Design and Application of Buoy System for On-the-fly Observation of Surface Current in Closure Water Area

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***Abstract*-The current velocity and direction can be monitored by acoustic Doppler current profiler (ADCP) or flow velocity and direction meter. However, both the two devices need vessel as support. Moreover, it is dangerous to run the vessel in the water area with acute-current velocity. Besides, ADCP exists blind area in the upper of ADCP transducer, and can not acquire the current velocity in this area. In order to overcome the above problems, a buoy floating system for on-the fly observation of surface current in closure water area is designed for fulfilling the work. The buoy design, data acquisition, data processing are study in this paper. The system is proved to stability and accuracy in acquiring the surface current velocity and direction. An actual engineering application was also proved above conclusions.**

I. INTRODUCTION

Generally, artificial reservoirs are formed by the closure project in the nature river. In the project, the surface-current will become more and more acute with closure gap becoming narrow. The hydrographic situation will bring potential safety hazard for the artificial dam. Thus, it is very necessary to monitor timely the change of the velocity and direction of surface current so that a precaution can be given out early and timely. The monitoring current velocity and direction can be done by acoustic Doppler current profiler (ADCP) or flow velocity and direction meter [1]. However, both the two devices need vessel as support. Moreover, it is dangerous to run the vessel in the water area with acute-current velocity. Besides, ADCP exists blind area in the upper of ADCP transducer, and can not acquire the current velocity in this area. In order to overcome above problems, a buoy floating system is designed for fulfilling the work. In the following, the buoy design, data acquisition, data processing and applications are depicted in detail.

II. DESIGN OF THE BUOY

In order to implement the measurement of current velocity, the buoy is designed as a cylinder with the radius of 1.1 m for the upper and bottom surfaces and the height of 1.5 m. Under the bottom-surface center, a metal pole is designed for loading the balance weight. The balance weight makes sure the balance of the buoy in the vertical direction and keeps that the gravity center of the buoy is on the same horizontal surface with the drift surface of the buoy. In the design of the buoy, the balance weight is set according to Archimedes' law.

$$F = \rho g V_1 + \rho g V_2 = \rho g S_1 h_1 + \rho g V_2 \quad (1)$$

where, ρ is the density of steel material; g = 9.8 N/s^2; V_1 and V_2 are the volume of cylinder under water and that of the balance weight respectively; S_1 and h_1 are the buoy bottom area and the height from the buoy bottom to buoy draft surface.

Then actual balance weight $m_2 g$ should equal the buoyancy F of whole buoy subtracting the weight of the buoy $m_1 g$.

$$m_2 g = F - m_1 g \quad (2)$$

On the upper surface of the buoy center, a vertical pole is welded for fixing GPS antenna.

According to above theory and methods, a completed buoy is designed as Fig. 1. The floating buoy is shown as Fig. 2.

Figure 1. The designed buoy floating system

Figure 2. Floating the buoy system

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III. Components of the Buoy System and Their Functions

The designed buoy is only a carrier, which is used for loading GPS receiver, inertial navigation system (INS), digital compass, and motion reference unit (MRU).

In the system, Trimble R8 GPS receivers are used. R8 takes the role of observing the velocity and direction of surface current, which is a main unit in the whole system. R8 antenna is fixed at GPS antenna pole which is welded on the top of the buoy, while its receiver is arranged at the bottom layer in buoy body. Due to more influences to the radio communication in GPS real-time kinematic (RTK) measurement at the closure gap, the technique of post processing kinematic (PPK) is adopted in the GPS observation so as to avoid the decrease of positioning accuracy due to the radio interference [2]. Besides, in order to accurately monitor instantaneous change of the current velocity at the water area, 20 Hz is chosen as R8 sampling rate in the actual observation.

At the middle layer of the buoy body, MRU is fixed, which is used for monitoring the buoy attitude. Before the floating operation, MRU is initialized about 10 minutes under horizontal situation when the buoy is hanged up. Synchronously, PPK initialization is implemented. 50Hz sampling rate of MRU is adopted in the floating operation.

INS is also arranged in the middle of the buoy body, and used for monitoring the heading of the buoy. Before INS is arranged, INS is initialized by GPS orientation method. Using two GPS RTK receivers which are along the vessel keel and set at the vessel bow and vessel buttock respectively, the instantaneous orientation of vessel is calculated by the synchronous coordinates of the two GPS receivers.

