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Ship Under-Keel Clearance Monitoring Using RTK GPS

Tim P. Gourlay[1] **and Wallace G. Cray**[2]
[1]Centre for Marine Science and Technology, Curtin University, Perth, Australia
[2]Voyage Management Systems, Brisbane, Australia

Abstract

This article proposes a new method to assist with under-keel clearance (UKC) management, using real-time kinematic (RTK) GPS receivers. The proposed GPS method is intended to be integrated with existing UKC planning methods. The current state of the art in RTK GPS technology is discussed, and a method is outlined for using such measurements to monitor the clearance between a ship's keel and the sea floor. The method uses permanently installed GPS base stations in the area of interest, together with surveyed-in GPS receivers on ships wishing to use the system. An example use of the method is given based on measurements taken in Torres Strait.

1 Introduction

The most accurate GPS positioning method currently available for absolute positioning of moving objects is the real-time kinematic (RTK) system.

High-accuracy RTK GPS units receive dual-frequency GPS signals from satellites, and compare the phase of the carrier signal with that of a fixed base station at a known location, to accurately determine the latitude, longitude and altitude of the GPS unit (specifically the antenna). Typical positioning RMS error can now be as low as 10 – 15mm in the horizontal and 20 – 25mm in the vertical.

RTK GPS measurements on ships have been used to calculate dynamic sinkage, by comparing the vertical position when under way, to the vertical position at rest (Feng & O'Mahony 1998, Gourlay & Klaka 2007). Allowances are made for the changing tide height throughout the transit.

Up until now, such measurements have been used primarily for validating ship squat formulae.

2 UKC predictions

The net under-keel clearance of a ship is generally predicted by summing the chart datum depth and tide height, and subtracting the draft and estimated local sinkage. This method is shown in Figure 1 and Equation 1.

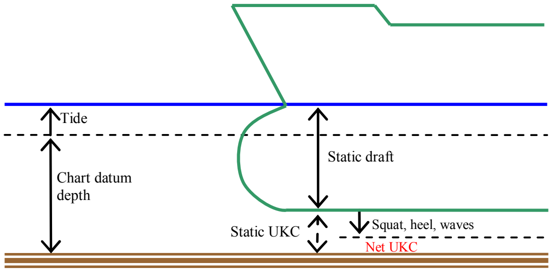

Figure 1: Predicting UKC for a ship in shallow water

$$
\begin{aligned}
[\text{Net UKC}] = {} & [\text{Chart datum depth}] + [\text{Tide}] \\
& - [\text{Static draft}] \\
& - [\text{Squat, heel and wave response}] \qquad (1)
\end{aligned}
$$

This method allows the UKC to be predicted over an entire proposed transit, using the changing bathymetry, tide height, and sinkage due to squat, heel and waves.

3 UKC monitoring using depth sounder

UKC monitoring can be done using the ship's depth sounder. To get accurate results in shallow water, it is desirable to use different settings (high frequency, short pulse length) to those used in deep water. Depth sounder accuracy is also affected by ship electrical interference and transducer ringing. These combined factors mean that accurate depth soundings can be obtained by hydrographic surveyors when carefully performed, but not necessarily so on ships with limited depth sounder quality and time constraints on the crew.

In any case, depth sounder readings are of limited usefulness unless they can be used to help predict the UKC in the near future. This requires correlation of the measured depth sounder data and the exact bathymetry in the area. Otherwise the measured UKC is composed of an unknown keel elevation and an unknown chart datum depth. In future it may be possible to perform such a correlation, once sufficiently accurate bathymetry data are available, by combining the depth sounder, GPS and bathymetry data. This is a topic for further research.

In the meantime, technology is currently being developed for real-time monitoring of keel elevation relative to chart datum, which can be combined with chart datum depths to assess ship UKC. This is the method which will now be described.

4 UKC monitoring using GPS

The rapid advancement in GPS technology that is under way allows us to imagine a time in the next five to ten years when RTK GPS technology may be sufficiently affordable and user-friendly to be deployed permanently onboard ships. This idea opens up new possibilities in ship UKC monitoring.

The ability of GPS receivers to determine the altitude of fixed points on the ship relative to a known vertical datum means that the potential exists to bypass the measurement of tide heights, ship drafts and local sinkage in determining the elevation of a ship's keel relative to chart datum. When combined with charted bathymetry, the under-keel clearance can then be obtained.

