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Design of the unmanned surface vehicle simulation system using unity 3D software

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Abstract
In recent years, technology to build intelligent maritime management systems has been a new trend in maritime countries worldwide. Therefore, intelligent, self-propelled vehicles are increasingly being developed and applied. Unmanned Surface Vehicle (USV) is used to survey and inspect seaport areas, rivers and channels. Building maritime simulation systems helps save costs and is safe during testing. This article presents the steps to create a USV simulation system in Unity 3D software. Next, build a USV controller based on the PID algorithm to control the direction of the device. Simulation results help evaluate technical parameters and test other control algorithms for USVs in the future.

Keywords: USV simulator, USV controller, PID algorithm, USV simulation in Unity 3D

Introduction

An Unmanned Surface Vehicle (USV) is a self-propelled device with many functions, such as integrating Sonar scanning technology to serve hydrological measurements, map underwater geographical objects, and survey dangerous water areas that are difficult to access. In addition, they also support collecting environmental and water quality data in seaport areas, support warnings of pollution levels, and monitor the number of ships entering and exiting the port. Currently, USV is equipped to develop additional smart measuring sensor devices to collect more data and increase accuracy during the survey process.

In the world, many projects are researching and manufacturing USV devices for testing in different environments. Designing software to simulate AUV and USV equipment helps save investment costs and risks when testing. Besides, the simulation environment allows the simulation of physical properties and dynamic equations of objects in cases such as water surface and underwater.

USV integrates intelligent control systems to help accurately control the process of searching for targets for rescue work. This is one of the critical roles in developing today's intelligent maritime traffic management systems. Nanhang Luo, *et al.* designed a USV controller with a prediction algorithm before control. Several factors, such as wind, currents and weather turbulence, are inputs for prediction during movement [1]. In the study [2], the authors Xiaofeng Xu, *et al.* presented a method to self-restore the balanced position inside the USV while tilting outside to help ensure the stability of the cargo during transportation. Using self-propelled vessels is a new shipping trend in the world. However, this evolutionary change poses serious problems regarding compliance with the International Regulations for the Prevention of Collisions at Sea 1972 (COLREGs).

Based on the comparison between the two methods, visual observation and using mechanical systems in research [3], some things need to be revised. In the work [4, 6], the authors used the firefly algorithm (FA) introduced into the ADRC algorithm to realize the self-setting of nonlinear feedback control law parameters.

In Vietnam, projects related to self-propelled ships have not been developed. Some research has built a maritime simulation system, ROV and AUV simulation based on the Unity 3D platform [7]. However, autonomous ship simulation and in-depth research manufacturing have not been applied in education and training. Manufacturing real- models have high costs, while building models on simulation software still meets current object research requirements [8, 10]. For this reason, the authors constructed a 3D model of the USV object in a 3D virtual environment. Building different simulation scenarios and control objects

through the PID controller in Matlab software.
The rest of the paper is described in Section 2, dynamic equations and PID controller for direction. Section 3 proposes building a 3D USV model in Unity 3D software and a controller on Matlab. Section 4 simulation results. Conclusions and future work are summarized in Section 5.

3D dynamic model and USV control algorithm

Modelling dynamics and environmental disturbances

Simulating the operation of the device requires the dynamic equations of a real ship, then through the C# programming language to model the objects in the simulation. Based on the ship's technical records, the authors simulated a real USV object using a 3D model and a 6-degree-of-freedom equation system. This study assumes that the ship model has a propeller and gear. The 6 degrees of freedom equation system that can be applied to USV is presented as follows [11]:

$$\dot{\eta} = J(\eta)\upsilon$$
$$M\dot{\upsilon} + C(\upsilon)\upsilon + D(\upsilon) + G\eta = \tau_E + \tau \quad (1)$$

where: $\eta = [x, y, z, \phi, \theta, \psi]^T$ is the position and direction vector; $J(\eta)$ is the transformation matrix, $\upsilon = [u, v, \omega, p, q, r]^T$ is the linear velocity vector and angular velocity in the coordinate system attached to the ship's hull; M and C are the inertia matrix and Coriolis matrix and centripetal force taking into account the influence of hydrodynamic forces and moments, G is a constant matrix, is the damping matrix, and $D(\upsilon)$ are the forces and moments due to environmental disturbances and the propulsion system, respectively.
Weather factors affect the ship's direction, speed and dynamics. Therefore, in equation (1), the environmental disturbance moment includes the following main components: wind, waves and currents. Re-express equation (1) as follows:

