# Software Development for the Determination of Instantaneous Height of Transducer Based on the Blend of GPS Height and Heave

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***Abstract*-In order to improve the accuracy of underwater topographic measurement, the method for the precise determination of instantaneous height of transducer is studied. The software, which is used for implementing the blend of GPS height and heave so as to accurately present instantaneous height of transducer, is developed. The software structure design, key techniques and main function modules including quality control, time synchronization, attitude correction, as well as signal extraction and blend are depicted in detail. Moreover, the software is tested and applied in the actual experiments. The results show that the accuracy and performance of the software are high and can satisfy the actual application.**

## I. INTRODUCTION

Nowadays, both single-beam and multibeam sounding system can achieve 0.3% depth sounding accuracy under ideal situation. However, the actual accuracy of underwater topographic measurement is far away from this accuracy due to the influences of other factors. Among these influences, the error of the instantaneous height of transducer brings obvious influence to the final result by the transducer height subtracting depth. Thus it is necessary to study the accurate determination of instantaneous height of sounder transducer[1]. Generally, the instantaneous height is provided by tidal level and transducer draft, while tidal level model error will bring obvious influence to it, especially in the water area of complex tide. Although tide-independent hydrographic measurement technology provides a height to the transducer by GPS RTK (real time kinematic) technique, the time-series height can not meet the requirement of sounding system with high sampling rate, such as multibeam bathymetric system (MBS). Thus, in this paper, the software, which is used for implementing the blend of GPS height and heave so as to accurately present instantaneous height of transducer, is developed. In the following, the design thought, structure, function models, test as well as applications of the software are depicted in detail.

## II. SOFTWARE STRUCTURE DESIGN

The software is used for processing GPS positioning data and heave from motion reference unit (MRU), and then implementing the blend of the two data resources. Thus, the flow of data processing in the software can be designed as Fig. 1.

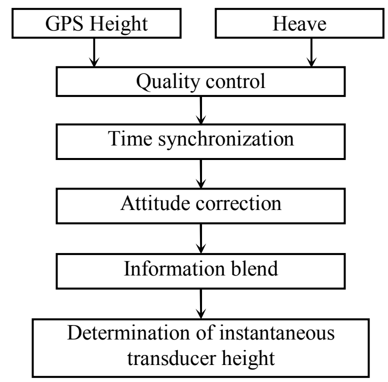


Figure 1. Flow chart of the software

Software structure is designed based on Fig. 1, which includes 7 function modules such as file operation, quality control, time synchronization, attitude correction, information extraction and blend, text display as well as help.

## III. STUDY ON KEY TECHNIQUES AND MAIN FUNCTION MODULES

In above function modules, the 4 main modules, such as quality control, synchronization, attitude correction, the extraction and blend of valid frequency-band information, are studied and introduced in detail.

### A. *Quality control*

Quality control is designed for smoothing observation data, such as GPS height data and heave from MRU, and eliminating the abnormal data from them.

For heave data from MRU, due to internal algorithm, heave data will appear abnormal with acute change of the vessel velocity. In order to guarantee the quality of heave data, high-pass filter is adopted. In the processing, a cut-off frequency is required for the filter. According to known datum, heave signal is valid within 15-second period band. Thus, the cut-off period is defined as 1/10 Hz.

Generally, Kalman filter is used for smoothing GPS kinematic height data. However Kalman filter will appear divergence when the longer continuous abnormal or interrupt records exist in the whole GPS height records. Thus, in the paper, a method, which is heave modifying GPS height, is considered. Because both GPS and MRU at a location monitor the same vertical motion, both of their waves show similar

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vertical motion. Thus, in virtue of heave data, the abnormal GPS height data can also be checked and modified.

