ARV Navigation and Control System at Arctic Research

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Abstract: **ARV is a new concept unmanned underwater vehicle (UUV) which has both the characteristics of autonomous underwater vehicle (AUV) and that of remote operated underwater vehicle (ROV). It is a hybrid ROV/AUV. ARV can cruise at a range of 3km at the speed of 3kn, in a depth shallower than 500 meters. At the attractive point the vehicle can be operated as a ROV with the ability of dynamic positioning. The vehicle has a Fiber Optic Micro Cable (FOMC) system with the length of 5km for transferring image and other payload sensors' data in real time. The payload segment is a reconfigurable module that can be changed according to different scientific related missions. ARV was used in China's third Arctic expedition in 2008.**

Keywords: ARV；Navigation Under Ice；GPS Direction Indicator；DVL

1, Introduction

ARV is designed mainly for ocean research under Arctic ice. The primary objective is to study the changes taking place in the Arctic such as the thinning of the sea ice, to take measurements of salinity, temperature, and ice draft. ARV has the characteristics: ability to navigate under ice, payload sensor modularization, capability to transmit data to scientists and operator in real time, long durance battery. ARV can carry multiple sensors and equipments to carry out large-scale scientific observation under the ice, and obtain important information for polar research, such as hydrological data under the sea ice and the thickness of the ice. This observational data must be combined with accurate location information, otherwise it is no use. Arctic high-latitude features make some navigation equipment not normally work, such as the magnetic compass, causing that some of the traditional navigation technology can not be well achieved. In addition, a wide range of sea ice covering the polar regions make the use ,deployment and recovery of the vehicle difficult. In response to this special environment, this paper introduces an ARV navigation technology based on GPS measurement to the ice surface. Through introducing the floating ice movement information regularly, we can accurately locate the ARV at any time. The simulation and experiment prove that this method is effective. This paper discusses the navigation and control system of ARV in Arctic research and the issues remain.

2, Vehicle Description

The vehicle ARV is shown in Fig.1. The vehicle consists of aluminum frames, some pressure hulls for protecting control system and other electrical devices, and buoyancy materials using for additional buoyancy. The vehicle has six actuators driven by D.C. brush-less motors. Two horizontal thrusters at the sides of the vehicle are used for cruising and heading control, other two horizontal thrusters (one at the bow, the other at the end) are used for side movement. The vertical thrusters are used for depth control. The power source is Li-ion rechargeable battery.

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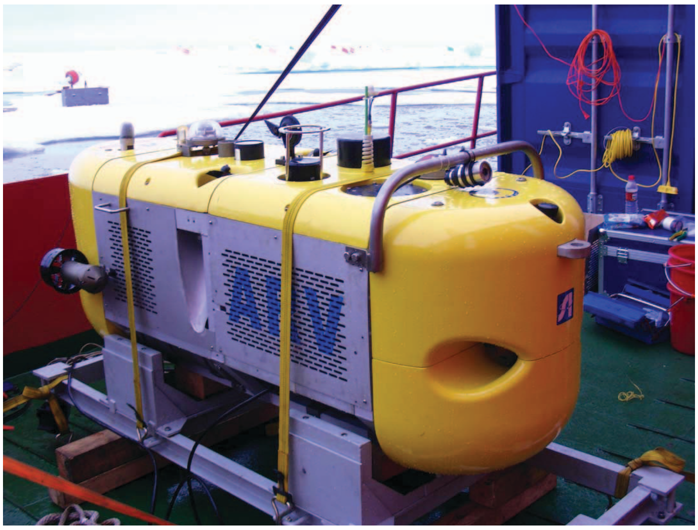

Fig.1 ARV on its support vessel

ARV navigation system is an integrated INS/DVL/GPS system. The navigation instruments include: Ixsea OCTANS Gyrocompass, TCM2, RDI DVL, GPS, depth sensor and altimeter sonar. DVL was pointed upward to measure velocity with respect to the ice. The objective of the integrated system design is to provide the best estimate of position, velocity, and attitude by combining information from these instruments.

The primary payload sensors are CTD systems, luminous flux, ADCP, ice profiling sonar, high resolution cameras. The ice profiling sonar allows the vehicle to estimate the ice thickness, so the vehicle knows if it is safe to rise to sea surface.