The RTK GPS concept for monitoring real-time ship under-keel clearance is shown in Figure 2 and Equation 2.

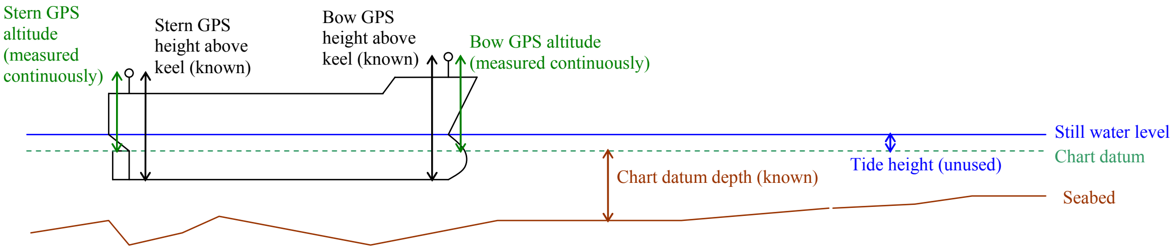

Figure 2: GPS concept for monitoring ship UKC

Real-time UKC at bow
= (chart datum depth at latitude and longitude of bow at that instant)
+ (measured bow GPS altitude above chart datum at that instant)
– (bow GPS antenna height above keel)
(2)

Similar relations are used at other points on the ship.

In order for this method to be valid, the datum used for GPS elevations must be chosen to be the same as the chart datum used for bathymetry.

As seen in Equation 2, the GPS concept delivers a direct method of monitoring ship UKC, which does not require input of tide height, ship draft or ship sinkage. The combined effect of all these is measured directly by the GPS.

Note that standard UKC planning methods must still be used for estimating UKC over the remainder of a given transit, to take into account future variations in tide height, ship speed and so on.

5 RTK GPS hardware requirements

The RTK GPS monitoring system for ship UKC would require the following hardware to be installed:

Permanent RTK GPS base stations

The method can be used in any area in which a permanent RTK GPS base station is able to be installed. The base station transmits RTK GPS corrections to the shipboard receivers.

The accuracy of RTK GPS measurements decreases with distance between the base station and roving receivers. In addition, RTK GPS corrections can generally only be transmitted over line-of-sight distances. Therefore for ports with fairly short approach channels (e.g. less than 8 nautical miles), a single base station should be sufficient, while for long channels multiple base stations may be needed.

Permanent ship-mounted RTK GPS receivers

RTK GPS receivers would be mounted permanently on ships wishing to use the UKC monitoring system. In order to measure the vertical elevation of any point on the ship's keel, three RTK GPS receivers should be used on each ship, ideally one at the bow, one at the port bridge wing and one at the starboard bridge wing. Each RTK GPS antenna should then be surveyed to determine its exact position relative to the ship's coordinate system.

The RTK GPS units receive GPS signals from satellites, as well as RTK GPS corrections from the shore base stations, and calculate accurate time-stamped latitude, longitude and altitude. This information is then transmitted to the ship's bridge. For the bow receiver, the ship's existing cable runs may be used. For the bridge wing receivers, either cable or wireless methods could be used.

6 UKC monitoring software

CMST and VMS have written a development version of the software "GpsKeelClear", which is designed to run on a laptop on the ship's bridge. Measured UKC would be displayed on this laptop, and could also be transmitted to the harbourmaster or pilot station ashore.

The software is designed to operate as follows:

Pre-input bathymetry data
Accurate bathymetry data is pre-input for each shipping channel that is installed with RTK GPS base stations. The bathymetry data is obtained from hydrographic surveys, giving chart datum depths on a (latitude,longitude) grid.

Pre-input GPS antenna positions
The onboard RTK GPS receivers are "surveyed in" on installation, so that their exact positions are known relative to the ship's coordinate system. The geometry of the ship is also pre-input.

Input measured RTK GPS positions
The software takes in the corrected RTK GPS positions from each of the ship RTK GPS units, which give the latitude, longitude and altitude of each receiver relative to chart datum. The pre-input geometry of the ship is then used to determine the latitude and longitude of each keel extremity at that instant, together with the vertical position of each keel extremity beneath chart datum at that instant.

Calculate corresponding bathymetry
The measured latitude and longitude of each keel extremity are combined with the pre-input bathymetry grid to determine the chart datum depth at each keel extremity at that instant.