*B. Time synchronization*

In actual applications, both GPS height data and heave are logged by computer and marked as computer time. Actually, heave and GPS height is not synchronous. As we known, GPS height is from GPS receiver and marked as UTC time, while heave is derived from MRU. MRU does not have the function to mark time. Heave is marked as computer time as it is logged into the computer system. The difference of the two time clock systems, such as time clock drift and initial time offset, results in the non synchronization between GPS height and heave[2]. The problem often appears in the applications of GPS RTK or post processing kinematic (PPK), which also leads to other attitude parameters such as roll and pitch non synchronization with GPS height, and strongly influences the blend of instantaneous height at transducer.

In order to fulfill the synchronization between them, the data acquisition model is studied. NMEA-0183 format data is also logged into computer and marked as computer time. In NMEA-0183 record, UTC time and computer time are possessed at the same time, while the difference between the two times is also that between GPS height and heave. If the time offset is calculated at each record, a time series of time offset can be acquired. In virtue of the series, the law of time-offset change can be found and used for correcting UTC time to computer time as well as fulfilling the synchronization between GPS height and attitude data.

*C. Attitude correction*

GPS height reflects the vertical motion at GPS antenna. Heave changes with locations at the vessel. Under the dynamic situation, GPS antenna in vessel frame system (VFS) will change with wave and vessel operation. In order to overcome the influence of vessel attitude, it is necessary to design the attitude correction module so as to implement the corrections from original GPS antenna to the transducer as well as those from original MRU to the transducer.

If a surveying vessel is thought to be a rigid body, the attitude parameters from MRU provide the vessel attitude change, and reflect the relation between the instantaneous VFS and ideal VFS. In virtue of these attitude parameters, two rotation matrixes, which are $R(p)$ and $R(r)$, can be constructed with roll and pitch. Integrating lever arm ($dx$, $dy$, $dz$) of GPS antenna, the instantaneous position ($dx'$, $dy'$, $dz'$) of GPS antenna in VFS can be calculated by (1).

$$(dx' \quad dy' \quad dz')^T = R(p)R(r)(dx \quad dy \quad dz)^T \tag{1}$$

If compass data is used in the processing, orientation angle $A$ will be used for transferring ($dx'$, $dy'$, $dz'$) from VFS to geographic reference frame (GRF).

$$\left(Dx \quad Dy \quad Dz\right)^T = R(A)\left(dx' \quad dy' \quad dz'\right)^T \tag{2}$$

In GRF, the height $Z_{RP}$ of RP which is the reference point of VFS can be determined by integrating GPS instantaneous height and the instantaneous vertical distance $Dz$ from above.

$$Z_{RP} = h_{GPS} - Dz \tag{3}$$

A similar processing is implemented with attitude parameters and the lever arm of transducer, the vertical distance $Dz_T$ from transducer to RP, and then the instantaneous height of transducer can be determined by (4).

$$Z_T = Z_{RP} + Dz_T \tag{4}$$

MRU is generally arranged near RP, an attitude correction is also used for heave correction. Referring to (1) to (4), heave is corrected to transducer. A new series $heave_T$ is produced.

Above attitude correction eliminates the influence of vessel attitude and ensures that both corrected GPS height and heave reflect the vertical motions of transducer.

*D. Information extraction and blend*

After above processing, two vertical motion series, $Z_T$ and $heave_T$, at the same position and time are acquired.

Due to the difference in sampling frequencies, heave presents the short-period vertical motions of transducer, while GPS height reflects the middle and long period ones [3][4]. In order to acquire a signal which can reflect the whole frequency-band vertical motion of transducer, digital signal processing technique is adopted in the work. In the blend, two filters, high-pass filter and low-pass filter, are designed. Based on the comparisons among many filters, FFT is chosen for the design, because FFT filter can ensure maximum magnitude response and time synchronization between the filtered signal and the filtering result.

Another problem, cut-off frequency, is also needed to be solved in the blend. Under analyzing the frequency distributions of GPS height and heave at transducer, it is better to choose the cut-off frequency within the common frequency band of the two signals, namely 1/15 ~ 0.5Hz. According to experiments, the cut-off frequency is defined as 0.1Hz.

