

The MRU and SRF Aligned

Part II: Solving the Pitch and Roll Angles

The alignment of the motion reference unit (MRU) is important for the accuracy of a multi-beam survey. The patch test is mostly used to solve angular offsets between the multi-beam head and the MRU; however, this does not solve all the aspects that must be taken into account. This article in two parts describes the method used by the Survey Department of the Directorate-General for Public Works and Water Management (Rijkswaterstaat; The Netherlands), which for reference purposes in this article we shall call the 'Dutch method'.



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AS EXPLAINED IN PART I IN THE previous issue of *Hydro INTERNATIONAL*, the alignment of the motion reference unit (MRU) is becoming increasingly important with increasing accuracies of positioning and multi-beam systems. The patch test does resolve the angular offsets between the multi-beam head and MRU, but not between the MRU and the ship's reference frame (SRF). In Part I, a method was described to align the vertical axis of the MRU with the SRF (yaw angle) in order to overcome cross-talk between pitch and roll. Here in Part II, the focus is on the alignment of the pitch and roll axis themselves.

For the best quality data, we need to position our vessel (or rather the transducer) within the dimension of the footprint, which will become smaller than 0.17 metres in water depths of less than 20 metres for a 0.5° nadir beam.

As Rijkswaterstaat uses real-time kinematic (RTK) for their 3D position, methods were needed and developed to measure sensor offsets and to align the MRU with the SRF, both with sufficient accuracy. Over the years, this resulted in methods that allow the alignment of the MRU

with the SRF within 0.05° for pitch and roll and 0.3° for yaw.

The patch test will not solve for the alignment angles between the SRF and MRU or multi-beam head. In Part I this was explained for the alignment of the vertical axis. Similar to the yaw, we may also expect that the pitch and roll angles found with the patch test are the sum of two misalignments: the misalignment between the MRU and SRF and that between the multi-beam head and SRF. When we apply these angles to the MRU or multi-beam head, we still have a misalignment between those two sensors on one side and the SRF on the other, introducing positional errors to the multi-beam head.

Aligning the Pitch and Roll Axis

Once the yaw is calibrated and applied to the MRU, the misalignment in pitch and roll can be measured. See Part I, with a description of how the yaw was calibrated using fixed points onboard the vessel that were surveyed together with the rest of the vessel's geometry. Typically, the centre of at least four but usually six or more bollards are surveyed, all marked with a physical centre point.

The pitch and roll calibration is done using these centre points and can be performed in three different ways:

1. on terra firma using total station data
2. on terra firma using levelling
3. in the water using levelling.

1. On Terra Firma Using Total Station Data

When measuring the ship's geometry using a total station on terra firma, the least-squares network adjustment will give the vessel with its attitude how it was lying on dry land in reference to the vertical. All calculated points are then rotated and shifted to have the required SRF (usually this means that the average measured waterline becomes the X-Y plane). The rotation angles needed to get the required SRF can be compared with data logged from the MRU during the geometry measurement and will directly give the offsets for pitch and roll.

2. On Terra Firma Using Levelling

When the vessel is measured using photogrammetry, the resulting products are not vertically related. On the one hand, this is an advantage as the measurement is not influenced or restricted by the SRF's attitude

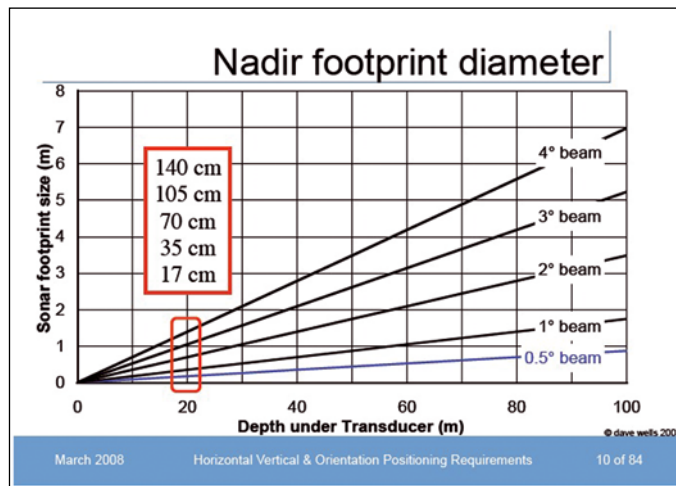


Figure 1: Nadir footprint diameter (Courtesy of the OMG).

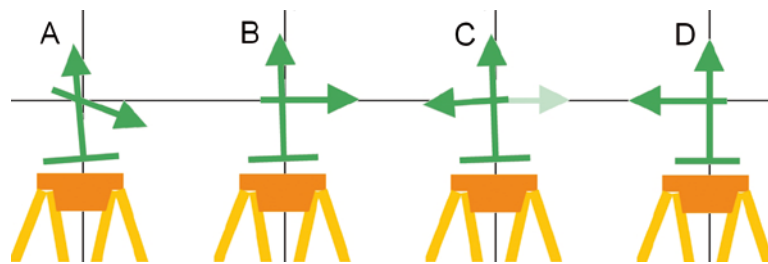


Figure 2: Aligning the primary and secondary axes of the tilting level.