$$\tau = \tau_{waves} + \tau_{wind} + \tau_{currents} \quad (2)$$

With $\tau_{currents}, \tau_{waves}, \tau_{wind}$ the forces and moments of the current, waves and wind acting on the ship, respectively. These components have been explicitly presented in Fossen's document [12].
Meanwhile, the forces and moments of the propulsion system in equation (1) that can be applied to the type of ship under study are presented as follows [11]:

$$\tau = [\tau_U, \tau_V, 0, 0, 0, \tau_R]^T \quad (3)$$

With τ_U is the force vector acting on the ship along the longitudinal axis, including two components: the thrust of the propeller and the force caused by the rudder. The force τ_V applied to the rudder will influence the ship along the horizontal axis and τ_R is torque to turn the ship.

Building a PID controller for USV

Several control algorithms for USVs, such as PID algorithm, optimization algorithm, GA, FA and PSO, are used to control the direction of the USV. Besides, these algorithms are widely applied in real projects [13]. Two input and output signals are included: the input signal of the USV $\psi_d(t)$ is set as the direction angle to the target, and the controller's output signal is the actual direction angle $\psi(t)$. The input signal, combined with the deviation $e(t) = \psi_d(t) - \psi(t)$, and output signal is set to control the steering angle of the USV, as shown in Fig 1.

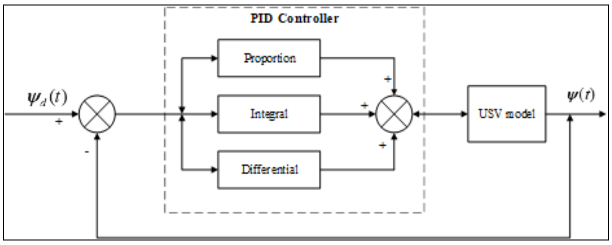

Fig 1: USV PID controller

The controller in Fig 1 consists of three segments: proportional, integral and differential. The relationship between the input signal and the output signal is expressed by formula (4) [2, 15]:

$$\delta(t) = Kp\left(e(t) + \frac{1}{T_i}\int_0^t e(t)dt + T_d\frac{de(t)}{dt}\right) \quad (4)$$

Where: the deviation between the target direction angle and the actual direction angle; refers to the proportional coefficient, the integral time constant, and the differential time constant. To facilitate the installation process, equation (4) is rewritten as follows [2]:

$$\delta(t) = K_p e(t) + K_i\int_0^t e(t)dt + K_d\frac{de(t)}{dt} \quad (5)$$

Building USV in Unity 3D

Design of USV model

Next, the authors build a 3D USV model based on Blender and 3DS Max software. These are programmer-friendly graphics and 3D modelling software, easy to set up and install all parameters. From the technical specifications of Shanghai Huace Navigation's APACHE 6 shown in Table 1, the authors have constructed the following parts [14, 16]:

Table 1: Parameters of APACHE 6

No.	Parameters	APACHE 6
1	Fuction	Surveying
2	Communications	UHF, 900 MHz/ 5.0GHz, 1.5 km upto 1 km
3	Size (L x W x H)	1.8 m*0.55 m *0.25 m, 15 kg
4	Maximum speed	3.5m/s
5	Power	4 x 18.5v 40Ah battery lipo
6	Navigation Mode	Auto/Manual
7	Lidar Laser Sensor	Frame Rate 5-20Hz

Fig 2 describes the structure of the USV device's surface with essential systems such as rudders and thrusters.

