

# GEOMETRICAL TRANSFORMATIONS FOR NAUTICAL CHARTS OF GREENLAND

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## ABSTRACT:

We present an algorithm for transformation and reconstruction of nautical charts, based on identification of common points in new orthophotos and old charts. The algorithm shows to be implementable and scalable, opening for its use in an operational setting.

## 1 INTRODUCTION

The state of nautical charting for the waters around Greenland has historically reflected Greenland's combination of huge size, small population, and (for large parts) inaccessibility due to harsh climate. The nautical charts in current use for the area are mainly based on surveys carried out in a long span of time from the 1930s to the 1980s. Most of the charts were produced in the 1960s due to a rising political awareness of the problem, after a dramatic 1959 event in the southern waters of Greenland, where the passenger ship "M/S Hans Hedtoft" was lost along with the lives of 95 passengers and crew members.

The current business development in Greenland includes a focus on petroleum and minerals prospection/exploration. This leads to increasing traffic through the archipelago as well as off-shore. Also the growing tourism industry has resulted in a steadily increasing number of large cruise ships in Greenlandic waters. In-shore, an increase of the number of small passenger ships is seen, due to a general change in the pattern of passenger transportation.

Hence, the need for more precise charts is growing significantly in these years, not only for the sake of the Greenlandic people but also for the sake of the vulnerable arctic environment. In this paper we summarize some recent work carried out in order to bringing the old charts up to date without having to do extensive and costly re-surveying.

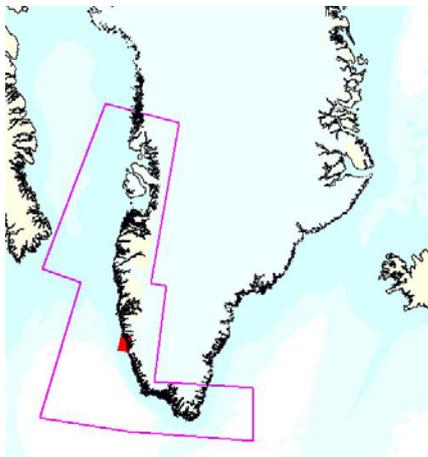


Figure 1: First part of the project involves updates for 65 charts inside the polygon outlined. The red spot indicates the coverage of chart no. 1212, which is our primary test site.

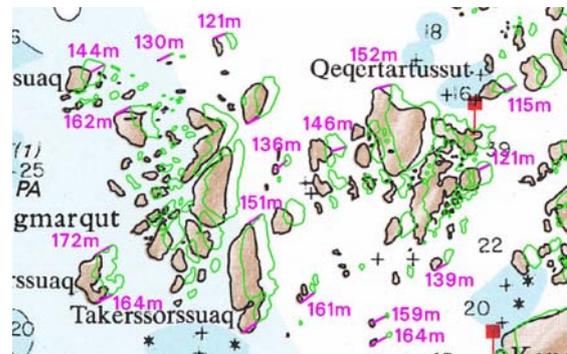


Figure 2: Major differences between the old chart no. 1212 Greenland and the new coastline.

### 1.1 The test site

Since Greenland is huge, it is important to select a good test site for initial development work. In our case, the initial part of the project involves enhancement of 65 charts covering the area indicated in figure 1. In the actual method development, we use chart no. 1212 (also sketched out in figure 1) for testing since the area covered by chart no. 1212 contains a fair amount of both new multibeam data and old soundings.

### 1.2 The problem

The reference frame used for the old nautical charts was based on astronomical observations and triangulations from the 1920s–1950s ("Qornoq datum"). It was readjusted in the 1970s and 1980s after introduction of new absolute positioning from DOPPLER and TRANSIT satellite observations, and a number of im-



Figure 3: Differences between the old chart no. 1212 and a set of newly measured multibeam data (shown in red). It is evident that the coastline registrations need adjustment.

