A hybrid underwater profiler used for persistent monitoring

Yushi Zhu
Mechanical Department
Zhejiang University
Hangzhou, China

Canjun Yang
Mechanical Department
Zhejiang University
Hangzhou, China

Xiaole Xu
Mechanical Department
Zhejiang University
Hangzhou, China

Qing Li
Mechanical Department
Zhejiang University
Hangzhou, China

Jun Wang
Mechanical Department
Zhejiang University
Hangzhou, China

Minjian Cai
Mechanical Department
Zhejiang University
Hangzhou, China

***Abstract*—Underwater profilers are widely used as measurement platform for ocean monitoring. However, these profilers only control the depth itself while lack the control ability in horizontal plane. The disadvantage of lacking horizontal mobility for profilers leads to drifting along with current passively and the deviation from the desired region. In this paper, we present a hybrid underwater profiler (HUP) aiming to overcome the disadvantage. The hybrid profiler has the characteristics as follows: it combines the capacity of an underwater profiler to have a good maneuverability in vertical direction, and the capacity of an underwater glider to glide in order to rectify the horizontal displacement offset generated by current. Due to the characteristics, the hybrid profiler could be used for ocean persistent monitoring to get the profiling data in a specified area.**

Keywords—hybrid; underwater profiler; persistent monitoring; bottom-sitting

I. INTRODUCTION

Underwater persistent monitoring means monitoring vertical profile data in a specified sea area. It helps people research the regional ocean information. However, since the ocean current has assignable effect removing the monitoring equipment away from the desired area, persistent monitoring has to settle the current mobility issue. Traditional lagrangian profilers with active current selection with controllability heat map based on historical data realizes persistent monitoring [1],[2]. An underwater glider called Tsukuyomi used for virtual mooring uses a large range attitude adjustment system to head upward and downward when it profiles in a designated area [3]. And an air-sea interaction profiler is designed for measurements below 100m depth [4].

In this article, we present the HUP, which could not only have a good maneuverability in vertical profiling monitoring, but also have a good performance on gliding movement [5],[6]. Due to the characteristics combing underwater profiler and glider, the HUP could be used for persistent monitoring. The persistent monitoring working pattern in each cycle for HUP contains (shown in Fig.1): surface drift, dive monitoring, bottom-sitting, ascend with gliding or profiling. The surface drifting is for data communication and surface current estimation, where the estimated surface current vector would be used to assist underwater navigation. The dive monitoring is for monitoring the profile data. The bottom-sitting keeps the HUP standing erect on the seabed realizing long-term acoustic monitoring especially for mamals. The ascending part works in gliding mode to rectify the horizontal displacement offset genertated by the current. For the gliding in the ascending, the localization information calculated in bottom-sitting part is used to calculate the optimized steering direction and pitch angle for the glide, in order to maintain the HUP in the desired area.

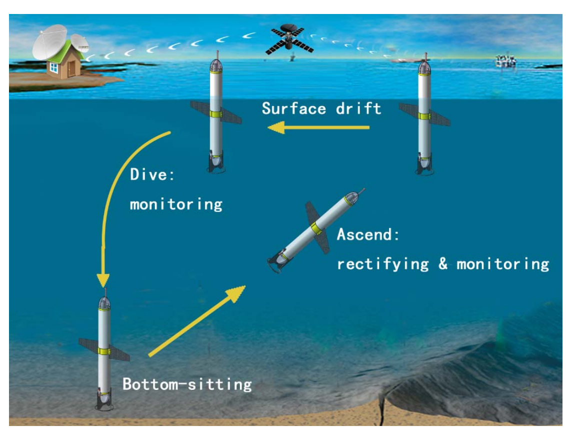

Fig.1. The working pattern for persistent monitoring

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The article is organized as follow: Section II shows the system integration; Section III is about the gravity center adjustment system (GCAS); Section IV elucidates how the bottom-sitting module works; and lastly, Section V analyse how different parameters influence the effect of persistent monitoring.