Before setting INS, INS is arranged to parallel to that of the vessel keel. Comparing the orientation from GPS RTK with that from INS at the same time, the bias of INS arrangement is acquired and used for INS initialization [3]. INS sampling rate is the same as MRU in actual operation.

Data acquisition adopts notebook PC. The PC is arranged in the upper lay in the buoy. PC is used to log attitude from MRU and heading from INS in buoy. Two RS232 communication cables are used for connecting PC and MRU as well as INS respectively. Experiments show that RS232 can meet the requirement of 50Hz data communication.

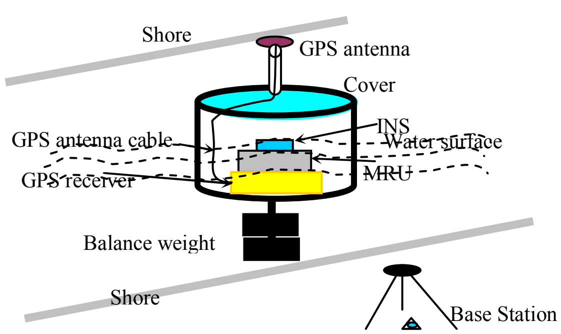

Figure 3. The arrangements of different sensors in the buoy

In buoy, Fig. 3 shows the arrangements of MRU, INS and PC.

IV. Measurement of the Buoy System

In the measurement of buoy system, PPK is adopted for the determination of instantaneous position of the buoy, and current velocity and direction. Before each of floating measurements, the base station of PPK should be set up and used for implementing measurement by the model of static observation. The sampling rate of the GPS receiver at the base station is set as same as that at buoy (namely rover station).

About 10~15 minutes preparation is required for the initializations of PPK, INS and MRU before the floating operation. After the initializations, Trimble R8 GPS receiver, MRU and INS are arranged on corresponding layer respectively in the buoy body. Then the buoy is closed by its cover, GPS R8 GPS antenna is arranged at GPS antenna pole which is welded on the top of the cover. In the arrangement, it is necessary to keep GPS antenna to be vertical and not be wimpled so as to guarantee integrated ambiguity to be tracked continuously.

If the floating operation is implemented from upperstream area to downstream, the service vessel runs to upper water area, and then the arranged buoy is hoisted up and put down at the side of shipboard. Using vessel drags the buoy at the upstream, and then let it free floating along the main current direction. After the floating operation, the buoy is dragged near another vessel which is at the downstream water area. About 10~15 minutes GPS PPK initialization need to be done again. After the initialization, the cover of the buoy is opened in vertical direction. All of observation devices in the buoy body are powered off and taken out from the buoy body. The observation data of these sensors are logged out and used for post processing.

V. Blend of Observation Data

All of observation data will be blended together for the determination of velocity and direction of surface current. A completed data processing procedure is introduced as following.

Firstly, PPK solution need be acquired by Trimble Geographic Office (TGO) software. TGO provides the function to get the positioning solution at each observation. In order to acquire ideal PPK solution, some parameters (such as attitude angle, ration rate etc.) and threshold limitation need to be set.

Secondly, a quality control should be implemented to ensure the PPK solution quality. Integrated the orientation and estimated location from INS, the work is done by self-adaptive robust Kalman filter [3].

$$\begin{aligned} X_k &= \Phi_{k,k-1} X_{k-1} + \Gamma_{k-1} W_{k-1} \\ Z_k &= H_k X_k + V_k \end{aligned} \tag{3}$$

Where, X_k is status vector composed by horizontal position and their accelerators in x and y direction; Z_k is observation vector composed by PPK horizontal solution and the estimated location according to INS orientation. H_k、Γ_{k-1}、W_{k-1} and V_k are affiliation matrix of the observation, noise matrix, noise vector and observation noise vector.

Thirdly, the time synchronization among PPK solution and heading as well as attitude parameters is done. Although rover GPS receiver adopts PPK observation model and save raw observation data in the receiver, it can also output NMEA 0183 data which can be logged into PC by Hypack software. In Hypack file, NMEA 0183 data is marked as computer time. At the same time, GPS UTC time is included in the record. Thus it is not difficult to get time offset between GPS UTC time and computer time. The time offset is also that among PPK solution and heading as well as attitude parameters because these parameters are logged by Hypack software and marked as computer time. In virtue of the time offset, the GPS PPK solution can keep synchronization with heading, attitude.