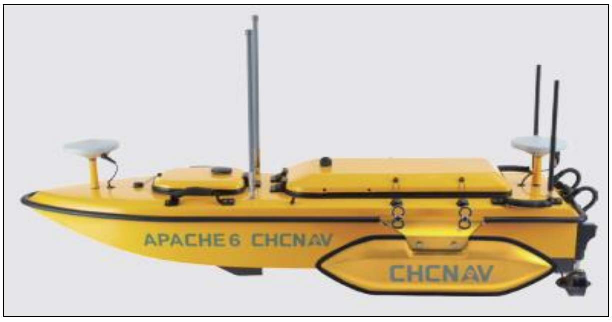

Fig 2: USV APACHE 6 MODEL

Environmental interference effects

As in section 2.1, equation (2) is related to environmental disturbances such as wind and waves, which have an essential influence when controlling USV. Potential distribution of average wave height by month at offshore island stations Bach Long Vy, Ly Son, Con Co, Phu Quy, Tho Chu, and Phu Quoc shows that in the winter months (October to January), Except for Tho Chu and Phu Quoc, which have high wave heights, causing difficulties in rescue work. Figure 4 shows the wave heights during the measured months [12].

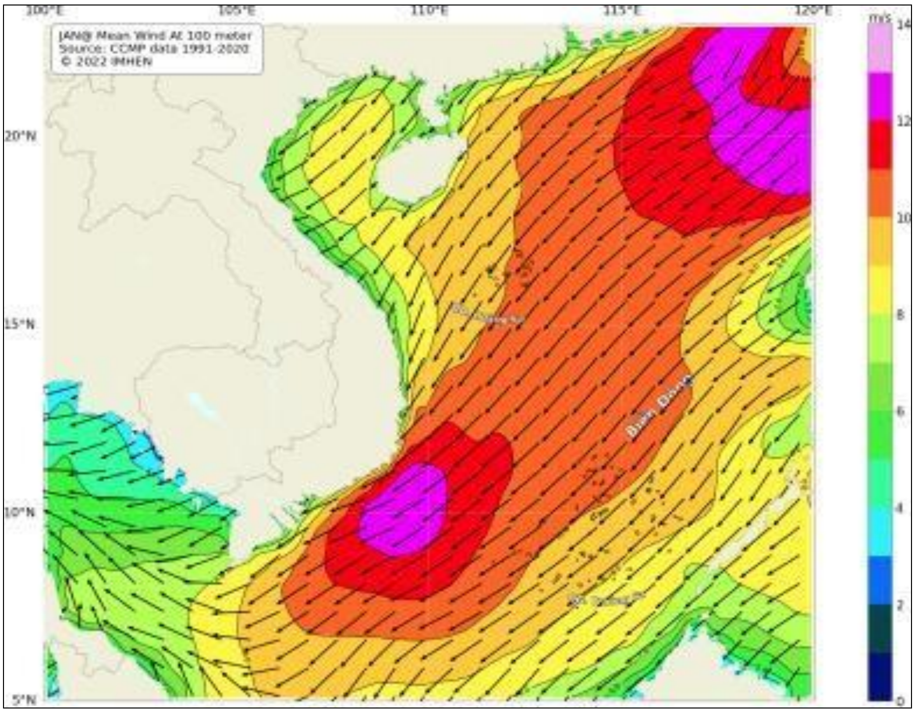

Fig 3: Map showing wind speed in the East Sea area

In addition, wave factors such as average wave height, wave movement speed and wave appearance time are also considered by the authors based on the simulation.