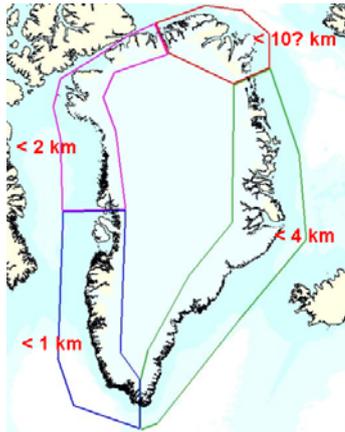


Figure 4: Area-wise maximum errors in the coastline position on the old charts. Mean errors are typically approximately an order of magnitude smaller.

proved station-to-station distances from a campaign based on electronic distance measurement (EDM). The readjustment resulted in significant improvements, but in pre-GPS times, high accuracy navigation in arctic regions was non-trivial, so despite an improved reference system, the surveys from the 1970s and 1980s were not necessarily of very high accuracy, although the relative positioning within a single survey (i.e. the *precision*) could be very high (Weber, 2007). Hence, it should come as no surprise that the introduction of GPS positioning and GPS based reference frames, has revealed major errors in the old charts: while the overall geometrical accuracy varies from area to area, we do actually find examples where the coastline appears to be misplaced by several nautical miles.

In most areas the errors are, however, less than 200 meters and most often better than 100 meters. In general the old charts have a good relative accuracy while their absolute accuracy is insufficient for modern navigation. This is evident from figure 3, where a recent multi beam survey is overlaid on the old chart: the shape of the “ribbon” of multibeam reflections follows the shape of the narrow strait on the chart neatly. It is, however, somewhat displaced as seen from the fact that some of the multibeam reflections actually come from areas which (according to the chart) are on land.

These inconsistencies result in major problems with the day-to-day maintenance of the charts: as new data become available they must to be fitted onto the old chart with reference to a coastline which is seriously misplaced. The fact that the old charts are still in raster format adds further to the complexity, making updates of the chart a time consuming and often impossible task.

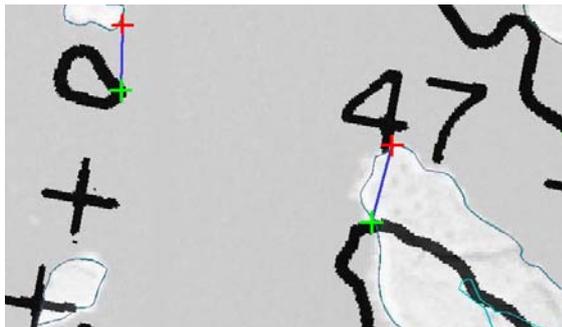


Figure 5: Digitizing homologous points: green points from old coastline and red points from new coastline.

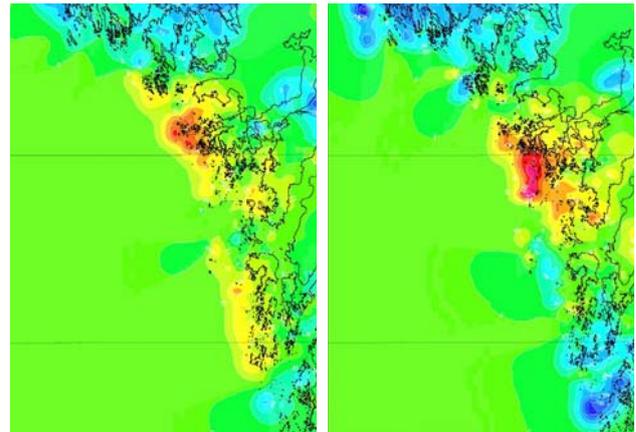


Figure 6: Shift in northing (left) and easting (right) for chart no. 1212. In both directions, the shifts vary between between -200 m (blue) and +200 m (purple).

## 2 METHOD

The method developed in order to update the old nautical charts is based on an idea resembling the NADCON procedure (Mulcare, 2004) used for transforming from the NAD27 to the NAD83 datums in North America: our first aim is to derive individual grid shift models for easting and northing coordinates. This will allow us to transform coordinates of points in the datum of the old charts to GR96, the most recent realisation of the Greenlandic reference frame (a Greenlandic densification of the ITRF94 frame).

Each chart has its own maintenance history and has been adjusted in ways which are difficult (or impossible) to track. Much data used in the charts is of unknown origin making it impossible to handle the nautical information in groups according to its origin: it is necessary to transform each chart as a whole. Hence, it was decided to base the transformation on deviations between the coastline on the chart and a new, photogrammetrically registered, high accuracy (*and* high precision) coastline.

