Research on UE4 - based Visualization Simulation of Underwater Vehicle Polar Region Sailing

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Abstract. With the continuous exploration of polar sea areas, the reliability and safety of polar navigation have become the top priority. Due to various influencing factors in the polar region, including sea ice, ocean currents, geomagnetism, gravity, etc., navigation equipment in the polar region cannot achieve the performance of the mid-low latitude region. Because of the limitation of the actual ship entering the polar region, the performance of navigation system in polar region cannot be fully verified. It is difficult to verify the performance of equipment on a real ship. In order to reduce the cost of the experiment while ensuring the accuracy of the verification and making the simulation training system available at the same time. Based on UE4(Unreal Engine4) to design a virtual 3D visual simulation platform of underwater vehicle that is able to simulate the six-degree-of-freedom(6-dof) motion of the underwater vehicle and verify the performance of navigation equipment in polar region. Verify the virtual simulation platform is able to simulate the movement of underwater vehicle in the virtual polar sea and realize the operation training simulation of underwater vehicle.

1. Introduction

With the continuous development of the polar waters in recent years, the strategic importance of the Arctic region has continued to grow, and it will be included in the global geopolitical and economic agenda in the next few years. It is not only related to the countries in this region, but also closely related to the major world powers outside this region. With the establishment of commercial relations between the Arctic seas and the North Atlantic and the North Pacific, it becomes possible. A stable energy supply is not only an important factor for a country’s national security and economic development, but also directly affects domestic politics and foreign policy, which in turn affects regional security and even global stability [1]. The United States, Russia and other Arctic countries have continued to strengthen their military presence in the polar regions. In recent years, the US military and its NATO allies have continued to strengthen their deployment and military capabilities in the polar regions. Operations such as military exercises in the Arctic region have become normalized and scaled up [2]. Because the polar regions are rich in natural resources, including: fishery resources, forest resources, mineral resources, etc. The polar regions therefore have important strategic and economic value. And the polar regions are rich in energy, so China needs to incorporate the Arctic into China's overall strategy. In modern naval combat training, it is not only necessary to train soldiers to conduct operations through screens or other media, but also to train combat and response capabilities in the event of direct combat damage. These training objectives can be effectively accomplished through battlefield simulation [3]. The operating skills of the operator can be trained through the virtual simulator. At present, the mainstream virtual simulation training systems in the world are such
as the H01 FNPT II helicopter simulation training system of the US Army, the Prepar3D fighter simulation training system and the SCTT submarine training simulation system of the British Navy [4]. With the development of computer graphics and virtual reality technology, it is technically supported to design digital simulation models with the same key attributes as physical models. At the same time, with the rapid development of sensors and radars, machine vision technology has become more and more complicated [5]. VR technology uses virtual simulation technology to replicate real-world navigation tests. The implementation of an underwater vehicle simulation platform can reduce costs and improve safety, which not only minimizes costs, but also accelerates the development cycle to achieve end-to-end deep learning [6]. System simulation technology is currently one of the most widely used technologies. It is based on control theory, similar theories, information processing technology and calculation technology. It uses computers and other special physical effect equipment as tools, use system model to test real or hypothetical systems, get decisions through analyzing test results [7]. The ship handling simulator consists of three subsystems: vision system, bridge system and control system. These systems and functional simulators are universal systems [8]. Use visual simulation technology with UE4 virtual engine to simulate the three-dimensional world, construct a real simulation model, simulate the real simulation environment, and achieve real simulation results. During the development of the polar region, the reliability and safety of the polar region navigation have become the top priority. Because of various environment factors in the polar region, including sea ice, ocean currents, geomagnetism, abnormal gravity, etc., that makes the navigation equipment in polar regions cannot reach the performance of the low and mid-latitude regions and there are restrictions on the entry of real ships into the polar regions, so that the performance of the navigation system in the polar environment cannot be fully verified. In order to fully verify the performance of the navigation equipment in the polar region, this paper designs an all-element virtual simulation training platform in the polar sea area based on UE4 in the computer space to simulate the navigation process of the underwater vehicle in the polar region, analyse the results of simulation and verify the hypothesis that the all-element simulation platform can fully verify performance of navigation equipment and play a training role.