Fourthly, due to buoy attitude influence, the GPS antenna is changed with attitude. If PPK solution at GPS antenna is used directly for determining the current velocity and direction, the current velocity can not represent the actual buoy orientation. Thus it is necessary to implement attitude correction so as to correct the instantaneous PPK solution from GPS antenna to the gravity center of the buoy, because the center of gravity of the buoy is more stable with respect to other locations at the buoy. Attitude correction is implemented in virtue of attitude parameters (such as roll, pitch and heading). By constructing rotation matrix with roll and pitch angle, the relationship between the instantaneous vessel frame system (VFS) and the ideal VFS can be determined [4]. Integrated the coordinates of GPS antenna in VFS, the coordinate of the gravity center of the buoy can be determined.

Similarly, the 3-dimension coordinate of the projecting point on the water surface of the buoy gravity center can also be calculated by attitude correction.

Finally, both velocity and direction can be calculated according to the 3-dimension coordinate of projecting point on water surface. The current velocity and direction are also those of water surface.

$$v = \frac{\Delta S}{dt} = \frac{\sqrt{\Delta x^2 + \Delta y^2}}{dt} \tag{4}$$

$$A_G = tg^{-1}\frac{\Delta y}{\Delta x} \tag{5}$$

Where $\Delta x = x^{t+\Delta t} - x^t$, $\Delta y = y^{t+\Delta t} - y^t$

VI. Applications

The system is used for an actual closure project. The closure gap is near Chongming Island, the water area of Changjiang Estuary (Fig. 4). A reservoir will be formed by cutting off upstream and downstream river water. In order to ensure the safety of closure gap, current velocity and direction need to be monitored timely. The buoy system depicted as above was used for the work.

Figure 4. The closure water area

One of floating operations is chosen as the studied aim. A completed data processing is implemented for the logged data. The result in the floating is shown in Fig. 5

The change of current velocity and direction at the closure gap is depicted in Fig. 5. According to the upper map, it is not difficult to find that the floating track is line. In the floating, a stable change of current direction and velocity is presented at the beginning part, while acute change is reflected at the middle segment, and then the gradually stable change appears at the end of the track. The phenomena can be explained by the hydrologic characteristics at the closure gap. At the beginning part, namely the upstream, water current is stable and slow due to wide watercourse, while the obvious change happens with the watercourse being narrow at the closure dam. Current velocity will become relative stable after the closure dam due to wide water area.

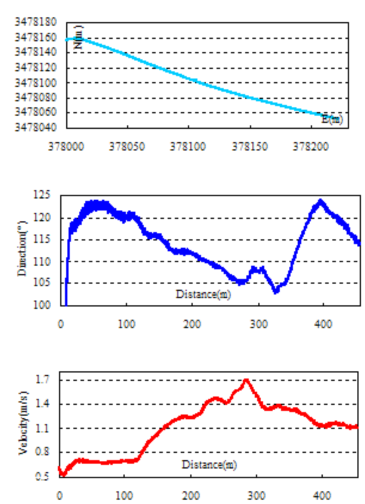

Figure 5. Track, current direction and velocity at a floating operation

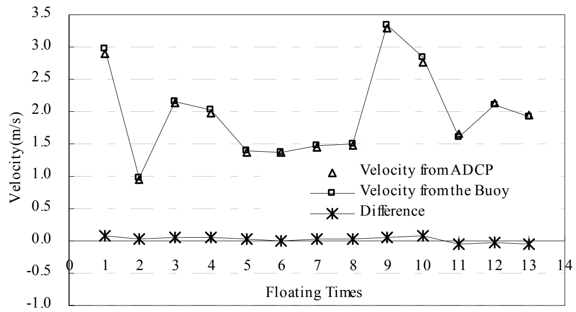

Figure 6. Comparison between current velocity and direction from the buoy system and those from ADCP

In order to test further the method and system depicted as above, 13-time floating work were implemented in the closure gap. In each of floating operation, ADCP measurement was implemented synchronously at the upstream. The results from the buoy system and those from ADCP are compared and shown in Fig. 6.

According to the difference between the current velocity from ADCP and that from the buoy system, it is easy to find that there exists a high consistence between them. A statistic analysis is done for the difference. The statistic result shows that the minimum bias is 0.01m/s, maximum bias is 0.07m/s, means bias is 0.02m/s, while standard bias achieves 0.037m/s.

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