II. System Integration

The HUP is designed with endurance time of 30 days, and the profiling frequency is 3 times a day.

The HUP is 2.1 m in length and 0.23 m in diameter. It weights 76 kg in air and has the capacity of adjusting buoyancy of 0.5 kg. The HUP is shown in Fig.2. It consists of 5 parts: casing part; sense part; electronic part; GCAS part; bottom-sitting part.

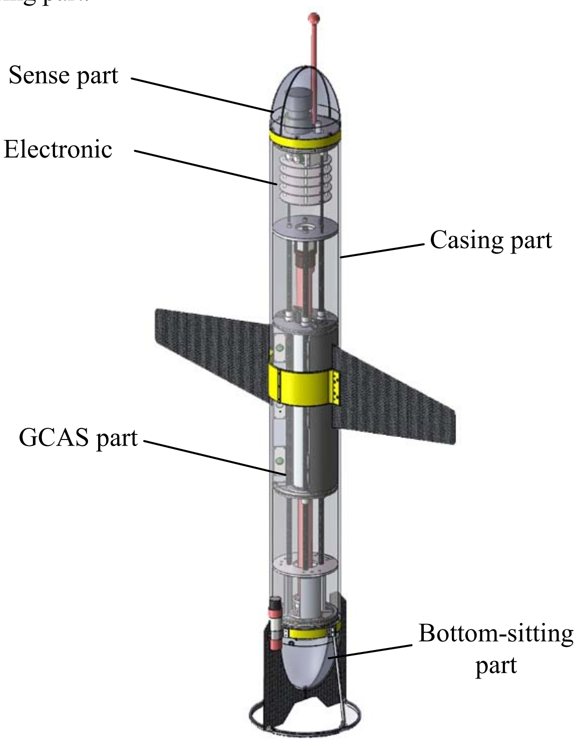


Fig.2. The HUP system

A. Casing part

The casing is made of 6061 aluminium alloy. The casing has the dimension of 1.75 m in length, 0.23 m in outer diameter, and 0.215 m in inner diameter. The maximium endurance pressure is 12.5 Mpa with the security coefficience of 1.5.

B. Sense part

The sense part consists of temperature and depth sensor, turbidity sensor, attitude sensor, satellite communication module, and acousitc sensor.

Since the profiler is designed for working in a specific area, it could get environment data stamps with location.

C. Electronic part

The electronic part plays the roles of main controller, power converter, memory.The communication bus line for different electronic part is CAN bus.

D. GCAS part

The GCAS part is a very important part for the HUP, it changes the position of the gravity center of the HUP, so that the HUP could have different attitude for different working mode.

E. Bottom-sitting part

The bottom-sitting helps the HUP lands on the seabed and keeps up-right when making long term data acquiring

III. The Gravity Center Adjustment System

Since the HUP has the capacity to work both in profiling mode and gliding mode, this requires the GCAS to change the gravity center in large range. As an equivalent model for the GCAS shown in Figure 3, the HUP has a moving mass module with multiple Degree Of Freedoms (DOF). These characteristics help the profiler have a quick response when it switches between the profiling and gliding mode. When the profiler works in vertical profiling mode, the gravity center of the profiler is adjusted closed on the longitude axis of the hull by moving the mass Meanwhile, when the profiler needs to rectify the position offset generated by current, it works in gliding mode. In gliding mode, the gravity center of profiler moves away from its longitude axis by moving mass and the yaw angle is controlled by rotating the moving mass

