An Air-Water Integrated Auxiliary Navigation System for Complex Waters

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Abstract. The auxiliary navigation device described in this paper can effectively make up for the shortcomings of the existing navigation mode. It has designed a targeted detection module for various unstable factors in complex waters, such as large ship flow, frequent water level changes, low visibility, hidden reefs and floating ice. With the advantages of both water and air, excellent navigation performance and all-round detection means on water and underwater, the device can achieve excellent auxiliary pilot effect. In addition, the device has the advantages of low operation difficulty, short training period, high safety, good social and economic benefits, which is suitable for wide range promotion in navigation areas such as ports, inland rivers and coastal areas.

1. Research Background
As early as 2001, China promulgated the Regulations on Navigation Management of Ships, which stipulate that ships should apply for navigation when navigating, berthing, leaving or moving in the navigation area. Other countries and regions have similar provisions, and the importance and necessity of navigation work is self-evident. The current navigation modes can be summarized as two types. One is the traditional navigation mode in which pilots board the ship to guide the ship alone. The other is the new navigation mode in which pilots are assisted with unmanned equipment [1]. However, the two modes have the following shortcomings: single means to obtain navigation information, insufficient performance of auxiliary navigation equipment, and high cost. Therefore, an air-water integrated auxiliary navigation system suitable for complex waters is presented to make up for the above shortcomings.

2. Design principles
2.1. Overall shape design
An air-water integrated auxiliary navigation device (hereinafter referred to as auxiliary navigation device) described in this paper is suitable for complex waters. It consists of 2 front and back symmetrical drums which can utilize Magnus effect [2], a flat ship type which can utilize ground effect [3], 8 cabins including 6 orange ones and 2 transparent ones, 2 culvert fans located in the middle, and modules for detecting water surface and underwater. The overall shape of the auxiliary navigation device is shown in Figure 1, and the relevant parameters are shown in Table 1.
2.2. Working principle of water-air integration
Auxiliary navigation device includes water navigation mode and air navigation mode. When navigating on water, the front culvert closes, and the rear culvert rotates at 90 degrees and then advances horizontally. This structure is controlled by two large-torque electronic steering machines (20kg) of the same size in parallel, which ensures the stability and feasibility of the structure. The rotation status of the culvert is illustrated in Figure 2 and Figure 3.

2.3. Principles of remote control
The control system of the auxiliary navigation device adopts 2.4GHz wireless technology, including the receiving end inside the device and the controlling end controlled by the user. It runs in a simple and reliable mode of "remote control + display + receiver", which has lower waterproof requirement and simpler and more reliable structure than the "development board + flight control" mode. The mechanical rotation of the auxiliary navigation device depends on the different specification of the electronic rudder, and the working strength of the culvert fan depends on the installed electronic speed regulator. The simple and reliable control mode makes the device easy to operate, maintain and repair after long and frequent auxiliary navigation work. The working sketch of remote control is shown in Figure 4.
3. Validation analysis

3.1. Simulation analysis of the overall flow field

The flattened design of the auxiliary navigation device can help maintain high-speed navigation close to the water surface by using the ground effect, and quickly capture large areas of underwater auxiliary navigation information. The overall flow field is simulated by applying 72 km/h (i.e. 20 m/s, 120% of the maximum navigation speed) air flow field to the simplified model of the auxiliary pilot. The flow field distribution is shown in Figure 5. According to the simulation analysis results, the air flow velocity distribution at the tail of the auxiliary pilot decreases by a small and more uniform margin, that is, the flat overall structure can make use of the ground effect while having a better drag reduction effect.

3.2. Analysis and verification of water surface detection module

The water surface detection module integrates a high-definition camera, an infrared camera, a thermographic camera and an ultrasonic range finder, all of which are located in the transparent cabin below and middle of the auxiliary navigation device. The high-definition cameras are used for daytime shooting in general, infrared cameras and thermal imaging cameras are used for navigation aids in complex conditions, and ultrasonic ranging is used for obstacle identification and ranging that is difficult to distinguish with the naked eye. The module can detect the navigation conditions under complex weather conditions such as heavy fog more accurately. The comparison of defogging effect of water detection module is shown in Figure 6.
3.3. Analysis and verification of underwater detection module

The module consists of an underwater phase laser range finder and a two-degree-of-freedom high-definition camera, both located in the transparent cabin at the bottom right of the auxiliary navigation device. The high-definition camera is used to take real-time underwater scene, and the underwater phase laser range finder is used to measure the distance indirectly by phase change [4]. The principle is as follows. Firstly, the luminous intensity of the laser source is continuously modulated by high-frequency sine signal, and then the phase delay and the wavelength of the modulated laser signal are measured after the modulated laser signal reciprocates the target and the laser sending point once. The distance represented by this phase delay is calculated. Its mathematical expression is:

\[ t = \frac{\omega}{2\pi f} = \frac{2\pi f + \Delta \phi}{2\pi f} \]

\[ S = \frac{1}{2} \cdot \frac{c}{f} = \frac{1}{2} \cdot \frac{c}{f} (N + \frac{\Delta \phi}{2\pi}) \]

In the two formulas: \( t \) is the transmission time of laser; \( \omega \) is the phase difference between the change of laser output and reception; \( f \) is the frequency of modulated broad wave; \( \Delta \phi \) is the phase number of less than one wavelength; \( S \) is the distance between the laser emission point and the target to be measured; \( c \) is the speed of light; \( N \) is the number of complete wavelengths of laser transmission. The working diagram of the underwater detection module is shown in Figure 7.

4. Conclusion

The auxiliary navigation device described in this paper can effectively make up for the shortcomings of the existing navigation mode. It has designed a targeted detection module for various unstable factors in complex waters, such as large ship flow, frequent water level changes, low visibility, hidden reefs and floating ice. With the advantages of both water and air, excellent navigation performance and all-round detection means on water and underwater, the device can achieve excellent auxiliary pilot effect. In addition, the device has the advantages of low operation difficulty, short training period, high safety,
good social and economic benefits, which is suitable for wide range promotion in navigation areas such as ports, inland rivers and coastal areas.

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