2. Virtual All-element Polar Simulation Training Platform

Virtual all-element polar simulation training platform that uses polar region physical models, sensor data update, historical operating data to generate a multi-physical quantity, multi-scale, multi-probability simulation process, complete the mapping of the physical model to the virtual model, and reproduce the real polar physical scene in a digital way. Obtain the digital twin model of the physical model with it running in a synchronous and dynamical mode to realize visual simulation and data running unified.

![Virtual all-element polar simulation training platform](image)

**Figure 1.** Virtual all-element polar simulation training platform.

2.1. Digital Twin

Digital twin refers to a physical entity, process or system established and simulated in an information platform. Through the digital twin, the status of the physical entity can be understood on the information platform, and the predefined interface components in the physical entity can be controlled.
Integrate physical feedback data, supplemented by artificial intelligence, machine learning and software analysis to build a digital model in the information platform. This model will automatically make corresponding changes as the physical entity changes based on feedback. Digital twin model is able to learn from feedback data of multiple sources and present the real situation of physical entities in the digital world in real time [9].

2.2. Virtual Reality

Virtual reality is a virtual world created by computer and electronic technology. It is a seemingly real simulation world. Through various sensing devices, users can inspect or manipulate objects in the virtual world according to their own feelings. The virtual simulation platform brings together a number of key technologies including computer graphics, artificial intelligence, and visual simulation. Its characteristics of immersion, dynamics, interaction, and multi-dimensional perception make it widely used in the field of military training. There are broad application prospects in the training of nuclear submarine operators, fighter pilot training and missile training systems [10].

3. 6-dof Motion Model of Underwater Vehicle

Simplify the traditional six-degree-of-freedom motion model of the underwater vehicle and incorporate it into the underwater vehicle model in the virtual simulation training platform to make the motion process of the virtual underwater vehicle under the action of the virtual polar physical field equal to the motion process of the underwater vehicle in the real polar sea area.

3.1. Simplification of Six-degree-of-freedom Motion Model of Underwater Vehicle

Since the marked six-degree-of-freedom motion model of the underwater vehicle contains 108 hydrodynamic parameters, it is difficult to obtain all these parameters in a real scene. According to the actual operating experience and the influence of hydrodynamic parameters on the space motion of the underwater vehicle to simplify the six-degree-freedom motion model. Regard the underwater vehicle as a symmetrical geometry. The derivation process of the simulation model can refer to this document [11].

