Study of attitude adjustment and positioning methods for navigational vehicles

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Abstract. In recent years, with the development and progress of science and technology, all kinds of water and underwater vehicles have been gradually integrated into all kinds of commercial and civil marine operations, which are self-energy, autonomous control, flexible and convenient, and can be widely used in fish monitoring, population migration, environmental protection, early warning, underwater survey, etc., while better attitude adjustment and positioning methods can effectively promote the promotion of all kinds of submersible vehicles.

Keywords: submersible, attitude adjustment, positioning.

1. Background of the study
Since the General Secretary first put forward the strategy of strengthening the country by the sea at the 18th National Congress, there has been an increase in the attention paid to maritime jobs and maritime workers throughout China, as well as a strengthening of the supervision of maritime offences. At present, there are various emergency measures in place to deal with accidents at sea, but these measures have certain shortcomings and deficiencies in terms of the current development status, and if an attitude adjustment method and positioning method can be designed for various types of above and underwater vehicles, they can be effectively avoided. Based on this, this paper has studied and researched the common attitude adjustment methods and positioning studies of existing marine submersibles (Figure 1).

Figure 1. Common marine craft
2. Current status of domestic and international research

2.1. Navigator attitude adjustment
Since the 1990s, with the maturation of related technologies, underwater vehicles have been valued by various countries and have developed rapidly. The USA, as one of the first countries to attach importance to unmanned vehicles and currently a technological leader, has positioned itself for a more complete development of the overall manufacturing philosophy of the vehicle (Figure 2).

![Figure 2. US Submersible Unmanned Aerial Vehicle Development Roadmap](image)

The United States is expected to have at least 2,000 to 4,000 UUVs by 2020, and more than a dozen countries around the world have plans to research UUVs, while Germany has developed a new type of UUV and carried out demonstration activities; France has successfully developed several types of multifunctional anti-mine UUVs with advanced performance, which have been exported to dozens of countries; and Saab of Sweden has also worked on UUVs in recent years with a number of results. The Swedish company Saab has also been working on the UUV in recent years and has a number of achievements.

In China, China's first underwater robot, the Sea Man No.1, was successfully launched in 1985, with Jiang Xinsong as chief designer, and completed sea trials the following year. In 1994, the Shenyang Institute of Automation successfully developed the 'Explorer' cableless underwater robot (AUV). This was a leap from 'cable' to 'cableless' and was the first Chinese underwater robot to reach the deep sea. In recent years, a new underwater glider, the Seawing, developed entirely independently by China, has completed a large depth dive observation mission and recovered safely, breaking the world record for maximum dive depth. Today, our self-developed underwater robotics technology is among the world's best, but according to foreign analysts, China still faces some difficulties at this stage in developing unmanned vehicles, with battery power remaining the main bottleneck.
2.2. Positioning of the navigator
At present, the core of the mainstream positioning system for common navigators is a ship positioning system based on a navigation receiver, which gives the position and speed of the navigator in real time. Its application area is more widespread as it is cheaper than other receiving bodies. Such receivers generally use C/A code pseudo-distance measurement, with low single-point real-time positioning accuracy, typically ±25mm, with SA influence ±100mm. The emerging mainstream is now more accurate geodetic measurement receiver loads and navigation, geodetic line receivers are also divided into static (single frequency) receivers and dynamic (dual frequency) receivers, or RTK, depending on use and accuracy.

Table 1. Determination of the accuracy of various types of receivers

|               | Dynamic horizontal accuracy | Dynamic vertical accuracy | Static horizontal accuracy | Static vertical accuracy |
|---------------|----------------------------|---------------------------|---------------------------|-------------------------|
| Huace Navigation | 10mm+1ppm                  | 20mm+1ppm                 | 5mm+1ppm                  | 10mm+1ppm               |
| Trimble       | 10mm+1ppm                  | 20mm+1ppm                 | 5mm+0.5ppm                | 10mm+0.5ppm             |
| Topcon        | 10mm+1ppm                  | 15mm+1ppm                 | 3mm+0.5ppm                | 5mm+0.5ppm              |
| South Surveying & Mapping Instrument | 2cm+1ppm                | 3cm+1ppm                  | 5mm+0.5ppm                | 10mm+1ppm               |

Table 1 is the current mainstream enterprise emerging measurement receiver accuracy, compared with the navigation receiver, the accuracy is also greatly improved, the price compared with the navigation receiver, and did not produce a higher improvement. Therefore, the current research direction and research trend is to improve and enhance the existing measurement receiver, such as improving the wireless communication transmission speed and information transmission accuracy.

3. Optimised design

3.1. Posture change approach
Under normal circumstances it is not necessary to change the attitude of the vessel, and the only example of the current method of changing the attitude of the vessel is the US floating instrument platform. In the normal state, the submersible is submerged, its buoyancy and gravity are equal and in the same line, when the first weight falls, the buoyancy of the submersible decreases and the centre of gravity moves backwards, but the gravity decreases more, thus forming a rotational moment, and the buoyancy is greater than the gravity, the ship floats and rotates (as shown in Figure 3). This method is essentially the same as the method of changing ballast water, but there are major differences in the method and it is much faster.
Figure 3. Mechanics of attitude change

3.2. Shake reduction module

The function of the submersible requires that the submersible must change its attitude and stabilise quickly in a short period of time, the shorter the time required for the whole process the better. The shortest possible time is required for the whole process. In order to keep the de-shaking time as short as possible, the project has selected the most suitable de-shaking principle for the working environment of the submersible, based on the existing de-shaking methods and de-shaking devices, and has designed the corresponding new de-shaking devices. There are the following.

