Supporting Hydrographic Vessel Vertical Motion Determination Using RTS Geodetic System

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Abstract. The paper presents the results of vertical trajectory determination called “heave” of hydrographic vessel using Robotized Total Station (RTS). A reference water level for bathymetric measurements, the most frequently adopted in surveys on small areas, is not a flat horizontal surface. The water level changes significantly over time and distance. For this reason, hydroacoustic survey is performed on an unstable floating platform. During hydrographic sounding raw data had to be brought to the common water level. To reach the final reduced depth measurements, it is necessary to obtain the precise vertical position of the platform. Usually roll, pitch and heave vessel motion effects are defined by the Inertial Measurements Unit (IMU) sensors. Unfortunately, the slow rise of water level is difficult to measure by the hydrographic inertial system. For this reason, the author decided to use a geodetic RTS measurement system. A modern robotized instrument has been adopted for precise hydroacoustic measurements carried out in situation when the water level was changing slightly over time. The study describes an experiment conducted on Gdansk Bay in Poland, where the changing vessel height was determined with the use of RTS, Real Time Network (RTN) and Motion Reference Unit (MRU) systems. The final results show that RTS provides sub-centimetre determination of vertical vessel motion. Robotized Total Station proved to be very useful and essential in engineering inland and coastal bathymetric measurements.

1. Introduction

The dynamic growth of Global Navigation Satellite Systems (GNSS), geodesy, laser scanning, aerial photography, hydroacoustic techniques, inertial navigation systems, remote sensing and GIS technologies provide a great opportunity to study the underwater environment, adjacent areas and analyse bottom shape with high resolution [1,2]. Lakes, rivers and other inland reservoirs must be monitored and tested periodically with the utmost care for reasons of their interference with the adjacent environment. The reliability of bathymetry highly depends on the accuracy and precision of positioning and depth detection techniques used. In shallow inland water the bathymetric data are being acquired using Single Beam Echo Sounders (SBES) or Multi Beam Echo Sounders (MBES). Both of them need roll/pitch/heave motion corrections. The key element is the height of the water surface during depth measurements. All raw depth data should be referenced to the common water level. Integrated Bathymetric System, including echo-sounder transducer, is mounted on the motorboat. This vehicle is in motion, and the state of the surface on which it moves exerts a considerable influence on the dynamics
of this movement. A reference water level for bathymetric measurements, the most frequently adopted in surveys on small areas (based on readings from water gauges), is not a flat horizontal surface. The water level changes significantly over time and distance. For this reason, hydroacoustic survey is performed on an unstable floating platform. Usually roll, pitch and have vessel motion effects are defined by the Inertial Measurements Unit (IMU) sensors. Unfortunately, the slow rise of water level is difficult to measure by the hydrographic inertial system. For this reason, the author decided to apply a geodetic Robotized Total Station (RTS) measurement system.

2. Methodology
Vertical vessel motion is usually computed using Motion Reference Unit (MRU) and Inertial Navigation System (INS). It can also be monitored with the use of RTK/RTN satellite positioning technique or classical geodetic Robotized Total Station (RTS). Precise Real Time Kinematic (RTK) or Real Time Network (RTN) positioning provides a centimeter three-dimensional accuracy. RTK/RTN GNSS techniques must be supported by Ground Based Augmentation Systems (GBAS) or local GNSS reference station [3,4,5]. Recently, the modern automatic TS instruments are widely used in geodesy and even navigation [6]. A modern robotized instrument has been adopted for precise hydroacoustic measurements carried out in situations when the water level was changing slightly over time. The study describes an experiment conducted on Gdansk Bay in Poland, where the changing vessel height was determined with the use of RTS, Real Time Network (RTN) and Motion Reference Unit (MRU) systems (Figure 1).

![Figure 1. Gdansk Bay in Poland - study area. Trajectory no. 1 has been analysed.](image)

The methodology described in the study demonstrates the technology of unstable water level determination with the use of classical RTS geodetic technique. The main emphasis of presented work is on the accuracy of vertical trajectory determination of the hydrographic ship using RTS dynamic positioning.

3. Measurements
The vertical survey unit motion was observed by conducting bathymetric sounding with the total station prism located on a hydrographic vessel “Hydrograf 10” (Maritime Office in Gdynia). Experimental measurements along the Trajectory 1 were made at distances from 653 to 799 meters from the geodetic
instrument. The Leica Nova MS50 tachymeter was set up on the control point PKT2, located close to the shore of the Gdansk Bay [7]. Coordinates of the PKT1 and PKT2 geodetic points were calculated on the basis of static GNSS measurements connected to the ASG-EUPOS Polish GBAS network. The experiment was made in good weather conditions (no wind and no big waves). The visibility between the instrument and the mirror was not impaired.