In somewhat simplified form, the workflow of the method developed is:

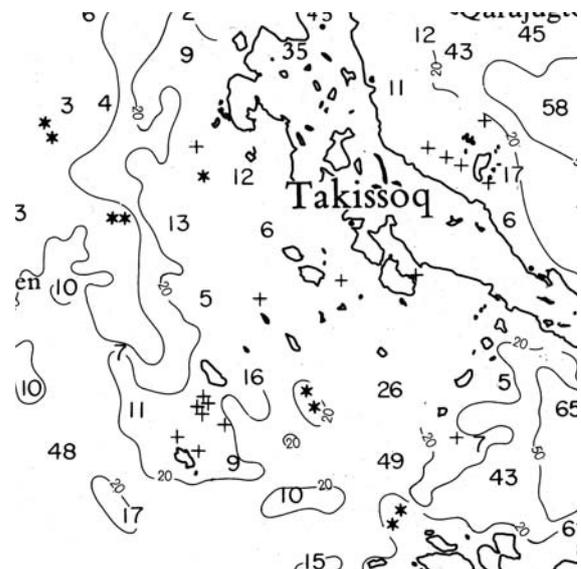


Figure 7: A small part of chart no. 1212, emphasizing the primary object types being reconstructed in digital form: coastline, archipelago, rocks, depth soundings and depth contours.

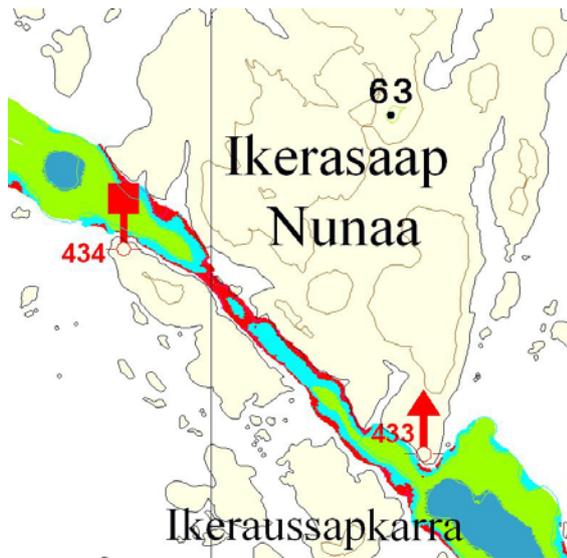


Figure 8: The new multibeam data fit perfectly with the transformed map.



Figure 9: Effects of the transformation of existing soundings: old positions printed in grey, new in cyan.

1. Digitize homologous points on the new coastline and on the old coastline in the chart.
2. Estimate grid shift models for the shift in northing and easting by collocation/kriging.
3. Rectify the existing nautical information by interpolation in the grid shift models.
4. Combine the rectified old nautical information with newly measured nautical information (multibeam) and a new coastline etc. into a new chart.

The local differences within the charts are distributed very irregularly and show significant variations over short distances, making the selection of a sufficient number of points non trivial.

The problem is, however, somewhat offset by the fact that we can put the focus on the coastal areas (where the nautical information was traditionally geocoded using sightings to fiducial points on land). The information in the chart farther from shore is of less importance for the transformation: in the deeper waters the nautical information was traditionally geocoded using astronomic observations, so we should not expect superior results from coastline based transformations in these areas.

In order to support the local variations in the transformation up to 1000 sets of homologous points are digitized manually for each

chart giving pairs of pixel coordinates and GR96 coordinates in UTM zone 24. The points must be very carefully selected focusing on stable distinct features along the coastline. To improve the selection both the coastlines and a newly produced orthofoto were used - see figure 5.

These homologous points are the basis for the estimation of the grid shift models (cf. figure 6) in a kriging process (Cressie, 1993; Journel and Huijbregts, 1978).

The old charts are on raster format and are first being vectorized before each objecttype individually are geometrically transformed from pixel coordinates to the proper GR96 datum by interpolation from the grid models.

When all the nautical information has been geometrically rectified all the different data sets can be gathered to a new improved chart. The data sets includes new coastline and topographic information and newly measured multibeam data in selected areas. Also the geometrically rectified nautical information. The rationale behind this collection of data is that we need a high degree of completeness and accuracy. When for example a rock is found in the old chart it is vital that it is also represented in the new chart. Only 100% completeness is satisfactory and this demands an extended use of visual inspections with focus on especially small islands, rocks and soundings.