\[
\begin{align*}
\mathbf{f}_1 &= \mathbf{u}(\mathbf{v} - \mathbf{w}) + \frac{1}{2} \rho \mathbf{U} [\mathbf{X}_{u} \mathbf{q}^2 + \mathbf{X}_{i} \mathbf{r}^2 + \mathbf{X}_{p} \mathbf{r}^2] + \frac{1}{2} \rho \mathbf{U} [\mathbf{X}_{u} \mathbf{u}^2 + \mathbf{X}_{i} \mathbf{u}^2 + \mathbf{X}_{p} \mathbf{u}^2] + \mathbf{X}_i, \\
\mathbf{f}_2 &= \mathbf{m}(\mathbf{r} - \mathbf{u}) + \frac{1}{2} \rho \mathbf{U} [\mathbf{Y}_{u} \mathbf{p}^2 + \mathbf{Y}_{i} \mathbf{p}^2 + \mathbf{Y}_{p} \mathbf{r}^2 + \mathbf{Y}_{i} \mathbf{r}^2] + \frac{1}{2} \rho \mathbf{U} [\mathbf{Y}_{u} \mathbf{u}^2 + \mathbf{Y}_{i} \mathbf{u}^2 + \mathbf{Y}_{p} \mathbf{u}^2] + \mathbf{Y}_i, \\
\mathbf{f}_3 &= \mathbf{m} - \mathbf{w} + \frac{1}{2} \rho \mathbf{U} \left[ \mathbf{Z}_{u} \mathbf{p}^2 + \mathbf{Z}_{i} \mathbf{p}^2 + \mathbf{Z}_{p} \mathbf{r}^2 + \mathbf{Z}_{i} \mathbf{r}^2 + \mathbf{Z}_{u} \mathbf{w}^2 + \mathbf{Z}_{i} \mathbf{w}^2 \right] + \frac{1}{2} \rho \mathbf{U} \left[ \mathbf{Z}_{u} \mathbf{u}^2 + \mathbf{Z}_{i} \mathbf{u}^2 + \mathbf{Z}_{p} \mathbf{u}^2 + \mathbf{Z}_{i} \mathbf{u}^2 \right] + \mathbf{Z}_i, \\
\mathbf{f}_4 &= \left( \mathbf{l} - \mathbf{I}_1 \right) \mathbf{q} + \frac{1}{2} \rho \mathbf{U} \left[ \mathbf{K}_{u} \mathbf{q}^2 + \mathbf{K}_{i} \mathbf{q}^2 \right] + \frac{1}{2} \rho \mathbf{U} \left[ \mathbf{K}_{u} \mathbf{u}^2 + \mathbf{K}_{i} \mathbf{u}^2 \right] + \mathbf{K}_i, \\
\mathbf{f}_5 &= \left( \mathbf{l} - \mathbf{I}_1 \right) \mathbf{p} + \frac{1}{2} \rho \mathbf{U} \left[ \mathbf{M}_{u} \mathbf{p}^2 + \mathbf{M}_{i} \mathbf{p}^2 + \mathbf{M}_{p} \mathbf{r}^2 + \mathbf{M}_{p} \mathbf{r}^2 + \mathbf{M}_{u} \mathbf{w}^2 + \mathbf{M}_{i} \mathbf{w}^2 \right] + \frac{1}{2} \rho \mathbf{U} \left[ \mathbf{M}_{u} \mathbf{u}^2 + \mathbf{M}_{i} \mathbf{u}^2 + \mathbf{M}_{p} \mathbf{u}^2 + \mathbf{M}_{p} \mathbf{u}^2 \right] + \mathbf{M}_i, \\
\mathbf{f}_6 &= \left( \mathbf{l} - \mathbf{I}_1 \right) \mathbf{y} + \frac{1}{2} \rho \mathbf{U} \left[ \mathbf{N}_{u} \mathbf{p}^2 + \mathbf{N}_{i} \mathbf{p}^2 + \mathbf{N}_{p} \mathbf{r}^2 + \mathbf{N}_{p} \mathbf{r}^2 + \mathbf{N}_{u} \mathbf{w}^2 + \mathbf{N}_{i} \mathbf{w}^2 \right] + \frac{1}{2} \rho \mathbf{U} \left[ \mathbf{N}_{u} \mathbf{u}^2 + \mathbf{N}_{i} \mathbf{u}^2 + \mathbf{N}_{p} \mathbf{u}^2 + \mathbf{N}_{p} \mathbf{u}^2 \right] + \mathbf{N}_i \right)
\end{align*}
\]

(1)

3.2. Design and Analysis of Polar Ocean Scene

In order to improve the authenticity of the simulation. The physical model of underwater vehicle is built through 3Dmax. of virtual underwater vehicle. The UE4 physical system adds physical collisions to the simulation process of underwater vehicle closer to reality. The collision network is composed of 4502 triangular modules. The blueprint of underwater vehicle model includes the main body of the underwater vehicle, a camera with a front view angle and a camera with a side view angle to ensure it is bale to observe motion state of underwater vehicle and surrounding environment from two different perspectives during the simulation process. Take the underwater vehicle as root component and bind the cameras and motion components to the root component. The motion component changes its motion state under the influence of sea waves and ocean currents to make motion of the underwater vehicle confirm to its motion model.
4. Design and Analysis of All-element Virtual Ocean Scene

The virtual polar ocean scene is a digital twin model with the same main attributes constructed by virtual reality technology compared with real polar ocean scene. It not only includes topography with realistic seabed topography and surface cultural features, but also is able to reflect various natural scenes and climatic phenomena, such as sea waves, rain, snow, fog, etc., and the terrain environment also includes three-dimensional solid models, which are divided into static entity model and dynamic entity model. The static entity models include cultural features of the surface, such as lighthouses, buoys, etc., the dynamic entity models refer to various simulation entities such as airplanes, underwater vehicles, etc [12].