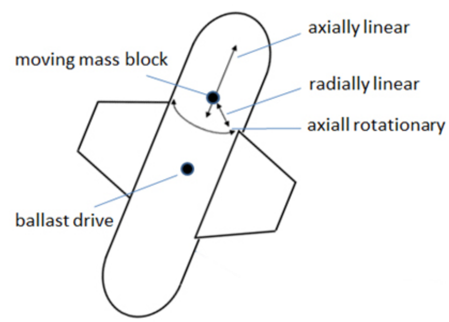
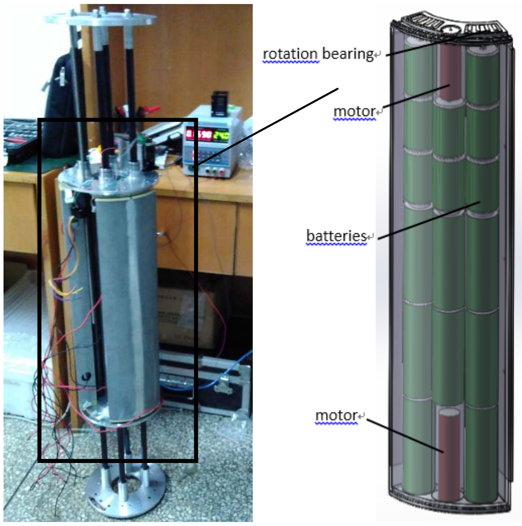


Fig.3. The equivalent model for GCAS

To realize the capacity of 3 DOFs for the GCAS, the GCAS contains one linear moving platform supporting two rotating moving mass. The gravity center adjustment module could change the position of gravity center axially, radially, and tangentially of radius.

Moreover, the mass blocks house the batteries. The batteries are customized in shape, so that they can agree with the shape of the mass block. The batteries are disposable in order to have a better performance on endurance and discharging.



(a) (b)

Fig.4. The GCAS: (a) the main parts of GCAS; (b) the integration of mass block

IV. BOTTOM-SITTING PART

Since one goal of the hybrid profiler is to collect the background acoustic data in a specific area, it requires the profiler to bottom on the seabed in long term. In order to bottom on the seabed, the profiler needs to realize 2 functions: landing and standing

A. Consturction

The bottomg sitting module contains: altitude meter and bottom sitting shelf (shown in Fig.5). The altitude meter is used to measure distance between the HUP and the seabed. The bottom-sitting shelf enables the HUP to land on seabed.

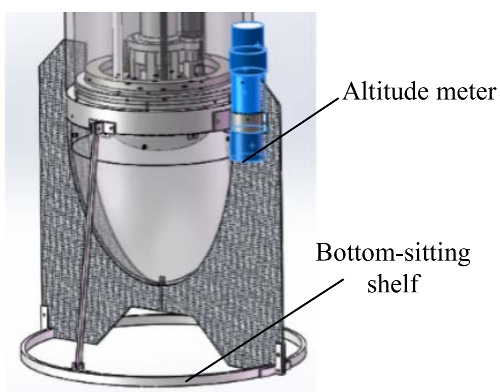


Fig.5. The bottom-sitting module

B. Landing

Landing is aimed to make sure that the profiler could correctly get contacted to the seabed.

In order to protect the profiler from being damaged, the contact force should be limited when landing. Limiting the contact force is mainly relied on limiting the contact velocity.

The maximium contact velocity is to keep the bottom sitting shelf from being damaged. Crash simulation is conducted as free fall model with mass of 70kg, and acceleration of 0.042m/s2. According to the simulation, we could find out that with the maximium velocity of 0.1m/s, the maximium contact force stress is 82.4Mpa shown in Fig.6, while the yield strength of 6061 aluminium alloy is 270Mpa. In this case, the bottom sitting shelf is protected.

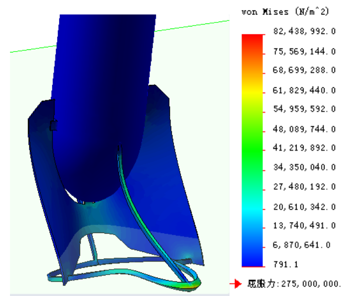


Fig.6. The crash simulation for landing

To make sure that the contact velocity is limited below 0.1m/s, the profiler has to decelerate in a proper way before getting contact with the seabed. Moreover, to save the energy consumption for this process, the buoyancy adjustment system has to run as less as possible.