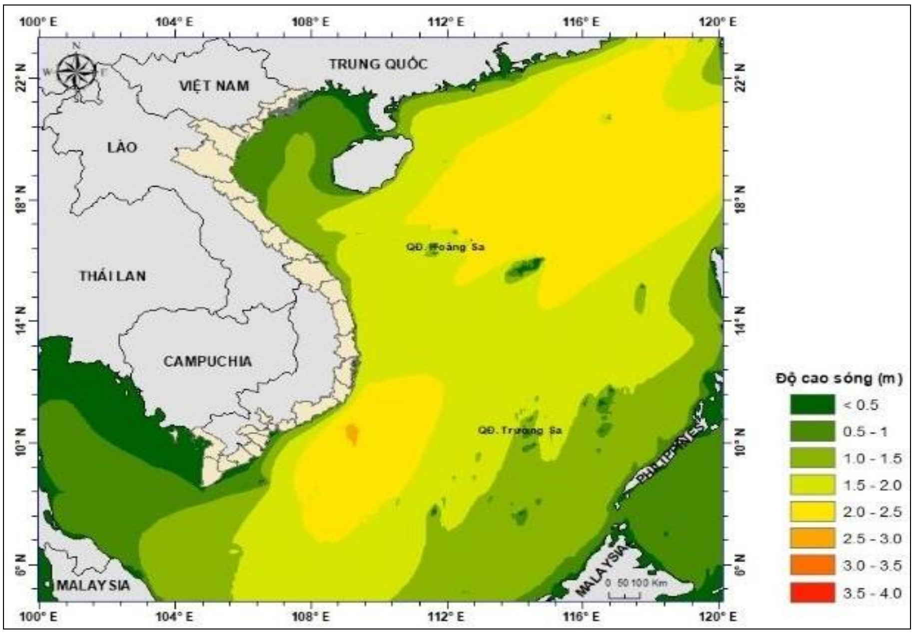

Fig 4: Map showing wave height in the East Sea area

PID controller for USV

From equation (5), the author builds a PID controller model combined with author Fossen's model. The output signal will respond to the PID controller to determine the steering angle. Parameters of mass, speed, current angle and thrust of the USV are based on Table 1. Parameters for the controller $K_p = 300$, $T_d = 1.2$ and $T_i = 11$ are set in the PID tracking controller block.

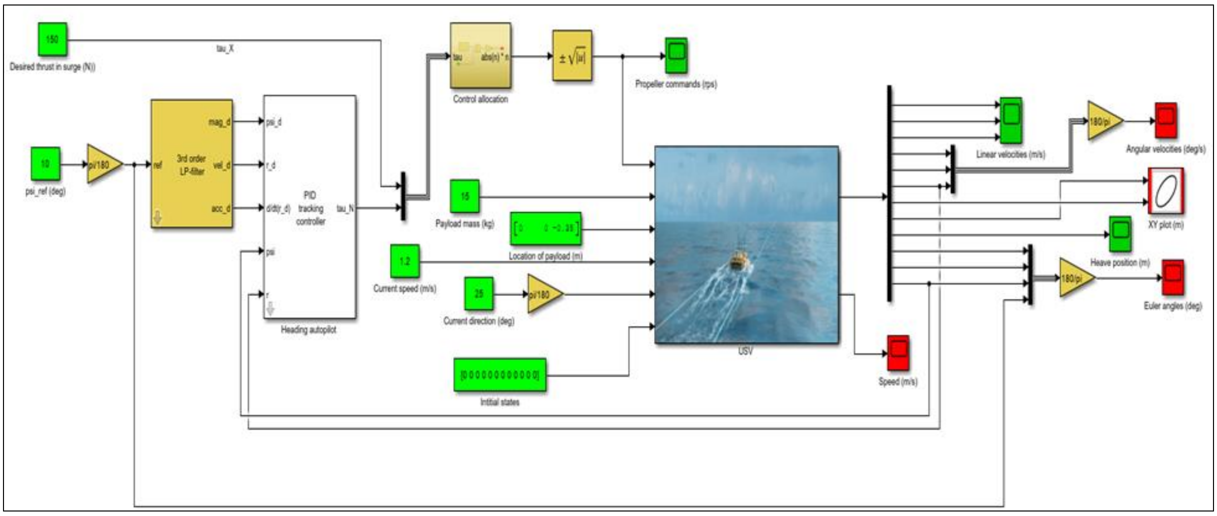

Fig 5: PID controller in Matlab

Simulation results

Test scenarios

To simulate the USV object, from the kinematic equations of the USV in section 2, the author converts the buoyant forces and ocean current disturbances based on the C# programming language to put into 3D space [13].

From equations (1), (2), (3), then create modules to enter the object.

- **Ocean Renderer. CS:** used to create wave surfaces, some typical waves.
- **Ocean Shape FFT. CS:** used to adjust wave level and direction.
- **Ocean Debug GUI. CS:** creates a wave-level observation window.
- **Ocean Depth Renderer. CS:** used to adjust the direction and level of ocean currents.