3, Vehicle Control

ARV is required to have the ability of keeping depth, heading and position. The PID controller has been adopted for control of ARV because of its simple structure and robustness for long time operation. The heading control law was simply taken to be

$$\delta_r = K_p(\varphi_d - \varphi) - K_d r + K_I \int(\varphi_d - \varphi)d_t \qquad (1)$$

Where K_p, K_d, K_I are the proportional, derivative and integral gains respectively. φ_d and φ represent the desired heading and actual vehicle heading. r represents heading rate and d is the sampling interval.

The depth control law was simply taken to be

$$\delta_s = K_{ZP}(z_d - z) + K_{ZI} \int(z_d - z)d_t \qquad (2)$$

Where K_{zp}, K_{ZI} are the proportional, integral gains respectively. Z_d, Z represent the desired depth and actual vehicle depth. δ_r, δ_s are horizontal and vertical control input.

In order to suppress the effects of high-frequency disturbances, the measurements were digitally low-pass filtered. The desired value φ_d, z_d were also low-pass filtered in order to obtain smooth course-changing maneuvers.

ARV has two operating modes: autonomous operating mode and remote operating mode.

The remote operating mode uses a thin optical fiber cable for communication between the vehicle and the support vessel. By using this cable, we can remote operate and monitor all equipment status at real time. The vehicle has no restriction by tether cable because of the optical fiber cable is very thin. This mode is used at the stage of launching, recovery and interesting spot survey.

In autonomous operating mode, the working schedule is preset on the computer in the vehicle before starting observation. The schedule includes the cruising course and procedure of observation devices. The vehicle independently cruises without any information from support vessel. When the vehicle notices some obstacles in the cruising, it takes an avoidance action by itself.

Design a path that the vehicle will follow at inertial frame or ice frame, then the vehicle cruises following the preplanned path, the image and other sensor data is transmitted to support vessel simultaneity, when something interesting is found, the autonomous mode can be halted and the operator can operate the vehicle at ROV mode, and then the autonomous mode can be continued. There are two kinds of paths: heading path and way point path.

4, Vehicle Navigation

Navigation at Arctic under ice is a challenge because of ice drift. The path that the vehicle will follow should be planned in ice reference frame or inertial reference frame according to research demands, The Arctic ice has rotational movement, the attitudes of the vehicle are measured in inertial frame. Traditional navigation method (Using inertial measurements and Doppler velocity logger) cannot provide ice-relative navigation accounting for the full motion of free-floating ice. Traditional methods have been used successfully in inertial space. However these existing systems cannot provide accurate ice-relative position estimates around free-floating, rotating ice. OCTANS provides information about how the vehicle moves with respect to an inertial frame, not with respect to the ice. DVLs can measure ice-relative velocity measurements, but they cannot account for any rotation of the ice. Hence, extensions to the navigation system are required for these missions.

Operation in these under-ice environments requires that an AUV possess some capability of navigation with respect to the ice surface. How to drive the vehicle following the path in ice frame is discussed in detail in this paper. Simulation results demonstrate the feasibility and effectiveness of the proposed method.

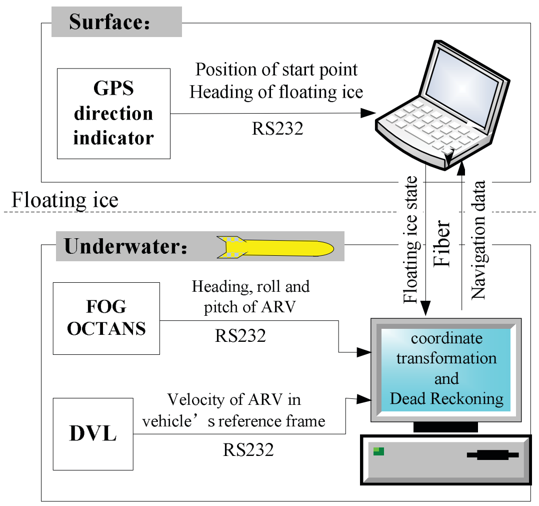

Fig.2 ARV navigation architecture

The ARV navigation architecture is shown in Fig. 2. The motion of the ice is measured by an equipment called GPS Direction Indicator which outputs the translational speeds, rotational speeds and the position of the ice. GPS Direction Indicator has two antennas and it use the difference between the two antennas to calculate the motion of the ice. The line connecting the two antennas is called the baseline. In the ice reference frame the baseline is defined as X axis which is attached to the ice.