Using FFT high-pass filter, the high-frequency signal $S_1$ is derived from $heave_T$, while low-frequency signal $S_2$ is derived from $Z_T$ by the FFT low-pass filter.

Due to the difference between GPS and heave, an interpolation processing needs to be done by spline function and fulfills the one to one between $S_1$ and $S_2$. Finally, the blended signal $S_T$ is acquired by (5).

$$S_T = S_1 + S_2 \tag{5}$$

## IV. SOFTWARE DEVELOPMENT

Based on the structure in Fig. 1 and the key techniques, the software, the determination of instantaneous height of transducer, is developed (see Fig. 2).

In order to use conveniently, the function modules are presented by three ways. They are menu model, pop menu model and hot-key model. Eight main menus are designed in the software, which are File operation, parameter input, parameter preparation, data processing, signal blend, browse, view as well as help.

The file operation is used for opening and saving file.

The parameters input menu is designed for acquiring some parameters such as the lever arms of different sensors in VFS (see Fig. 3). The lever arms of GPS antenna and heave need to be input in the interface. Besides, arrangement angle offset of MRU in roll direction, pitch direction and heading direction are also required. Moreover, sampling rates of GPS and MRU are required for later signal processing. An assistant function, the determination of on-the-fly tidal level, can be provided by the software. Thus, the vertical distance between GPS antenna to water surface is also required to fill in the form.

The parameter preparation is used for the determination of time offset between GPS time and computer time (see Fig. 4).

The data processing module includes quality control, time-offset correction, attitude correction, height transformation. In the interface (see Fig. 5), the upper figure shows the raw GPS height series while the down one is the filtered data series. In the time-offset correction interface (see Fig. 6), the upper figure shows the time series and the down one shows the GPS height series corrected by the instantaneous time offset.


Figure 2. Main Interface of the software

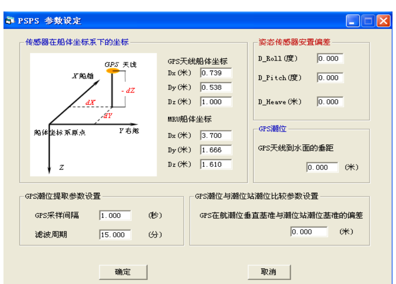

Figure 3. Parameter input

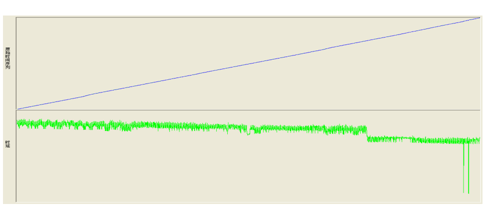

Figure 4. Determination of time offset

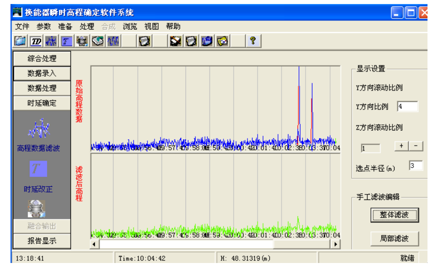

Figure 5. Quality control

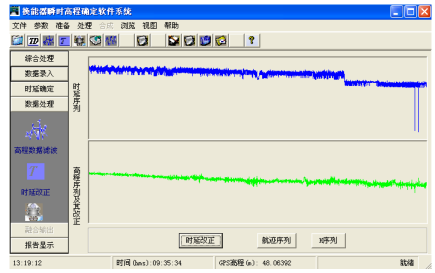

Figure 6. Correction of time offset

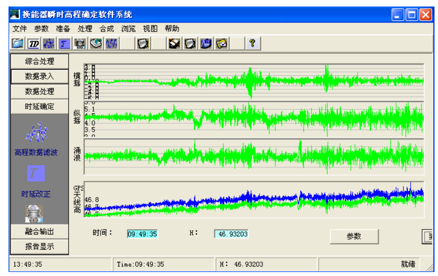

Figure 7. Attitude correction

Attitude time series, such as roll, pitch and heave are shown in upper three figures in the interface of attitude correction (see Fig. 7), and the bottom one show the raw height series and the corrected one which are depicted with blue color and green color respectively.