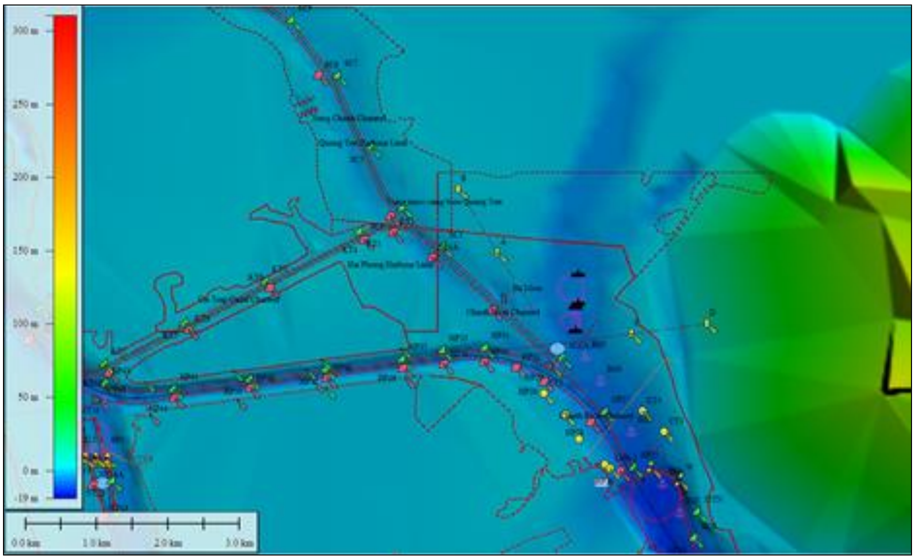

Fig 6: Topography of the simulation area

Next, the thrust and rudder forces follow equations (1) and (2) to create force modules such as ThrustersEngine.cs, RudderUSV.cs, etc. Environmental factors are also included in the section. Simulation software through external force modules acting according to equation (4) is Envirskyrendering. cs, Camera Rotation. cs.

Based on actual data in the Hai Phong port area, Vietnam, the author's assumed survey coordinates for several underground pipelines are to be able to control access equipment. First, the author chose the simulation location in the Gulf of Tonkin Sea area with coordinates 20º5962 and 106º8390. Figure 7 depicts the USV simulation system operating in the survey area.

Fig 8: USV simulation system

Result

Based on factors affecting environmental interference from Section 2, the authors changed different environmental levels to consider the impact of weather on the operation of the device. Figure 9 shows the USV model testing with environmental impact considering the marine buoy incident.

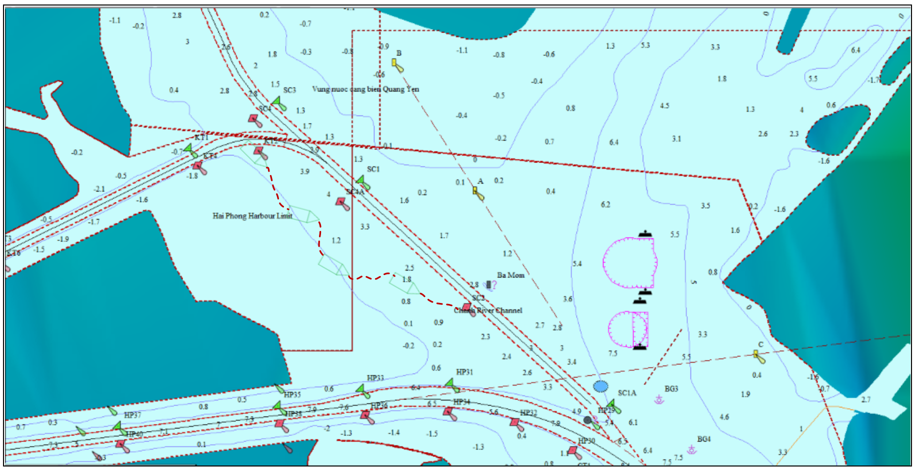

Fig 9: USV survey route.

