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A New Conceptual Design for Subsea Charging Station

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ABSTRACT

With the deepening of ocean development, a larger scale Internet of Underwater Things (IoUT) is being realized with the deepening of ocean development. Underwater vehicles are already difficult to meet the energy demand of the high-energy batteries carried by these facilities due to the increased operating time and power consumption in the deep ocean. Facing the charging needs of deeper waters and more complex multi-shaped deep-sea vehicles, current solutions are not sufficient. Therefore, based on the scenario orientation of IoUT, this study designs a subsea charging station that can serve multiple vehicles. The concept is similar to a collection station of a power bank on land, providing multiple sub-charging devices that can be carried on the move to charge several different types of subsea vehicles simultaneously. It also uses ocean energy to provide in-situ produced power to the underwater charging base stations. In the long run, the combination of available equipment will significantly reduce the cost of long-term exploration of the regional seabed and expand the range.

Keywords: IoUT, Subsea vehicles, Subsea charging station, Conceptual design

INTRODUCTION

China has vast seas and rich marine resources. With the deepening of marine development, IoUT requires reliable power supply and data transmission (Wang *et al.*, 2021) (Li *et al.*, 2020). IoUT evolved from the development of traditional marine cable network and cableless network. Zhejiang University (China) proposed a new IoUT architecture with Zhoushan Islands waters as a typical case. From the comparison of existing research and the new framework, miniaturization, cable-free and intelligence are the development trends of underwater observation devices (Qu *et al.*, 2021). Currently, China's research in subsea charging stations lacks solutions for charging in the face of diverse underwater vehicles, which will limit the development and promotion of IoUT in the future.

At present, the main way to power underwater equipment is to salvage and replace the batteries ashore, a solution that is costly to deploy in a single run. Alternatively, wired charging is performed underwater through a wet plug interface, but this approach has low automation and carries the risk of short circuiting. Underwater wireless power transmission (UWPT) technology has a broad application prospect because charging using wireless power transmission technology does not require a physical connection and is characterized by insulation safety and high autonomy. The magnetic field UWPT technology is the most mature UWPT technology compared to the electric and ultrasonic UWPT. It has the advantage of high-power levels and high transmission efficiency (Gu *et al.*, 2021).

In order to reduce the cost of power exchange and extend the duration of underwater devices, a prototype has been developed using magnetic field UWPT. The prototype is a funnel structure whose counterparts are fixed to the docking station and the AUV, respectively. When they are coupled, the AUV is charged by electromagnetic induction. The energy transfer has been tested and this solution has achieved over 90% efficiency in underwater experiments (Agostinho *et al.*, 2021). The next step for this prototype is the commercial development and practical exploration of an integrated UWPT.

In areas already commercialized, Blue Logic has produced the world's first three common, open-standard subsea UAV docking stations based on Equinor's Underwater Intervention Drone (UID) standard interface definition. A subsea docking station (SDS) is a semi-permanent structure mounted on the seafloor, consisting of a subsea docking base (SDB) and an interchangeable subsea docking module (SDM) (Abicht *et al.*, 2020). The disadvantage of this solution is that the charging base station is underutilized and can only service one subsea device at a time.

These solutions are not enough to address the charging needs of diverse underwater devices in the framework of IoUT in the face of deeper waters and larger ranges. This project compares the development status of underwater charging technologies and devices through literature research. Through structured interviews, we listened to deep-sea device designers to clarify the design requirements. Through brainstorming method and solution building method, we analyze the product characteristics and problems, and summarize the design process and direction. Finally, according to the design requirements, the subsea charging station was conceptualized and designed. This solution can solve the charging problem of underwater long-term survey equipment and enable the AUV to operate continuously on the seafloor. It improves the efficiency of the use of the existing charging base station and reduces the charging cost of underwater vehicles (Abicht *et al.*, 2020).

USER RESEARCH

The user study consists of two parts: (a) Observe similar competing SDS and analyze the structural design of the equipment. Observe the entire process from pre-launch preparation, to actual subsea operation and look for design opportunities. (b) Interviews with deep-sea designers to seek design insights from the observations and to gather additional information from the interviews to develop design concepts.

Observation

We take a look at the competing Blue Logic subsea docking station (SDS). the SDS consists of a subsea docking base (SDB) and an interchangeable subsea docking module (SDM). All electrical components and connectors are placed on the SDM, while the SDB is predominantly mechanical. the SDM also supports infrastructure expansion such as sensors, navigation aids, etc. the SDB is designed as a permanent structure mounted on the seabed to support the SDM. the SDB is secured to the seabed using a gravity-based bottom fixing structure (Abicht *et al.*, 2020).