The polar ocean scene in the all-element polar simulation platform includes the design of sea water material, the design of the seabed terrain and the illumination rendering of the polar area. The rendering of the scene adopts forward rendering by default, which is not only faster than the default deferred rendering, but also has more anti-aliasing options, which brings a clearer and brighter display effect. Because the speed of forward rendering is faster than delayed rendering. The features that can be disabled on each material achieve the greatest performance improvement.

4.1. Design of Sea Water Material and Seabed Terrain Material

The production of the wave material includes setting the material parameters, customizing the rotation node to set the direction of the ocean current, controlling the transparency of the sea according to the Fresnel effect design, ensuring that the water surface has a transparent effect when viewed from the front, and setting the parameters in the MF-Panner function to simulate ocean currents flow special effects. The sea water is rendered differently under different illumination conditions such as global illumination and translucent illumination, the specific derivation process of the wave equation can be referred to this document [13]. Use the GPU particles of the vector field to simulate the post-processing process of ocean waves. Simulate ocean waves with Gerstner model and design multi-layer single wave blueprints to be superimposed on each other to achieve the effect of waves. The sea ice material has a new lighting model MLM-Subsurface, which has a slightly lower rendering quality than the general surface, but its performance is more efficient.

Figure 3. (left)Sea water material structure diagram. (right) Blueprint of polar ocean model.
\[ P(x, y, t) = \left\{ \begin{array}{l} x + \sum_{i=0}^{n} \left( Q_i \times D_i\times x \times \cos(\omega D_i (x, y) + \phi t) \right) \\ y + \sum_{i=0}^{n} \left( Q_i \times D_i\times y \times \cos(\omega D_i (x, y) + \phi t) \right) \\ \sum_{i=0}^{n} (A_i \sin(\omega D_i (x, y)) + \phi t) \end{array} \right. \] (2)

The finished virtual sea water material is as follows:

4.2. Design and Import of Virtual Seabed Terrain

The terrain data uses the SRTM15+ dataset as the original data source. The more DEM data obtained, the more accurate the description of the terrain. However, huge DEM data will have adverse effects on subsequent processing. Terrain structures of different complexity levels need to express different amounts of data points: for areas with flat terrain, less terrain data needs to be described; areas with complex terrain require more terrain data, so the original DEM data needs to be processed [14]. Import the terrain data after noise reduction and interpolation into Global Mapper. Perform three-dimensional expansion in GlobalMapper to obtain a terrain file in hfz format. Set the resolution and data range according to the adaptation range of the host and export the terrain file through WorldMachine to a 16-bit height map file. Design the terrain dynamic loading algorithm based on level streaming to realize dynamic loading and unloading of terrain module.

4.3. Ocean Current Simulation in All-element Polar Ocean Scene

The simulation of polar ocean currents is based on the FVCOM ocean current numerical model. The numerical method adopts the preferential volume method, which combines the advantages of the existing finite difference and finite element models in ocean research, and uses unstructured non-overlapping triangular grids in the horizontal direction. It is able to fit complex boundaries easily for local refinement [15]. For the polar sea area, the boundary conditions are set with historical data and used as the input of a single simulation module. The output of this module is the input of other adjacent modules, and the input of the same module is the output of the adjacent module. Using this iterative feature to design an
ocean current model error convergence algorithm based on the EM algorithm to reduce the model output error and improve the accuracy of the output module.

**Figure 6.** a) Schematic diagram of ocean current flow. b) Flow chart of EM algorithm.

5. **Virtual Underwater Vehicle Simulation Scene**

The digital twin model maps the physical model one-to-one and runs synchronously and dynamically. The parameters of ocean wave motion, the motion state of ocean currents, the spatial motion model of the underwater vehicle, and the rendering of light refraction are incorporated into the virtual underwater vehicle simulation scene to achieve visual simulation and the data running status is unified. Simulate the motion state of underwater vehicle in virtual all-element polar training platform.