Table 2: Coordinates of USV movement

No.	Name	Realistic coordinates	Simulation coordinates	Speed	Realistic Heading	Simulation Heading
1	*TA1*	20°55.1468'N 106°86.0365'E	20°55.1452'N 106°86.0474'E	1.15m/s	60°	59.2 °
2	*TA2*	20°56.0234'N 106°81.7542'E	20°56.06747'N 106°81.3652'E	1.05m/s	65°	64.2 °
3	*TA3*	20°58.4756'N 106°83.0644'E	20°58.4454'N 106°83.0345'E	0.84 m/s	80°	82.2 °
4	*TA4*	20°58.0244'N 106°85.05744'E	20°59.0472'N 106°85.0677'E	0.91m/s	90°	90.2 °

The above results show that the operations of the USV simulation software meet the requirements when simulating objects. The conditions set for testing were met.

Next, Matlab software's PID controller simulation results include speed and direction, as shown in Figure 10.

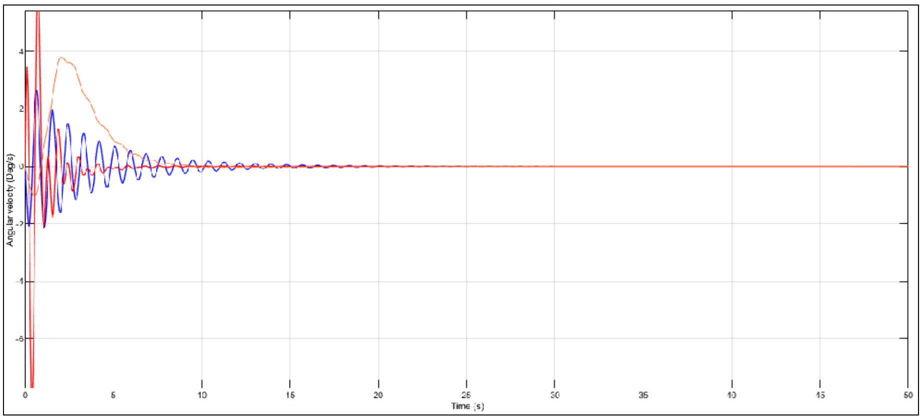

Fig 10: USV angular velocity graph

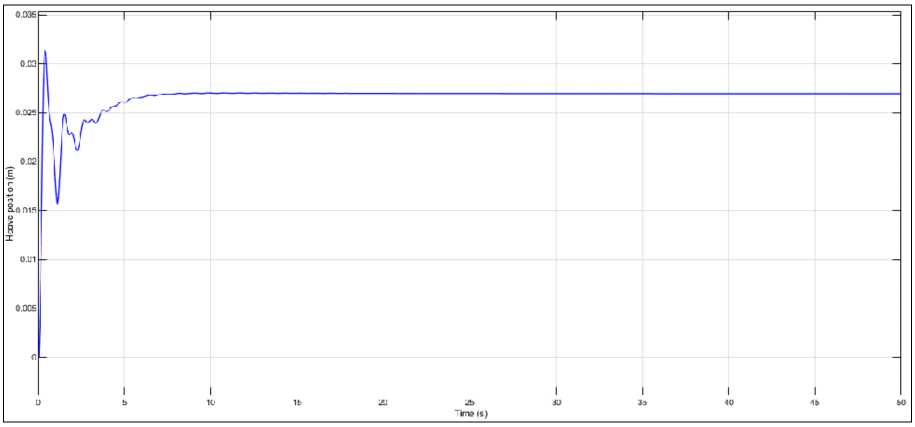

Fig 11: USV Heave position graph

During simulation, USV uses the PID algorithm to control the object. However, because the controller adapts to constantly changing weather conditions, it leads to significant errors, as shown in Table 2. The simulation results achieve about 75% of the actual requirements.

Conclusion

This article has presented the method of designing USV simulation software. Steps to build 3D objects and environments on Unity 3D software. Apply a PID controller to control the object's direction and study the device's essential operating characteristics in the underwater environment. However, the USV model has many parameters to investigate, so the system needs to develop and integrate many parameters to calibrate accordingly in the future. Data on sea depth and topographic features need to be better developed. Thereby helping to improve scientific research capacity and gradually access modern technology worldwide.

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