The following problems were observed: First, the overall structure is too exposed, which is not conducive to the long-term operation and parts protection of the equipment. Second, the utilization rate of the docking platform is low, and only one device is allowed for charging and transmission at the same time. Third, the setting of semi-permanent structure does not meet the needs of the new concept of IoUT, and the bottom fixed structure is too large in shape (Hu *et al.*, 2014) .

Interview

Then there were structured interviews with the opinions of the deep-sea equipment designers. These were collected on some of their top concerns. First, they want to ensure the versatility of the subsea charging station to serve most underwater vehicles as much as possible, thus improving operational efficiency. Secondly, they want to improve the efficiency of the station and thus reduce the cost of use. Finally, they hope to solve the surface cleaning problem of the station for long-term use without affecting the operation.

DESIGN PROCESS

The results of the user study provide valid data for design concept and prototype development. The following reference bases and solution directions are proposed for the subsequent design in view of the above problems and the model characteristics of the existing charging stations. The main summary is as follows.

1. As a general design principle, charging base stations are partitioned for functional design. Reduce the electrical set-up on the exposed docking module, separate from the power supply module.
2. In the color selection of the base station, it is recommended to use bright colors such as yellow and orange, because most of the visible light bands underwater will be absorbed and appear blue-green on the seabed.
3. The base bed section to be considered must take into account typical subsea conditions and the structural design of the existing infrastructure. The bottom section needs to maintain the balance of the airframe during landing, and also ensure that the top docking platform has sufficient space from the seabed.
4. Because of the need for power input from the repeater, a subsea wet interface should be left in the power section of the fuselage.
5. To address the cleanliness of the external surface, optimization is carried out by increasing the unity of the equipment and the smoothness of the surface material. The main performance is that the fuselage structure to reduce the turn and exposed structural support.
6. Because of the need for high precision coupling for electromagnetic wireless charging, the module is recommended to be designed with positive and negative shape to enhance the accuracy of docking (Mohsan et al., 2020).

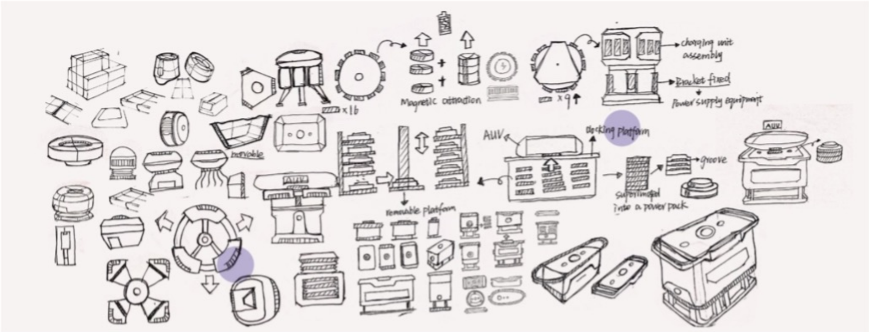

Figure 1: Conceptual design sketches.

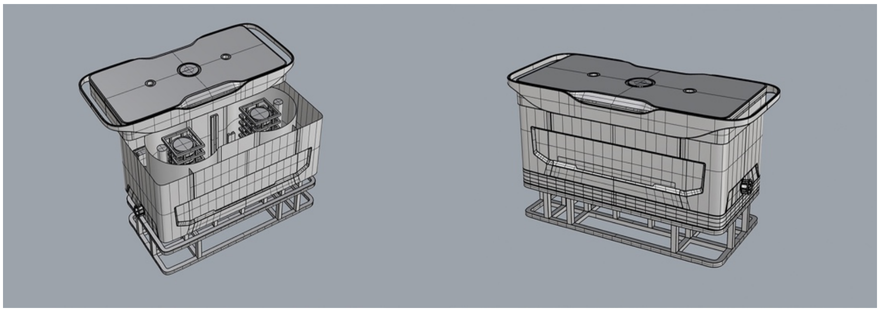

Figure 2: Conceptual model.

Concept

The SDS solves the problem of docking underwater platforms, but lacks the ability to power many devices within the underwater network at the same time. For this reason, we bring the concept of mobile charging to the design of an underwater charging base station, using the underwater charger as a prototype. A conceptual solution was proposed due to the distillation of some design references from previous user studies. After the initial concept was defined, specific design concepts were further developed and explored. The conceptual design sketches are shown in Figure 1.

Model

Considering the existing facilities and the typical conditions of the seabed, we finally chose the platform type charging base station solution in terms of the morphological structure of the model. The advantages of this structure are high overall station stability and high accuracy of charging coupling. At the same time, the mode of fixed wireless charging is optimized and replaced by the mode of mobile charging by carrying wireless charging batteries through the docking platform. The conceptual model is shown in Figure 2.