5.1. **Ocean Scene Parameters**

After setting the latitude and longitude range of the simulation, adjust the ocean parameters of selected area in real time, including ocean current speed, ocean current direction, wave amplitude, wave speed, wave offset, etc. The interface shown in Fig7.

![Polar Ocean Parameter Interface](image)

**Figure 7.** Polar ocean parameter interface.

5.2. **Simulation and Analysis of Underwater Vehicle in Virtual Polar Ocean Environment**

Design the fixed-track navigation mode and the fixed-speed navigation mode and design the program in UE4 to realize the real-time control of the underwater vehicle, including the underwater vehicle’s ascent, dive, steering, acceleration and other functions.

Import the designed underwater vehicle model into the simulator. The following figures show the dynamic simulation images of the underwater vehicle from different perspectives, showing the attitude information and absolute position of the underwater vehicle in real time. The underwater vehicle
performs dynamic simulation in the virtual polar ocean environment. The status setting options of the underwater vehicle are fixed course and non-fixed course. In the non-fixed heading mode, the heading of the underwater vehicle can be controlled in real time through external equipment.

![Real time sailing of virtual underwater vehicle](image1)
![Real time sailing of virtual underwater vehicle](image2)

**Figure 8.** (left) Real time sailing of virtual underwater vehicle from a front perspective. (right) Real time sailing of virtual underwater vehicle from a side-view perspective.

The simulated ocean current velocity is 15m/s, and the rudder angle is 10°, speed of underwater vehicle is 6kn. phi, theta, and psi represent the roll angle, pitch angle and heading angle of the underwater vehicle.

![Ideal attitude curve of fixed underwater vehicle](image3)
![Attitude simulation curve of fixed-course underwater vehicle in 500s](image4)

**Figure 9.** (left) Ideal attitude curve of fixed underwater vehicle. (right) Attitude simulation curve of fixed-course underwater vehicle in 500s.

![Attitude simulation curve of fixed-course underwater vehicle in 1000s](image5)
![Attitude simulation curve of fixed-course underwater vehicle in 2500s](image6)

**Figure 10.** (left) Attitude simulation curve of fixed-course underwater vehicle in 1000s. (right) Attitude simulation curve of fixed-course underwater vehicle in 2500s.
Within the maximum simulation time of 2500s, the underwater vehicle attitude curve of the virtual simulation training platform always follows the designed underwater vehicle simulation model curve. In condition of the heading is fixed, the maximum of pitch angle error is 0.9906°, the maximum of roll angle error is 2.7388°, the maximum of heading angle error is 2.3477°, that ensure the system can keep the attitude of underwater vehicle stable. The attitude angle error is always less than 3°, The maximum of velocity error is 0.9923m/s, that proof the immunity of simulation system in harsh ocean condition is superior, which can be applied to actual ship operation training. The peak in the corresponding simulation diagram is the attitude tilt that occurs when the underwater vehicle touches the terrain in the simulation scene during the simulation process of the underwater vehicle, and the attitude returns to the normal range in a short time. Through simulation comparison, it can be known that the virtual underwater vehicle can be used in practical training of the underwater vehicle.
6. Conclusion
This paper uses the 6-dof motion model of the underwater vehicle and the modelling software 3DMAX to establish the three-dimensional model of the underwater vehicle. The terrain data is expanded in three dimensions through GlobalMapper and WorldMachine, and it is loaded into the scene through ULevelStreaming dynamic streaming in UE4. The ocean current state is simulated according to the ocean current function, and the dynamic ocean current in the polar region is made based on the FVCOM ocean numerical model. Construct a complete virtual ocean scene and perform real-time control of the underwater vehicle, which simulates the movement of the underwater vehicle over and under water, as well as the situation of collisions. It has been verified that the training effect for real ships can be achieved. On the premise of ensuring the training effect, this system can greatly reduce the risks and costs of real-board polar region training, and has broad application prospects in carrying out real-board virtual training and polar region equipment performance verification.

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