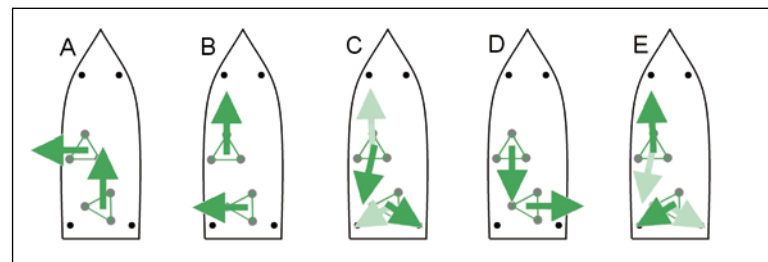


Figure 3: Pitch and roll calibration sequence.

but, on the other hand, additional measurements have to be taken to resolve pitch and roll misalignment. Again, this is done using the fixed points onboard the vessel. While data are logged from the MRU, the fixed points onboard are levelled using conventional survey techniques. As the fixed points are known within the SRF, we can now compare their relative positions with the results of the levelling and find the pitch and roll misalignment.

3. In the Water Using Levelling

Having the vessel on terra firma for the pitch and roll calibration is not general practice. In most cases, the MRU is brought onboard when the vessel is afloat. However, we still want to measure the pitch and roll of the SRF accurately. Again, this is done by conventional land survey techniques. As with the previous method, levelling is done using the fixed points onboard as reference. The problem is that the vessel is in the water and thus pitching and rolling. Calibration is therefore done using an uncompensated levelling instrument, preferably a dumpy level or a tilting level. When using the tilting level, the secondary axis of the instrument has to be set square to the primary axis as

with a dumpy level (see Figure 2). The method was described by Knol in 1982 (for reference see Part III, 1) and is done on land by levelling the instrument on a tripod using the circular level, then checking the plate level and adjusting it horizontally using the tilting screw (A and B in Figure 2). Then the secondary axis is turned 180° around its primary axis and the plate level is checked again (C).

Any difference found is taken away by adjusting both the tribrach and tilting screw so that each compensates half the error (D). The procedure is repeated until no further adjustment is necessary and a mark is made on the tilting screw to indicate its proper setting.

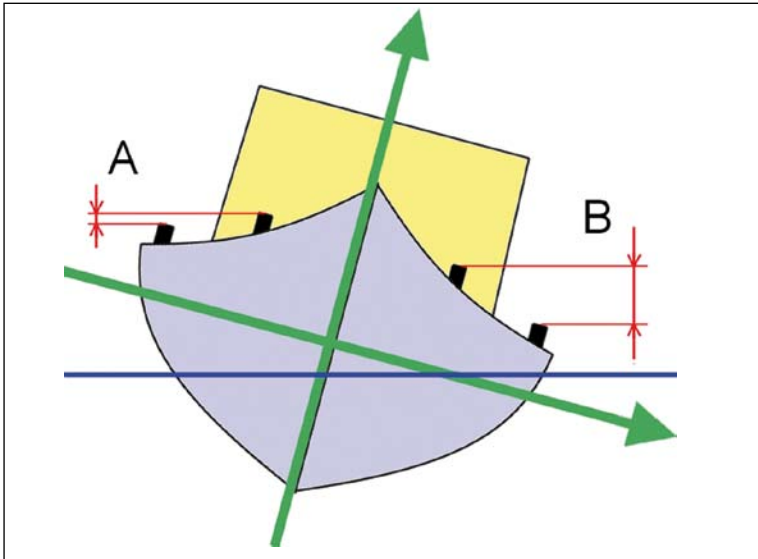
The instrument is now taken onboard and set up symmetrically between the points that will be used for the levelling (Figure 3 shows this

for both pitch and roll calibration). For convenience, the instrument is placed in a way that one screw of the tribrach is pointing towards the axis you want to calibrate, while the other two are perpendicular to it. In this way, the instrument can be levelled using only one screw during the actual calibration. Before we can start the calibration, the instrument is first oriented perpendicularly to the required axis and levelled as well as possible only using the screws of the tribrach (A in Figure 3). Then the instrument is rotated in the direction of the required axis and levelled in that direction as well, again only using the tribrach screw in that direction (B). Now two readings at the levelling rods are taken: one in front and one behind (C). The instrument is then turned parallel to the required axis again and levelled as well as possible (D, note that the instrument is now facing a direction

Figure 4: A tilting level set up for roll calibration.



Figure 5: Roll-induced error.



opposite to the first time to cancel out any instrumental errors) and another set of readings is taken (E). This procedure is repeated at least five times (resulting in 10 measurements), during which a computer logs all necessary MRU data. The entire calibration is then repeated on another set of fixed points and data are logged again. Finally, all observations are averaged and the attitude of the required axis can be calculated from the Z-coordinates of the fixed points and the levelling results. The logged data are also averaged, and compared with the calculated attitude to find the misalignment. As with the heading calibration,

Figure 6: Pitch calibration onboard.