![Figure 2. Hydrographic vessel during GNSS and RTS positioning.](image)

The vertical vessel motion (heave effect) was measured using: GNSS RTK/RTN, MRU Hydrins and RTS. Additionally, the 3D vessel positions were calculated using On The Fly GNSS technique. The Figure 3 shows 150 out of 375 measuring epochs analysed during the experiment along the first passage of the vessel at an average speed of 2.1 m/s.

![Figure 3. Vertical motion graph of the vessel determined by the RTK/RTN, RTS (Tachimetr), OTF and Hydrins techniques.](image)
4. Results and discussions
During the passage along Trajectory 1, the sea was calm and there was no undulations. Therefore, the ship's vertical movements were smooth, and the trajectories determined coincide with the indications of the water level on the local mareograph. The RTK/RTS and Hydrins heights were compared with the heights of the hydrographic vessel determined using OTF post-processing. Figure 4 presents height differences for 150 measuring epochs.

![Trajectory 1 - Height differences](image)

**Figure 4.** Height differences between OTF and RTK/RTS/Hydrins.

The largest differences were observed in the height determined by the real time GNSS technology. The maximum value is 0.122 m and the standard deviation is 0.046 m. Such a large difference in vertical motion determination may be caused by interruptions in the proper functioning of ASG-EUPOS GNSS base station in Gdansk on the day of field tests. The results of the height determination tests with the automatic RTS are significantly better. The differences range from -0.067 m to 0.061 m. The standard deviation is 0.038 m.

A stable and precise height was determined by the Hydrins system, supported by the Trimble MS 750 receiver (operating in RTK float mode). The standard deviation of Hydrins determinations was 0.016 m. It should be noted that for the initialization of the inertial system, the initial height value read from the local water level gauge had to be given. For this reason, the inertial height determination analyses performed are more indicative of their precision than of their accuracy. Values of height differences and standard deviations for Trajectory 1 are presented in Table 1.

**Table 1.** Height differences and standard deviations for Trajectory 1.

|          | dH            | SDH          |
|----------|---------------|--------------|
| GNSS/RTN | od -0.029 do 0.122 m | 0.037 m     |
| RTS      | od -0.067 do 0.061 m | 0.020 m     |
| Hydrins  | od -0.064 do 0.058 m | 0.019 m     |

Additionally, the speed values of the hydrographic vessel determined using the analyzed techniques are presented in Figure 5.
Figure 5. The speed of the vessel determined by different measurement techniques: RTK/RTN, RTS, OTF, Hydrins.

The most stable is the speed calculated on the basis of coordinates determined by the OTF post-processing technique. The vessel speed results from the Hydrins inertial system are also very stable. The speed calculated on the basis of the GNSS/RTN real-time position determinations has several outliers. RTS speeds are slightly noisy.

5. Conclusions
The main goal of the measurement experiment carried out on the Gulf of Gdansk was a direct comparison of the accuracy of vertical hydrographic vessel determination using RTN/GNSS satellite measuring technology with the Trimble R8 SPS800 receiver, the RTS Leica Nova MS50 robotic total station and an advanced inertial navigation system dedicated to hydrography MRU Hydrins/Trimble MS 750. The presented results show that Robotized Total Station survey provides a sub-centimetre determination of water level changes. The RTS geodetic technique with 0.02-0.05 m of vertical accuracy proved to be very useful and essential in engineering precise bathymetric measurements on small water areas. The presented analyses of the RTS vertical observations suggest that we can use classical geodetic method to determine 3D hydrographic vessel position. However, a surveyor should take into consideration that the distance from the reference geodetic point is a key element influencing accuracy and precision. Achieved accuracy depends directly on the distance between the prism and the station. Some gaps may occur due to no visibility between the total station and a prism mounted on the boat. The RTS measurements may also have outstanding observations, which should be analyzed, removed or estimated. To avoid large vertical error in observations we can also combine geodetic RTS with RTK/GNSS measurements and Inertial Navigation System. The integration of RTS/GNSS/INS observations can be used to estimate the final vertical boat trajectory for further raw bathymetric depths correction [8,9]. The final results show that RTS provides sub-centimetre determination of vertical vessel motion. Robotized Total Station proved to be very useful and essential in engineering inland and coastal bathymetric measurements.

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