Ice reference frame is shown in Fig.3.

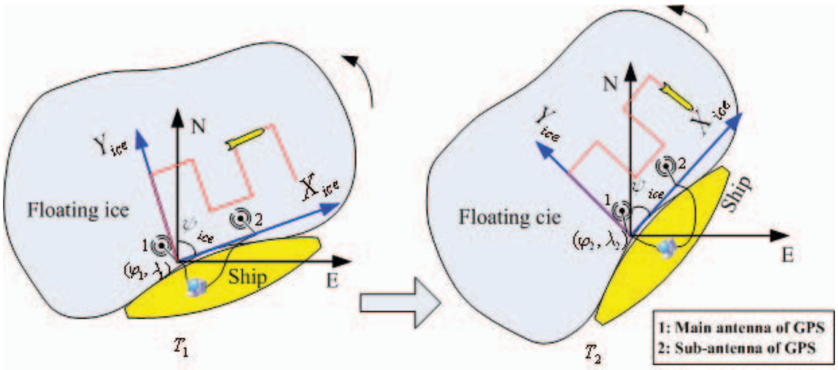

Fig.3. Ice reference frame definition

OCTANS provides information in an inertial frame, not with respect to the ice. DVL provides ice-relative velocity. We first calculate the translational matrix T_{earth}^{ice} which is the relationship between the inertial frame and the ice frame.

$$T_{earth}^{ice}=\begin{bmatrix}\sin\psi\cos\theta & \cos\psi\cos\varphi+\sin\psi\sin\theta\sin\varphi & -\cos\psi\sin\varphi+\sin\psi\sin\theta\cos\varphi \\ \cos\psi\cos\theta & -\sin\psi\cos\varphi+\cos\psi\sin\theta\sin\varphi & \sin\psi\sin\varphi+\cos\psi\sin\theta\cos\varphi\end{bmatrix} \quad (3)$$

$\psi=\psi_o+\psi_G$, ψ_o is the heading angle of the vehicle measured by OCTANS, ψ_G is the heading angle of the ice measured by GPS Direction Indicator. θ and φ are pitch and roll angle of the vehicle measured by OCTANS.

According to (3) velocities in ice reference frame can be calculated as:

$$\begin{bmatrix}V_{ice\_x} \\ V_{ice\_y}\end{bmatrix}=T_{earth}^{ice}\begin{bmatrix}V_x \\ V_y \\ V_z\end{bmatrix} \quad (4)$$

V_x, V_y, V_z are velocities measured by DVL. Integrate $V_{ice}(t)$, then we get the position of the vehicle in ice frame:

$$\hat{P}_{ice}(t)=\hat{P}(t_0)+\int_{t_0}^{t}\mathrm{V}_{ice}(\tau)d\tau \quad (5)$$

$\hat{P}(t_0)$ is the original position of ARV in ice frame ， defined as (0,0). $\hat{P}_{ice}(t)$ is the position at time t. The relationship between relative coordinate(Ice frame) and absolute coordinate(Inertial frame) is shown is Fig. 4.

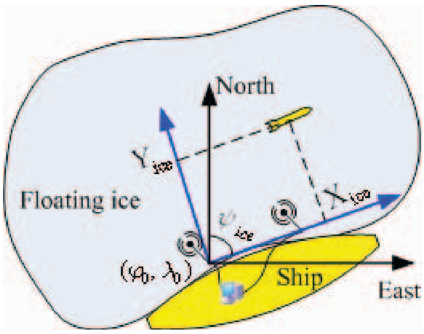

Fig.4. Relationship between relative coordinate and absolute coordinate

The position $\hat{P}_{ice}(t)$ is deduced in ice reference frame. In order to get the position in inertial frame, we make a translation from the ice frame to inertial frame.

$$P_G(t) = {}^{G}_{ice}R(t) \times P_{ice}(t) \tag{6}$$

${}^{G}_{ice}R(t)$ is the translation matrix，with GPS Direction Indicator output ψ_{ice} . $P_G(t)$ is the displacement in inertial frame with the unit meter. Multi $P_G(t)$ with curvature of the working place then we get the longitude displacement and latitude displacement. Add these displacements with the GPS Direction Indicator output then we get the absolute latitude and longitude.