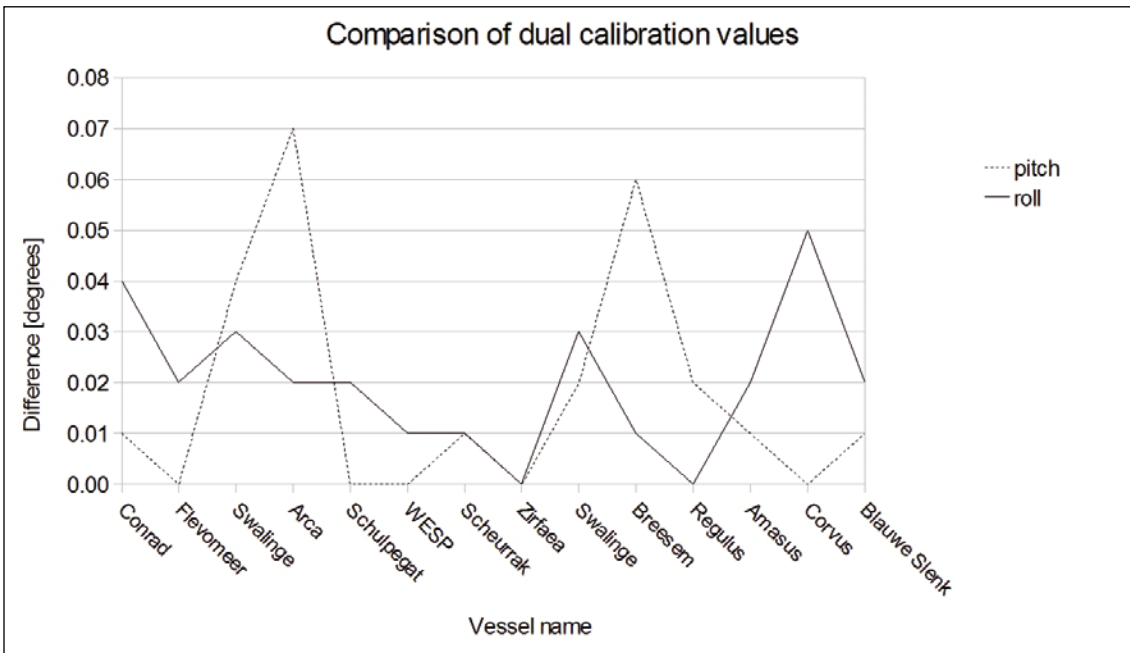


Figure 7: Comparison of dual calibration values.

methods two and three have a pitfall. The fixed points used in the levelling are known within the SRF, but the lines through them are not necessarily oriented perpendicularly to it. Most vessels are symmetrical along the centreline, but not in the direction perpendicular to that. As can be seen in Figure 5, the bollards on the bow are placed closer to each other than the ones astern. This means that the pitch calibration will have some roll-induced errors when the SRF has a non-zero roll and the fixed points are not distributed symmetrically (height difference B is larger than height difference A). For this reason, roll is logged during pitch calibration (and vice versa) to compensate for this effect mathematically.

Performing the pitch and roll calibration in the water has one large advantage over doing this on land. During the calibration, a crew of at least three works its way around the vessel, always standing on its extremities. This means the vessel is ballasted with about 250 kilograms on every end of the horizontal axis of the SRF. As a result of this, the changes in attitude of the MRU can be seen in the logged data and from

that it becomes clear how the rotational signs of pitch and roll are defined in the MRU (bow up = positive, starboard down = positive, etc.), something that is not always as easily done when the vessel is on terra firma.

Results

How well does the method work? Figure 7 gives a summary of 14 Rijkswaterstaat vessels calibrated in the past 12 months, where calibrations were done twice as described above (one vessel, the *Swalinge* was calibrated twice in this period). Each time, the difference between the two comparable calibrations is given. Ideally, the difference should be zero, and preferably less than 0.1°. The average calibration difference is 0.02° with a standard deviation also of 0.02° (1σ, 68%). Although the figures do not tell us whether the MRU was properly aligned with the SRF, they do tell us that, in general, the repeatability is well within the preferred values and we therefore may assume that alignment using the described 'Dutch method' was successful. 🌐

Acknowledgements

See Part III (1), where the history of the development of the method and

acknowledgement to those who contributed to it is given.

Editor's Note:

This article as initially submitted was far too long to be published in our magazine.

As we wanted to let our readership hear about this method of aligning MRUs with the SRF, we asked the author to re-write the article so that it could be published in two parts. The first part, 'Solving the Yaw Angle', was published in the previous issue (November 2008).

A third part to this aligning method is on the history of the development of the method and includes acknowledgement of those who contributed to the method. This part is published on our website only.



1. www.hydro-international.com

The Author

After his education in hydrography, **Nicolas de Hilster** was employed by Osiris from 1989 to 1996. He then moved to the Survey Department of Rijkswaterstaat (GAM Department). In 2000, Nicolas became the founding owner of Starmountain Survey & Consultancy. info@starmountain.nl