Research on the Realization and Technological Innovation of Intelligent Unmanned Survey Vessel System

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Abstract: As a core piece of equipment for modern hydrographic surveying and monitoring, the intelligent unmanned survey vessel is gradually transforming traditional hydrological measurement and marine investigation methods with its autonomous operation, high-precision perception, and strong environmental adaptability. The technical path centered on "Beidou empowerment + AI-driven + bionic innovation" provides a systematic solution for the intelligent breakthrough of unmanned survey vessels. This study focuses on the "Beidou Smart Expansion" project, analyzing its key technologies such as multi-source fusion positioning, intelligent perception and control, and bionic stability design, and exploring its application potential in complex water terrain surveying, hydrological data collection, emergency search and rescue, and other scenarios. Research shows that by integrating Beidou high-precision positioning, artificial intelligence algorithms, and bionic structure design, the operational accuracy, autonomy, and environmental adaptability of the survey vessel can be significantly enhanced, meeting the growing demands of smart water conservancy, marine development, and environmental protection. This paper further proposes strategic suggestions from the perspectives of product development and market promotion to promote the industrialization and large-scale application of such technical equipment.

Keywords: Intelligent unmanned survey vessel; Beidou navigation; Artificial intelligence

1. The technical foundation and research and development status of intelligent unmanned survey vessels

The intelligent unmanned survey vessel is a composite system integrating multiple technologies such as navigation and positioning, environmental perception, autonomous control, and platform design. "Beidou Empowerment" is manifested in the utilization of the high-precision positioning, timing, and short message communication capabilities provided by the Beidou Satellite Navigation System to achieve real-time pose determination and remote monitoring of the vessel, especially in areas without network coverage, where it plays an irreplaceable role. "AI-driven" refers to the endowment of the vessel with autonomous obstacle avoidance, intelligent task execution, and data analysis capabilities through artificial intelligence algorithms such as image recognition, path planning, and intelligent data processing, significantly reducing the reliance on manual operations. "Bionic Innovation" involves optimizing the vessel's fluid shape and stability design by drawing on the structures and movement mechanisms of natural organisms, enhancing its navigation performance and load adaptability in complex wave conditions. The deep integration of these three technologies constitutes the core competitiveness of the new generation of unmanned survey vessels.

Currently, the research and development of unmanned survey vessels in China has evolved from initial remote control operations to highly autonomous and multi-functional integration. However, in practical applications, there are still many technical bottlenecks. High-precision positioning is prone to failure in waters with obstructions such as bridges and canyons; the real-time performance and accuracy of obstacle perception in complex dynamic environments are insufficient; and the stability of small and medium-sized survey vessels in wind and waves is poor, affecting the quality of data collection. At the same time, issues such as low system integration, limited intelligence level, and high costs have restricted their wider application in various scenarios.

This project, initiated by a student team, integrates professional courses and school platforms, and based on the industry background and the wave of high-tech development, the project team has carried out systematic technical research and development to address the above-mentioned pain points. In terms of positioning, it innovatively integrates Beidou/GNSS RTK with inertial navigation to ensure uninterrupted positioning in obstructed environments; in perception, it builds a multi-sensor fusion system mainly based on 77GHz millimeter-wave radar, achieving an obstacle avoidance rate of over 90% in complex waters; in platform design, it adopts a bionic M-shaped hull and active roll reduction design, achieving a wave resistance

capability of up to level 6. The project has been certified by the National Marine Technology Center and has resulted in multiple patents and research papers, demonstrating the effectiveness of "industry-university-research-application" collaborative innovation.

2. Market demand and industry application analysis

With the advancement of national strategies such as the marine power strategy and the smart water conservancy strategy, as well as the increasing demand for digital and precise water management, the market acceptance of intelligent unmanned survey vessels has rapidly increased. Traditional manual survey methods have limitations such as low efficiency, high risk, and difficulty in coverage, especially in dangerous waters and long-term monitoring tasks. Unmanned vessels, with their advantages of safety, efficiency, and low cost, are gradually becoming the preferred tools in fields such as hydrographic surveying, environmental monitoring, engineering exploration, and emergency search and rescue.

According to industry analysis, the market size of unmanned vessels in China reached 2.82 billion yuan in 2024, with a compound annual growth rate exceeding 70%, among which unmanned survey vessels hold a significant share. The main drivers of market growth include the procurement demands of various levels of hydrological stations and natural resource departments for automated surveying equipment; the demand for efficient surveying tools in major water conservancy projects and coastal zone projects; and the need for intelligent upgrades in water surface monitoring and inspection by environmental protection, emergency response, and cultural tourism departments. In terms of regional distribution, the demand is most concentrated in economically developed regions with heavy water management tasks, such as the Guangdong-Hong Kong-Macao Greater Bay Area, the Yangtze River Delta, and the Yangtze River Economic Belt. Meanwhile, regions with accelerated infrastructure construction, such as the western regions, have broad future market potential.