The main part is integrated and the storage part is enclosed to isolate the wireless charging battery. The module batteries are also electromagnetically connected to each other, so the capacity of the batteries carried can be adjusted to the charging needs of different sizes of subsea vehicles.

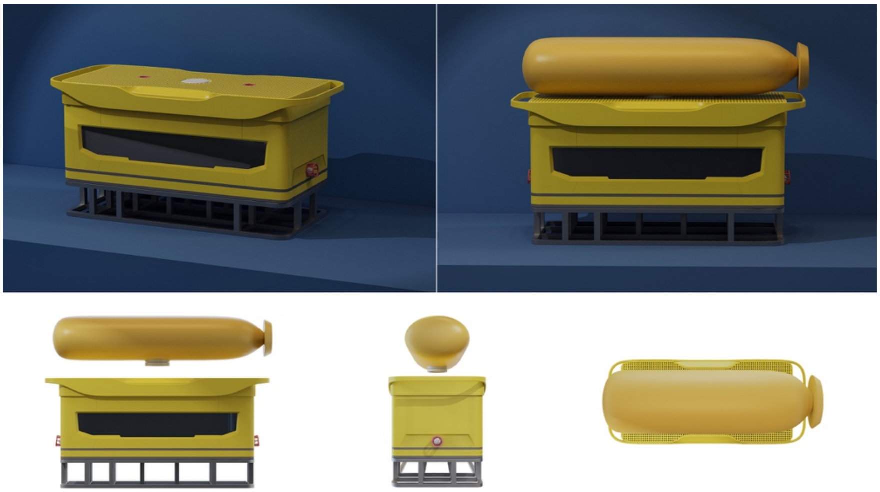

Figure 3: Final design.

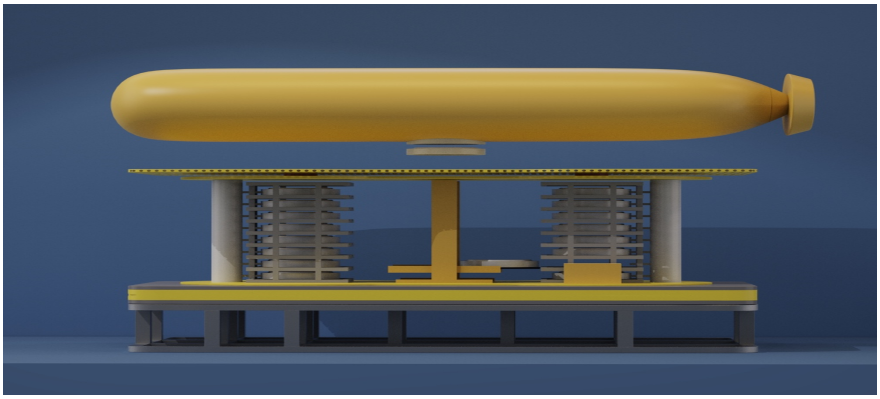

Figure 4: Internal structure.

EVALUATION OF DESIGN

Based on the previous design directions and suggestions, we modified the model by computer to produce the final design as shown in Figure 3.

From top to bottom, firstly, the platform provides an effective docking solution for most of the underwater vehicles. The second is that the middle battery storage part uses an integrated outer envelope design, which plays a sealing role while solving the cleaning problem of the facade to some extent. The fuselage part is placed at a certain distance from the seabed to retain the wet interface to provide electrical energy for the device and access to the valve of IoUT. Third, the bottom bracket of the lowest level is made into a more lightweight structural frame design, which facilitates the autonomous landing of the charging base station. The cost of underwater deployment of the equipment is reduced.

Internally, the subsea charging station refers to the electric vehicle containerized battery exchange service station, using a forklift-like delivery pallet for battery pick-up and drop-off (Shen *et al.*, 2018). The internal battery management structure is shown in Figure 4. By accessing IoUT, the intelligent management system effectively manages the battery and maximizes the effectiveness of the station.

CONCLUSION

The focus of this study is to improve the efficiency of subsea charging through innovative design of subsea charging stations. The goal is to extend the operating time of underwater vehicles and improve the long-term group operation of underwater vehicles. Despite the conceptual design, the charging modules and connection methods used in it are all still under further study. For example, the advantages of the charging base station's facade form in terms of equipment cleaning need to be combined with the coating material of the facade to be further revealed. However, the program hopefully completes the IoUT layout and extends the boundary of IoUT. It lays the foundation for later deeper ocean exploration and commercial development.

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