the center of gravity. The specific expressions of hydrodynamic force and moment of the hull at the center of gravity can be obtained [2-3].

The motion equation of a ship is established as follows:

\[
\begin{align*}
& m(\ddot{u} - vr - x_G r^2 + y_G r^2 + z_G \beta_r) = X \\
& m[v^2 + w^2 - y_G (p^2 + r^2) - z_G \beta_t + x_G r^2] = Y \\
& I_x \ddot{r} + m[x_G (v^2 + w^2) - y_G (\dot{u} - vr)] = N \\
& I_x p + m[y_G pv - z_G (v^2 + w^2)] = K
\end{align*}
\]

In the formula: \((x_G, y_G, z_G)\) are three components of the center coordinate; \(m\) is the ship mass; \(I_x\) and \(I_y\) represent the rolling and swaying moment of inertia; \(v\) is the velocity component in the \(y\) direction at the center; \(\ddot{u}, \dot{v}\) is the acceleration in the \(x\) and \(y\) directions; \(r, \dot{r}\) is the yaw angular velocity and angular acceleration; \(p\) and \(\dot{p}\) are the yaw angular velocity and angular acceleration; \(X\) and \(Y\) are the action in the yaw angular velocity and angular acceleration respectively. The force of hull, the yaw moment and the roll moment of \(N\) and \(K\) are respectively applied to the hull [4].

At the same time, \(X, Y, N\) and \(K\) acting on the hull can be expressed as fluid inertial force term and fluid viscous force. Formula (1) Right term expression (2):

\[
\begin{align*}
X &= X_H + X_P + X_R \\
Y &= Y_H + Y_P + Y_R \\
N &= N_H + N_P + N_R \\
K &= K_H + K_R - C_{44} \Phi - B_{44} \dot{\Phi}
\end{align*}
\]

In the formula, subscripts \(H, P\) and \(R\) represent hull, propeller and rudder respectively; \(C_{44}\) and \(B_{44}\) represent hull static recovery force coefficient and roll attenuation viscosity coefficient respectively; \(\Phi\) and \(\dot{\Phi}\) represent roll angle and roll angular velocity respectively.
The hydrodynamic $X_H$, $Y_H$, and moment terms $N_H$, $K_H$ of medium hull can be got in the references.

The mechanical model of propeller thrust and torque is established as follows:

The $X_P$ expression of longitudinal propeller thrust is (3):

$$X_P = (1 - t_p)T$$

(3)

And $T_P$ is thrust reduction; $T$ is propeller thrust, and its specific expression is (4):

$$T = \rho n_p^2 D_p^4 K_T J_P$$

(4)

In the formula, $n_p$ is the speed of propeller, $D_p$ is the diameter of propeller, $K_T$ is the thrust coefficient of open water propeller and $J_P$ is the advance coefficient of propeller.

The expressions of effective rudder force $X_R$, $Y_R$ and $N_R$ are as follows (5):

$$\begin{cases} 
X_R = -(1 - t_R)F_N \sin \delta \\
Y_R = -(1 - a_H)F_N \cos \delta \\
N_R = -(x_R + a_H x_H)F_N \cos \delta \\
K_R = Y_R x_R 
\end{cases}$$

(5)

In the formula, $t_R$, $a_H$ and $x_H$ are the hydrodynamic interference coefficients between ship hull and rudder, and $F_N$ is the normal force of rudder. The concrete expressions are as follows (6):

$$F_N = \left(\frac{1}{2}\right) \rho A_R U_R^2 f_a \sin a_R$$

(6)

In the formula, $A_R$ is the rudder area, $f_a$ is the normal force coefficient of rudder, which is generally estimated by Fujii formula, $U_R$ and $a_R$ are the effective velocity and rudder angle before the rudder is affected by hull and propeller respectively.

### 3.2 Software Platform of Virtual Reality Technology

Software platform is the foundation of virtual reality technology, and the modeling of virtual environment must be completed in three-dimensional modeling software.

At present, the widely used three-dimensional modeling software includes 3DS MAX, Maya, Pro/E and so on. Image rendering and model surface processing are mainly accomplished by Photoshop image processing software. The ship's principle and separation mathematical model are used to model the ship's physics and behavior.