5, Experiment Results

Initial test was performed in june,2008, in QiPan Mountion pool. Fig. 5 shows the path of the vehicle. The blue line shows track measured by inertial navigation system. The red line shows track measured by GPS. The blue lime is good agreement with red line. The total cruising distance is 1069 meters. The tracking error is shown in Fig.6 .The biggest error is 1.5 meter. The navigation precision is 0.234%.

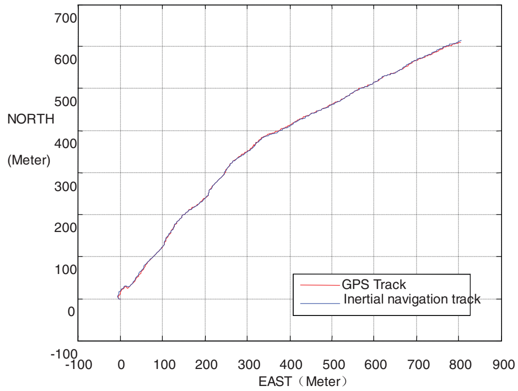

Fig.5. Inertial Navigation tracks and GPS tracks

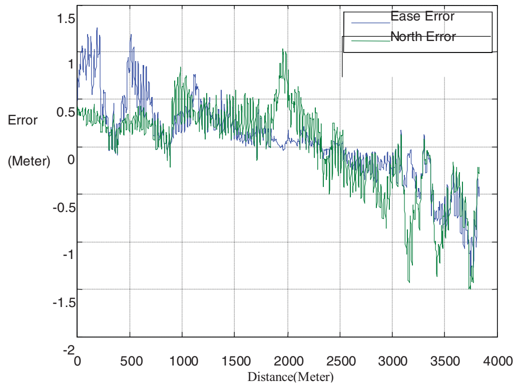

Fig.6. ARV Navigation error

In order to verify the effectiveness of the under ice navigation algorithm, a simulator is made with OpenGL. The elliptical region indicates the floating ice. The ice has translational and rotational movement controlled by the keyboard. The information of the ice movement is transferred to the vehicle simulating the GPS Direction Indicator. In Fig.7 the path ‘S’ is planned in ice reference frame and the vehicle cruises following the path accurately.

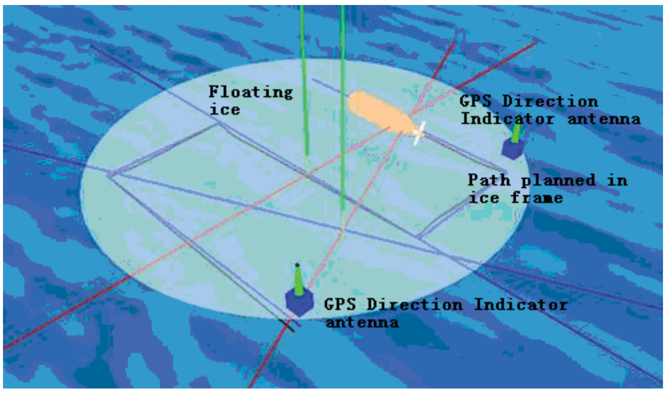

Fig.7 ARV navigation simulator

ARV was used in China's third Arctic expedition in 2008. Fig. 8 shows the vehicle in the Arctic just after deployment.

Fig.8 ARV in the Arctic ocean

6, Conclusion

A new concept underwater vehicle named ARV for arctic research under ice is presented. ARV provides a platform for deployment of a number of geophysical and oceanographic instruments in hazardous polar environments that ships and other manned vehicles cannot access. Sea trials are carried out for sea ice thickness monitoring and oceanographic observation. The experimental results are not totally satisfactory because GPS Direction Indicator may receive no satellite signal sometimes, then the parameters of the ice movement are not accurate. Related future works will try to solve this problem using other available sensors and advanced fusion techniques.

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