Users from different industries have varying functional requirements for unmanned survey vessels. Hydrographic surveying departments emphasize measurement accuracy, data reliability, and adaptability to complex water flows; environmental protection agencies focus on multi-parameter synchronous monitoring capabilities and the convenience of long-term deployment; and engineering enterprises value operational efficiency, cost, and equipment portability. Currently, users are not only satisfied with basic remote control and positioning functions but also expect highly intelligent products with autonomous operation, intelligent obstacle avoidance, breakpoint continuation, and real-time data processing capabilities.

3. Product development suggestions and promotion strategies

In terms of market competition, a number of domestic unmanned vessel manufacturing and solution enterprises have emerged, offering products at different levels and price points. The competition focus is gradually shifting from hardware parameters to system intelligence, ecological compatibility, and service integrity. Some enterprises, relying on the technological accumulation of universities and research institutions, have formed advantages in specific technical points (such as hybrid positioning and intelligent algorithms); others, leveraging engineering experience and market channels, provide overall solutions. Student innovation projects like "Beidou Zhituo", with their high degree of technology integration, good cost control, and alignment with actual scenarios, have demonstrated differentiated competitiveness in niche markets and verified the feasibility of their products and business models through pilot cooperation with hydrological units and environmental protection agencies. Continuously optimize the multi-source fusion positioning algorithm to enhance accuracy and reliability in extreme occlusion and dynamic environments. Develop a new generation of intelligent perception modules that integrate optical, acoustic, and radar data to achieve integrated identification of underwater terrain, surface obstacles, and water quality parameters. Create a remote simulation and control platform based on digital twins to reduce operation thresholds and training costs.

Develop a series of products tailored to different user and task requirements, such as lightweight models (≤10kg) for inspection and education, heavy-duty models for deep-sea mapping, and cluster systems for large-scale synchronous monitoring. Expand the application ecosystem by developing specialized function kits and data analysis services for scenarios such as reservoir safety, river and lake "clearing four disorders", water emergency rescue, and aquaculture monitoring.

Promote the standardization of hardware interfaces and the open-source of software platforms to attract universities, research institutions, and developers to jointly participate in algorithm development and function expansion. Establish partnerships with upstream suppliers of sensors, communication modules, and energy systems to enhance supply chain collaboration and customization capabilities.

Establish a brand image as a "high-precision intelligent measurement expert" or "provider of intelligent water domain perception solutions", highlighting technological advancement and in-depth scene understanding. Build professional and trustworthy market recognition through authoritative testing and certification, benchmark project cases, academic papers, and technical patents.

Adopt differentiated promotion methods for different customer groups such as government departments, large enterprises, and small and medium-sized engineering companies: participate in industry exhibitions, technical seminars, and government procurement projects; cooperate with regional agents and integrators to expand local markets; use online platforms to conduct product demonstrations and technical training to attract long-tail users.

4. Conclusion

In addition to equipment sales, explore models such as "equipment leasing + data services", "solution subscription", and "insurance + operation and maintenance" to lower the initial investment threshold for users. Establish a rapid response service network to provide full-service support from operation training, on-site support to data processing, enhancing user stickiness and word-of-mouth. As a typical carrier of the integration of "Beidou + AI + bionic" technologies, the intelligent unmanned survey vessel is becoming a key force driving the intelligent transformation of water area operations. Through the case analysis of the "Beidou Zhituo" project, this article systematically expounds on its technical realization path, market application prospects, and development strategies. Research shows that through cross-disciplinary collaborative innovation and close interaction among industry, academia, research, and application, student teams can also overcome key technologies and produce results with practical value and market potential.

In the future, with continuous technological iteration, further cost reduction, and the continuous enrichment of the application ecosystem, the achievements of more and more scholars and experts' research and investment will become increasingly evident. The intelligent unmanned survey vessel is expected to play a fundamental role in a wider range of water area management and economic construction, providing important support for the construction of an integrated monitoring network covering land, sea, air, and space.

References

1. Yang, Y.J.; Kuang, C.L.; Zhang, H.N.; et al. Positioning Performance Analysis of Marine Exploration Vessels Based on BeiDou

PPP-B2b Signal. Petrophysics 2025, *64*, 1–10.

2.Chen, H.R. Design of a New BeiDou-3 Shipborne Terminal. Ship & Ocean Engineering 2024, *53* (S01), 96–100.

3.Zhang, H.L.; Zhou, J.Y. Performance Testing and Statistical Analysis of BeiDou Short Message Communication Channel. Electronic Communication & Computer Science 2025, *7* (8).

4.Zhang, J.B. Construction of Development Model and Policy Simulation for BeiDou Satellite Navigation System in General Aviation Field Based on System Dynamics. Ph.D. Thesis, Civil Aviation University of China, Tianjin, China, 2024.

5.Huang, Z.C.; Liang, D.; He, L.Q. Precise Spatio-Temporal Service Network for the Power Industry Based on BeiDou Navigation. Microcomputers 2024, (3), 3.