Artefacts in Multi-beam Echosounder Data

This article is about my thesis project, which I did in collaboration with Auke van der Werf at the Dutch Nautical Academy at Terschelling (the Netherlands). The research for the thesis was done at the Dutch Directorate General for Public Works and Water Management (Rijkswaterstaat). This article presents a subset of the thesis. I would like to share the knowledge I gained and the lessons I learnt about lever-arm errors, motion time delays and yaw misalignment, which can result in dynamic motion residuals, also called artefacts or wobbles. <P>

Over the last decade, Rijkswaterstaat (part of the Dutch Ministry of Transportation and Waterworks) has invested heavily in state-of-the-art survey equipment and hydrographic quality-control procedures. Nowadays, the use of real-time kinematic (RTK)-GPS, motion sensors and multi-beam echosounders is standard on most survey vessels. These sensors improve the accuracy of hydrographic surveys, for instance, for safe navigation and dredging purposes.

During the last few years, Rijkswaterstaat has been using the shaded-relief technique (also known as sun illumination) as one of their quality-control tools for their surveys. This presentation technique makes sensor integration errors more visible than do techniques such as contours or colour-coded charts.

Artefacts

Artefacts are commonly 0.25–0.5% (Hughes Clarke et al., 1996) and therefore can be within survey specifications such as the International Hydrographic Organization (IHO) Special Order. The IHO Special Order states that all error sources must be minimised. Artefacts are not random: they are correlated with the motions of the survey vessel and can thereby be described as dynamic systematic errors.

There can be many sources of artefacts: software, speed of data transfer or, for instance, errors in the sound velocity. Three common errors that lead to artefacts are wrong lever-arm definitions, time delays on the roll component and a yaw misalignment of the motion sensor.

Method

The project was performed from February to July 2007 in Delft at the Geo Information and ICT Advisory Department of Rijkswaterstaat. The start of the project involved a literature research. I found that most of the relevant literature was written by the University of New Brunswick (UNB) (Canada). The project consisted of two parts: the first part dealt with a theoretical explanation of artefacts, the second part involved case studies. The case studies were carried out during a 10-day visit to the UNB. During that visit, I followed classes given by John Hughes Clarke and Jonathan Beaudoin about artefacts and their software program, called SwathEd. Doing field trials onboard the survey vessel Heron together with the staff of the UNB was a great experience for me.

Artefacts Related to Lever-arm Definitions

If the location of sensors within the ships coordinate system is incorrectly reported (for example, signs are often confused), it will result in incorrect sensor location prediction. The resulting errors are positional in nature as no angular misalignments are involved. These position errors are manifested as both static and dynamic errors.

Defining wrong lever-arm definitions in across (+ Y) or along track (+ X) will lead to an induced heave error. A Z lever-arm error, leading to an induced heave error (IH), has to be very large to show up in the survey data, as can be calculated in the following formula (Hughes Clarke, 2003):
?
IH = ?X sin (pitch) + ?Y sin (roll) cos (pitch) + ?Z (1–cos(roll) cos (pitch))?

As shown in the formula, an incorrect definition of lever arms correlates with the ship's motions during the multi-beam survey. Without motion, a wrong lever-arm definition will not appear in the data.
Figures 1 and 2 represent data of the same survey line. Figure 1 contains an along-track lever-arm error (2m) and Figure 2 has an across-track lever-arm error (2m). The sun illumination of both Figures shows a similar bottom; however, the correlation with either pitch or roll becomes clearly visible on plotting the vessel's motions.
?From these Figures it appears that both types (X lever arm and Y lever arm) of artefacts have the same structure. ?
Artefacts Related to a Motion Time Delay of the Roll Component?
The effect of a time-delay error in pitch and heave is very small on the bathymetry, but a time-delay error in roll may have a great effect on the bathymetry.

Artefacts caused by a roll-delay (time delay in roll) error can be prevented by importing the true time delay in the correct way. This means

that the time delay has to be imported in the motion sensor or in the survey software.
If a wrong value of roll delay is imported, artefacts will also develop if there is a roll rate. In this case, artefacts arise that cause the linear swath to make a slope on a flat bottom. Figure 3 represents data of the same survey line as in Figures 1 and 2, and contains a time-delay error of 35ms. ??
Artefacts Related to Yaw Misalignment?
Yaw misalignment in the motion sensor will cause cross-talk between the roll and pitch. So, if there is a yaw misalignment and the ship has a pitch only, the motion sensor will measure a roll, too.
Cross-talk can be calculated with the following formulas (Hughes Clarke, 2003):
?
sin(OR) = cos(E)sin(TR) + sin(E)sin(TP)

sin(OP) = cos(E)sin(TP) – sin(E)sin(TR)?

where OR is the observed roll (degrees), OP the observed pitch (degrees), TR the true roll (degrees), TP the true pitch (degrees) and E is the yaw misalignment angle (degrees).

The effect of yaw misalignment is artefacts that cause the linear swath to make a slope on a flat bottom. These artefacts look the same as artefacts caused by a roll delay.
Figure 4 represents data of the same survey line as in Figures 1, 2 and 3, and contains a yaw misalignment of 4SDgr. In this case, the yaw misalignment correlates with the pitch.

Lessons Learnt

The most important lessons learnt during this thesis are that:
•wrong lever-arm definitions, either along or across track, can lead to induced heave errors. An artefact caused by an X lever-arm error has the same structure as an artefact caused by a Y lever-arm error?SBlta time delay in the roll component of the motion sensor will lead to swaths that are out of phase?SBlta yaw misalignment in the motion sensor will cause cross-talk between roll and pitch.

Conclusion and Recommendations

The artefacts discussed in this article can be prevented. Yaw-misalignment artefacts can be prevented by aligning the sensors onboard to the ship’s coordinate system in the correct way.

When the lever-arm definitions are to be imported, ensure these values are not imported twice or with a wrong sign. This will prevent lever-arm errors.
It is recommended to formulate an extra procedure to recognise and detect artefacts at an early stage. This procedure can occur after the patch test. The procedure can be set up as follows:?SBltchoose a well-known area with a flat bottom
•sail two lines that are crossed to be sure that the (possible presented) artefacts do not present the true bottom?SBltperform the procedure when the ship’s motions are recorded (thus not at a flat sea level) ?SBltuse the sun-illumination technique to recognise possible artefacts?SBltbefore analysing software (such as SwathEd) is started up, first check if the settings of the baud rates are optimal in the software and sensors.

References

Hughes Clarke, dr. J.E., (2003), “Dynamic motion residuals in swath sonar data: Ironing out the creases: International Hydrographic Review”. Fredericton: Ocean Mapping Group, University of New Brunswick: Dept. Geodesy and Geomatics Engineering.

Hughes Clarke, dr. J.E., Mayer, L.A. & D.E. Wells, (1996), “Shallow water imaging Multibeam sonars: A new tool for investigating seafloor processes in the coastal zone and on the continental shelf. Marine Geophysical Research”. 18: 607-629. Fredericton: Ocean Mapping Group, University of New Brunswick: Dept. Geodesy and Geomatics Engineering.

Godin, A., (1997), “The Calibration of Shallow Water Multibeam Echo-sounding Systems”. University of New Brunswick: Dept. Geodesy and Geomatics Engineering.Hammerstad, E., (2001), “EM Technical Note, Subject: Multibeam Echo Sounder Accuracy”.