The strategy for the deceleration process is that when the profiler gets closed to the seabed within a certain deceleration height h_{dec}, the buoyancy adjustment system adjusts the net buoyancy to 0 g. This strategy could realizes that not only does the profiler decelerate with the drag force, but also make sure that the profiler do not ascend falsely after getting contacted.

Simulation is conducted with different h_{dec} to calculated the contact velocity. The result is shown in Table 1.

Table 1. The contact velocity with different h_{dec}

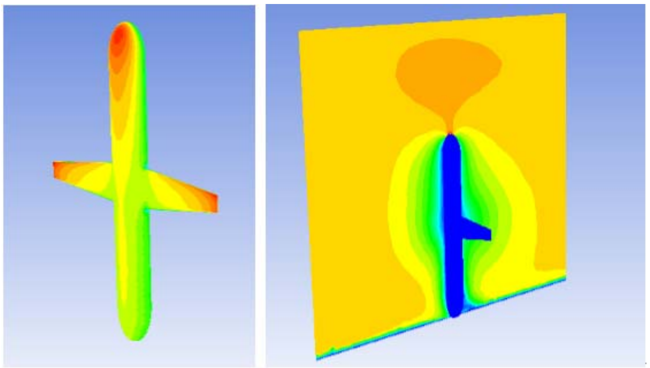
h_{dec} (m)	80	70	60
$V_{contact}$ (m/s)	0.044	0.082	0.133

The simulation elucidates that with a h_{dec} as 70 m, the contact velocity could be limited below 0.1 m/s, so the profiler has to start to decelerate before h_{dec} dropping below 70 m.

C. Bottom-sitting parameter

To make sure that the profiler could stand erect on the seabed with a slant in a few degree, the coverage radius for the bottom-sitting shelf has to be large enough to cope with the tilting torque generated by the current.

A tilting model is suggested to calculate the relationship among the the velocity of the current, the radius that the bottom-sitting shelf that covers, and the tilting angle. The tilting torque is calculated with the software FLUENT (shown in Fig.7) [7],[8]. The final result is shown in Table 2. It can be indicated that with the radius of 0.22m for the bottom sitting shelf, the tilting angle could be limited in a acceptable value.



(a) (b)

Fig.7. The CFD calculation for tilting torque.(a) pressure distribution, (b)velocity distribution

Table 2. The tilting angle for different current velocity

current velocity(m/s)	tilting angle(°)
0.02	2
0.04	7
0.06	10

V. PERSISTENT MONITORING METHOD

Persistent monitoring requires the profiler to rectify the position deviation generated by the current. To realize this requirement, the profiler has to calculate the position deviation from the specific center, and combine the basic parameter of the ocean current to generate the parameter of rectification for the next profile. The basic parameter of the ocean contains the maximium velocity of the current V_{max} , the maximiun intersection angle for the direction of the current $\theta_{intersect}$, the frequency that the direction of the current changes f_c. For the presented profiler, assumption is made that f_c is really low so that the direction of the current for an ascending process correlates with the value calculated by the last surface driting process.

A. Method

According to the assumption, the persistent monitoring method consists of several points:

- The persistent monitoring process: data acquisition (to acquire the position deviation and surface current vector), vertical diving, bottom-sitting, ascending with gliding to rectify position deviation, surface drifting.
- The steering direction strategy (shown in Fig.8): the steering direction for the ascend process is calculated as the direction of vector T_i where $T_i = S_i + k \cdot D_{i-1}$. S_i represents the current position deviation, D_{i-1} represents the drifting displacement vector when surfacing, k is the control parameter.
- The pitch angle strategy: fix the pitch where the pitch equals to the tangent value of the maximium dive depth and the length of T_i