Display keel and seabed vertical positions
The vertical position (beneath chart datum) of the seabed and ship's keel are displayed on screen for the ship pilot.

7 UKC monitoring example

To demonstrate the method, a UKC monitoring snapshot is presented in Figure 3, based on an RTK GPS trial of the ship "Iver Example" travelling eastbound through Prince of Wales Channel, Torres Strait on 12th February 2008. This trial was one of 11 RTK GPS trials on ships travelling through Torres Strait, which used three RTK GPS receivers on each ship, and an RTK GPS base station on Thursday Island. An escort vessel was also used as a moving base station for the squat prediction validations (following the method of Härting & Reinking 2002), however an escort vessel is not required for the UKC monitoring method described here.

The results given here were not generated in real time, as is proposed for the system, but were hindcast from collated real-time measurements.

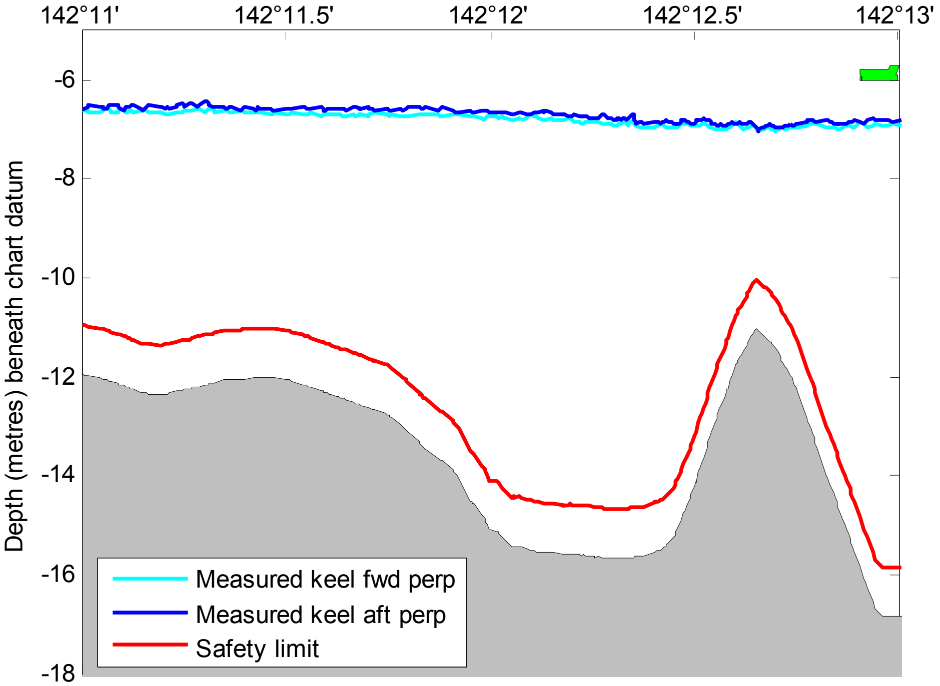

Figure 3: UKC monitoring snapshot for Iver Example, eastbound through Prince of Wales Channel on 12th February 2008

Since the transit is in an east-west direction, depths have been plotted against longitude, based on the position of the ship's bow at that instant during the transit. For port approach channels, depths would normally be plotted against distance along the channel.

The keel depths in Figure 3 have also been plotted using bow longitude. The ship is shown in green at the top right, to the correct horizontal scale. The snapshot is taken when the ship's bow reaches 142°13´E, and shows the previous two nautical miles (approx) of the transit. The keel depth beneath chart datum is shown at the bow and stern. Normally the maximum keel depth over all of the hull extremities (including port and starboard forward and aft shoulders) is also shown. However in this case the maximum keel depth is equal to the value at the forward perpendicular, so has been omitted for clarity.

The bathymetry grid used for this example has been taken from Australian Hydrographic Office charts, however recent surveys will soon produce more detailed bathymetry data which could be input to the software.

The plot shown in Figure 3 is a snapshot at the time the ship's bow passes 142°13´E. When running UKC monitoring software on the ship's bridge, the screen would update continually to show the latest position and depths.

8 Comparison with UKC predictions

The potential exists for the RTK GPS monitoring method to be used alongside predictive UKC software. For example, the measured UKC display shown in Figure 3 might also display the predicted maximum keel depth alongside the other values. Since conservative methods are used to predict the ship squat and wave-induced motions, the measured keel depth should always lie above the predicted value. This comparison would serve as a check on the predicted UKC.