XNA is a game development environment based on Direct X developed by Microsoft. It is the modification and optimization of Managed Direct X by Microsoft. XNA is based on Visual C# Express 2005, which provides users with a simple development environment. Compared with other similar software, XNA has many advantages, such as easy to use, low cost, powerful modeling function and good scalability.

Using XNA. NET Framework for game development greatly reduces the workload of developers, and more attention can be paid to game creativity in game development. The game developed can run across platforms, and it is easier to use and has higher scalability. XNA Framework encapsulates all the underlying technologies used for game programming, so game developers can concentrate most of their energy on game content and conceptual development, rather than on the migration of games to different platforms. As long as the game is developed on XNA platforms, all the hardware supporting XNA can run.

### 3.3 Hardware

XNA hardware mainly refers to computers with Windows operating system. Unlike other development platforms, programs developed by XNA technology can run across platforms.
3.4 Platform
The development platform of XNA technology includes NET Framework and Direct X technology. It supports many programming languages (VB, C++). NET Framework platform also provides XNA with a rich application program interface (API).

3.5 Tools
XNA development environment has a variety of tools, which can satisfy the functions and operations required for the construction of virtual environment.

3.6 Development of Ship Driving Simulation System Based on XNA
Ship driving simulation system is mainly divided into kinematics solution part (ship motion function model, power system function model, etc.) and actual navigation scene simulation.

3DS Max is a three-model, animation and rendering software. With the help of 3DS Max, we can create a magnificent game world, arrange wonderful scenes to achieve design visualization, and create immersive virtual reality (VR) experience. In this paper, the three-dimensional modeling of the ship bridge is completed in the three-dimensional software 3DS MAX. And the surface texture of the bridge model is rendered by Photoshops, so that the simulation degree of the virtual scene can be optimized[5-6]. Then the simulation system is developed on the XNA development platform. As shown in Figure 3.

In order to verify the correctness of the model, Simulink simulation is used to verify the model. One of the greatest advantages of the numerical simulation method is that it can reproduce the ship motion indefinitely, which includes the normal motion that can be made in the model test, such as rotary motion, Z-shaped maneuvering motion, etc., and also the overturning motion that is not suitable in the model test, such as parametric excitation, roll and so on. In order to achieve this goal, a simple method of realizing ship motion virtual reality by using Simulink's Virtual Reality toolbox is explored[7]. In this paper, the work of motion simulation is accomplished by solving the motion equation of hull maneuvering, while visualization is realized by using VR toolbox. The following are introduced separately.

4. Conclusion
This paper introduces the principle and development status of virtual reality technology, then establishes the functional model of ship motion and dynamic system by establishing coordinate system, and finally completes the development of ship driving simulation system on XNA development platform.
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Reference
[1] OGAWA A, KOYAMA T, KIJIMA K. MMG report-I, on the mathematical model of ship maneuvering [J]. Bull Soc Naval Archit Jpn, 1997, 575: 22-28.
[2] MATSUMOTO K, SUEMITSU K. The prediction of maneuvering performances by captive model tests [J]. J Kansai Soc Naval Archit Jpn, 1980, 176: 11-22.
[3] YASUKAWA H, YOSHIMURA Y. Introduction of MMG standard method of ship maneuvering predictions [J]. Journal of Marine Science and Technology, 2015, 20(1): 37-52.
[4] Goss M E. Motion Simulation: A Real Time Particle System for Display of Ship Wakes [J]. IEEE Computer Graphics & Applications, 1990, 10(3): 30-35.
[5] Grootjans R. XNA 3.0 Game Programming Recipes [M]. Apress, 2009.
[6] Pinheiro V B, Holliger P. The XNA world: progress towards replication and evolution of synthetic genetic polymers [J]. Current Opinion in Chemical Biology, 2012, 16(3-4): 245-252.
[7] Okazaki T, Ochiai H, Kashima H, et al. Development of override ship maneuvering simulator using AR toolkit [C]// World Automation Congress. IEEE, 2012.