GPS provide geodetic height, which has not engineering value [6]. Thus the interface of height transformation is designed for implementing the transformation from geodetic height to chart height. Two separations are required. One is height abnormal which reflect the separation between WGS-84 surface and quasigeoid. The other is the chart datum height which reflects the separation between quasigeoid and chart datum. Two models are used for the calculation. One is single-station model, the other is multi-station model. The single station, which has above two separations, can correct geodetic height to chart datum by the sum of the two separations. For multi-station model, we can get the sum of two separations at each of stations, a curve-surface function or a curve-line function will be constructed with the locations and the separations of these stations. Both the raw geodetic height series and the corrected one are drawn in the interface of height transformation (see Fig. 8).

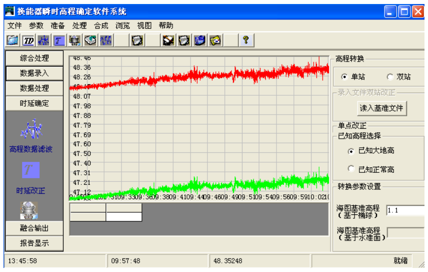

Figure 8. Height transformation

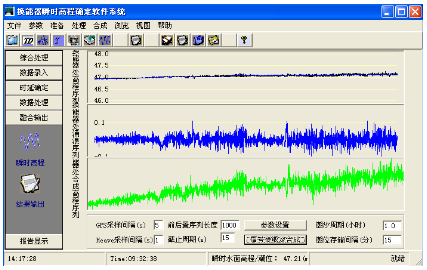

Figure 9. Signal blend

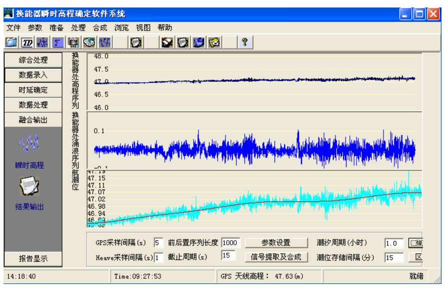

Figure 10: Extraction of on-the-fly tidal level

After above processing, the interface of signal blend (see Fig. 7) is designed in the data processing module. In the interface, the upper figure shows the low-frequency signal from the height series at transducer, the middle one shows the high-frequency signal from the heave series at transducer. The bottom one shows the blend of the two signals. The blend signal not only presents whole trend of GPS height change, but also reflect the subtle change of vertical motion at transducer.

An assistant function, GPS on-the-fly tidal level, can also be done[5]. In the interface of the signal blend, according to the transducer draft, the instantaneous height of water surface can be calculated. According to tidal period, the on-the-fly tidal level is extracted and shown at the bottom figure (see Fig. 10).

During above signal processing and blend, these parameters, such as sampling periods of GPS and MRU, cut-off frequency, tidal period and the time interval for saving on-the-fly tidal level, are filled in designed text boxes at the bottom of the interface. Some text boxes are interactive between the blend interface and above parameter input.

The browse menu is used for browsing these results produced in middle data processing procedure or the final procedure.

The view menu is designed for changing the display of pop menu and hot keys. Users can choose the optimum display according to their requirement.

In order to avoid user operation mistake, a sequence operation is designed in the software. Firstly, file operation is active and other operations become enable. After the necessary files are opened, the other operations become active step by step. The operation sequence is designed to be file operation, time-offset determination, quality control, time-offset correction, attitude correction, height transformation, and the signal blend.

## V. Software Test

The system is developed and tested in Changjiang Estuary. The traditional tidal level subtracting depth and the software presented in this paper are used in the data processing. The seabed topographic accuracies of the two methods are compared. The performance of the software is also tested. Experimental result shows that the software has higher accuracy and reliability in the determination of the instantaneous height.

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