An example use of this method is shown in Figure 4, at the same snapshot as shown in Figure 3, with the bow passing 142°13´E. In this case the plot shows the predicted maximum keel depth at each point during the transit, as developed during the passage plan. The measured keel depth (maximum over all keel extremities) is also shown up until the present time. The chart datum depth is over the measured track up until the present time, and over the predicted track for the remainder of the transit.

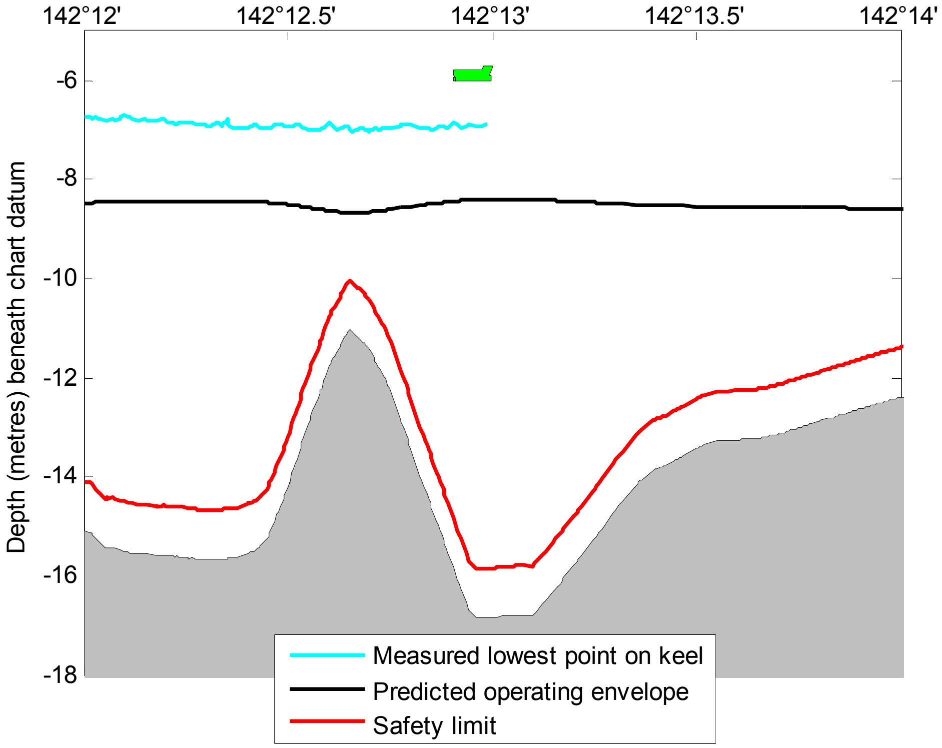

Figure 4: UKC monitoring snapshot for Iver Example, eastbound through Prince of Wales Channel on 12th February 2008, showing measured and predicted UKC

Such a display serves as a check on the UKC prediction method used. Also, if for any reason the measured keel depth lies below the predicted value, it can be seen whether this will lead to a possible grounding over the remainder of the transit.

In practice such a UKC display might show the whole transit in a single display, as well as a close-up of the present situation as shown in Figure 4.

9 Ship motions analysis

The area of ship UKC prediction which arguably involves the largest error is that of wave-induced motions. The study of wave-induced motions in shallow water is a complex topic, and research is ongoing in this area. Further full-scale data is desirable to continue validating the prediction models used.

If RTK GPS positions are obtained at a sufficiently fast sample rate (e.g. 1 second sample interval), statistics on the heave, pitch and roll of the ship can be calculated from the measured elevations. Along with concurrent measured wave data, the measured ship motions will help to build up a data set with which to validate ship motion predictions.

10 Conclusions

A new method of ship UKC monitoring has been proposed which uses RTK GPS receivers at known locations on a ship, as well as a permanent RTK GPS base station close to the channel. When combined with bathymetry data, the system allows the measured keel depth and seabed depth to be plotted concurrently.

Such a UKC monitoring system cannot take the place of good passage planning, which takes into account the changing tide height, ship speeds and other factors over the whole transit.

The UKC monitoring system is designed to be integrated with passage planning, so as to be able to show the measured and predicted keel depths on the same display in real time. This will serve as a valuable check on the accuracy of the UKC predictions in real time, and help to build up a data set of measured squat, heel and wave-induced motions results for improving future UKC passage planning.

11 References

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