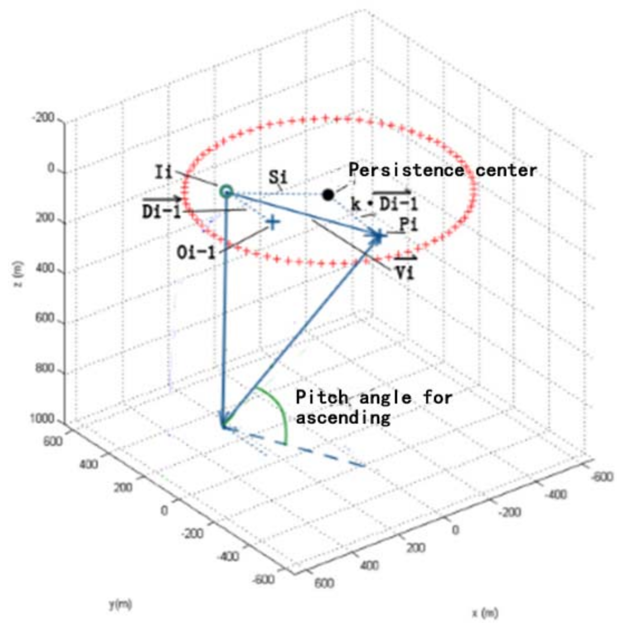


Fig.8. The schematic map for the strategy of persistent monitoring

Simulations have been made to estimate the effect for different parameters of the current. The parameters of the simulation are set as follow:

- The distribution of the velocity along depth is in exponent form; and the surface velocity alternates in 0.5m/s,0.9m/s, 1.2m/s.
- The dive depth value in 500m, 1000m.
- The maximiun intersection angle for the direction of the current $\theta_{intersect}$ is 100°
- The cycle that direction of the current changes fully the range is 24 hours.
- Each bottom-sitting process lasts 6 hours.
- The simulation consists of 30 profile cycles.

To appoint the radius for the persistent monitoring as 1000m (shown in Fig.9 with 30 cycles), the persistent probability could be calculated. The calculated persistent probability is shown in Table 3.

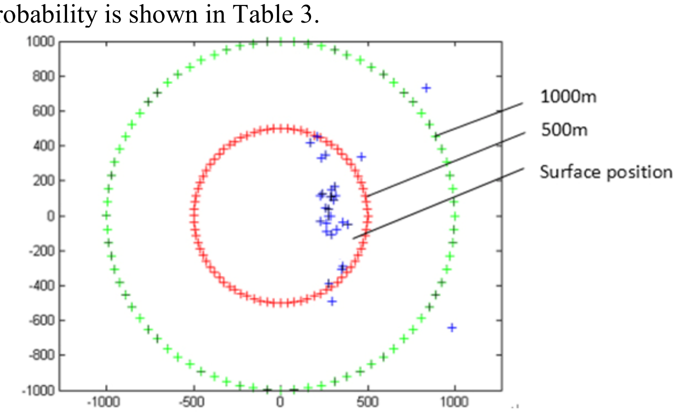


Fig.9. The suface postion for each ascending.

Table 3. The persistence probability for different factors

Diving depth(m)	Current velocity(m/s)	Persistence probability
500	0.5	92%
500	0.9	84%
500	1.2	75%
1000	0.5	88%
1000	0.9	78%
1000	1.2	60%

It could be indicated that with higher current velocity and higher diving depth, the persistence probability is lower. This is caused by the uncertainty of the ocean increase. To get a better performance on higher current velocity and higher diving depth, the HUP needs a buoyancy adjustment system with more net buoyancy to reduce the time consmption when diving and ascending.

VI. CONCLUSION

The HUP presented in this article is aimed to realize persistent monitoring. It combines the functions of profilers and gliders attributed to the GCAS of 3 DOFs. Moreover, the bottom-sitting function enables the HUP to work in long term on the seabed, which might could realize some in-situ analyse further. The analysis for persistent monitoring indicateds how the current velocity and the diving depth, and suggests that more net buoyancy could make a better performance in persistent monitoring. More net buoyancy reduces the time consmption when diving and ascending.

VII. ACKNOLLEDGEMENT

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