A: Head airbag - transplanting the idea of airbags for cars to submersibles, adding multiple layers of pop-up airbags to the head of the submersibles, using chemical reactions or compression cylinders to inflate and expand the airbags (Figure 4), the airbags can be fixed to the head of the submersibles, providing buoyancy on the one hand, and increasing the contact area between the head airbags and the water surface on the other, to achieve rocking reduction.

B: Bi-directional bilge keel - an improvement on the existing bilge keel to create an adjustable bilge keel suitable for the operating conditions of the submersible. The bilge keel is based on the principle of disturbing the flow field to reduce rocking, which is most effective at zero speed and is very suitable for the operating conditions of the submersible. The bilge keel is not significantly different from the normal bilge keel in the flat floating state, but when the submersible is upright, the bilge keel is also rotated by 90° (Figure 5), thus increasing the perturbation of the flow field in this case and allowing it to be used to maximum effect in different states.

Figure 4. Schematic diagram of the first airbag deployment

Figure 5. Bilge keel before (right) and after (left) rotation
C: Umbrella frame plate - this device is analogous to the structure of an umbrella, combined with the shape characteristics of the submersible, designed to reduce the shaking device, under normal conditions wrapped outside the submersible, does not affect the normal navigation of the submersible, when the submersible is upright, the wrapped umbrella frame plate like an umbrella propped open and stuck (Figure 6, Figure 7), the principle is the same as the bilge keel.

Figure 6. Top view of the umbrella stands plate  Figure 7. Detail of the umbrella stand plate

3.3. UWB positioning module
In the study of positioning technology for navigators, we have focused on UWB technology, whose main advantages are: low power consumption, insensitivity to channel fading (e.g., multipath, non-visual range and other channels), high interference immunity, no interference with other devices in the same environment, high penetration (able to position in an environment that penetrates a brick wall), high positioning accuracy and positioning precision.

In contrast, the UWB positioning principle is that the technology uses TDOA (Time Difference of Arrival principle), which uses UWB technology to measure the time difference in radio signal propagation between positioning tags relative to two different positioning base stations, thus deriving the distance of the positioning tag relative to four groups of positioning base stations (assuming 1# and 2# as the first group, 2# and 3# as the second group, 3# and 4# as the third group, and 4# and 1# as the fourth group) of the distance difference.

\[
\begin{align*}
    d_{1,12} &= r_{i,1} - r_{i,2} \\
    d_{i,23} &= r_{i,2} - r_{i,3} \\
    d_{i,34} &= r_{i,3} - r_{i,4} \\
    d_{i,41} &= r_{i,4} - r_{i,1}
\end{align*}
\]

where \(d_{i,12}\) to \(d_{i,41}\) is the distance difference of the positioning tag measured by the UWB technology relative to the four groups of base stations.

\[
\begin{align*}
    d_{1,12} &= \sqrt{(x_1 - x_i)^2 + (y_1 - y_i)^2 + (z_1 - z_i)^2} - \sqrt{(x_2 - x_i)^2 + (y_2 - y_i)^2 + (z_2 - z_i)^2} \\
    d_{i,23} &= \sqrt{(x_2 - x_i)^2 + (y_2 - y_i)^2 + (z_2 - z_i)^2} - \sqrt{(x_3 - x_i)^2 + (y_3 - y_i)^2 + (z_3 - z_i)^2} \\
    d_{i,34} &= \sqrt{(x_3 - x_i)^2 + (y_3 - y_i)^2 + (z_3 - z_i)^2} - \sqrt{(x_4 - x_i)^2 + (y_4 - y_i)^2 + (z_4 - z_i)^2} \\
    d_{i,41} &= \sqrt{(x_4 - x_i)^2 + (y_4 - y_i)^2 + (z_4 - z_i)^2} - \sqrt{(x_1 - x_i)^2 + (y_1 - y_i)^2 + (z_1 - z_i)^2}
\end{align*}
\]

The specific coordinates of the positioning tag can be derived immediately by combining the above equations.

It is important to note that when the number of base stations is insufficient, 3D coordinate positioning is not possible. When the number of base stations is only one, only distance measurements can be made, when the number of base stations is two, 2D coordinate measurements can be made, when the number of base stations is three or more, 3D coordinate measurements can be made, and the more the number of base stations, the more accurate the measurement results.

4. Summary
In this paper, we have studied and researched the attitude adjustment methods and positioning methods of water and underwater vehicles in recent years, and, after reviewing a large number of references, we
have proposed an optimized idea and design to enable submerged vehicles to change their attitude freely, and at the same time, we have made our own understanding and elaboration on the positioning methods of existing vehicles. It is hoped that further research and exploration of above and below water vehicles will be possible in subsequent research.

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References
[1] Wang Yun, Lv Haofu. A review of the development of marine jet propulsion technology [J]. Ship Science and Technology, 2008 (3): 31 - 33.
[2] Li Xiaohui, Zhu Yuquan, Nie Songlin. A review of research on the development of water jet propulsion [J]. Hydraulics and Pneumatics, 2007 (7): 3 - 4.
[3] Liu Zhu, Meng Fanli. Development of water jet propulsion technology for ships [J]. Marine Technology, 2004 (4): 42 - 43.
[4] Campbell S, Naeem W, Irwin G. A review on improving the autonomy of unmanned surface vehicles through intelligent collision avoidance manoeuvres. Annual Reviews in Control, 2012, 36: 267 - 283.
[5] Convair, ConvairFlyingSubmarineReport, 1962 (ConvairReportHP-62-016).
[6] DARPA.BroadAgencyAnnouncement:SubmersibleAircraft.DARP.