### 3 DATA

#### 3.1 Photogrammetrically derived data

Between 1978 and 1986 a complete photogrammetric coverage of the ice-free parts of Greenland was obtained by KMS, using super wide angle cameras and high resolution B/W film. The flying altitude was around 14 km resulting in a scale of approximately 1:150.000. In our project the relevant photos for the charts covering the southwestern part of Greenland was scanned with a resolution of 14 $\mu$ m.

A new aerotriangulation of the images was carried out using the improved datum of Greenland, GR96 (Engsager, 2007). Then a number of products were generated from the photogrammetry:

1. Digital elevation models with 100 m grid cell size
2. B/W orthophotos with 5 m pixel size
3. Photogrammetrical registration of coastline, rivers, lakes, glaciers, fiducial points, and spot heights.

The coastline and the orthofoto are the basis for digitizing the necessary homologous points for the geometrical rectification. The coastline is expected to have an accuracy of 10-15 meters.

#### 3.2 Digitally reconstructed nautical information

The original nautical observations in the charts are not available in a suitable format. Therefore the old original printing material for the black layer of the charts was scanned at a resolution of 600 dpi, resulting in bitmap files without any geographical reference. The object types of relevance were reconstructed in digitized form using commercially available semi-automatic services.

The primary object types reconstructed are depth soundings, bathymetric contours, rocks, coastline (including all small islands inside and outside of the archipelago),

Additionally, all geographical names were reconstructed in digital form. These data were transformed into new Greenlandic spelling in collaboration with Oqaasileriffik, the Greenland Language Secretariat.

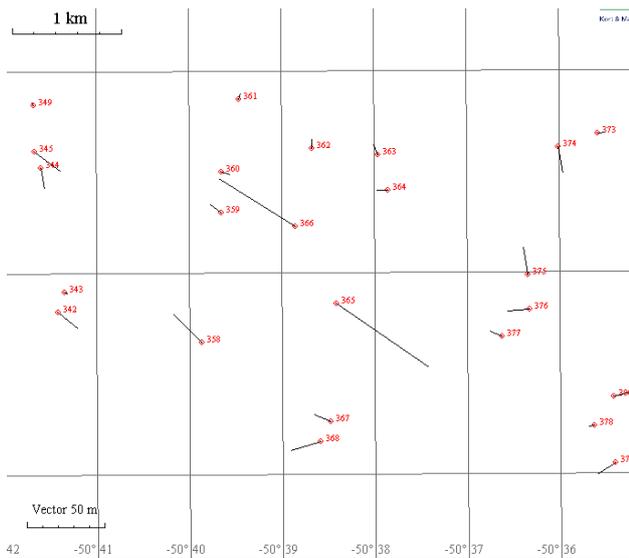


Figure 10: Local tension: while the transformation is overall successful, we find here two points less than 1 km apart needing a residual movement of approximately 50 m in almost opposite directions. Such large discrepancies cannot be resolved by the method in any reasonable manner.

### 3.3 New bathymetric data

The Hydrographic Office of the Danish Maritime Safety Administration is currently collecting large amounts of multibeam sonar data in the Greenlandic waters. With the update of the old data, these can (ideally) be merged seamlessly into the new generation charts.

Furthermore, experimental flights with red/green water penetrating laser scanner systems have provided new sets of independent test data.

## 4 RESULTS AND EVALUATION

When evaluating the results, two issues are particularly relevant:

1. how well does the new coastline fit the new GPS-tagged multibeam data?
2. how accurate is the rectification.

The first issue is illustrated in figure 8, where it is seen that the new multibeam data are clearly placed correctly relative to the new coastline. The width of the channel in figure 8 is around 100 meters and all comparisons with reference data indicate an achieved accuracy of 10–15 m for the coastline.

The second issue is illustrated in figure 9, where we outline the difference between rectified and unrectified positions for reconstructed sounding depth information.

Both issues are evidently solved in a satisfactory manner, but to quantify the quality of the solutions a bit more: a back transformation of the points used for the transformation reveals that out of 1050 points, 40 end up with a difference larger than 30 m. The mean absolute deviation is slightly better than 10 m for both northing and easting (for chart no. 1212).

Because of the unevenly distributed local variations due to the history of data, it is not always possible to ensure a perfect transformation. In figure 10, we show a pathological example: two

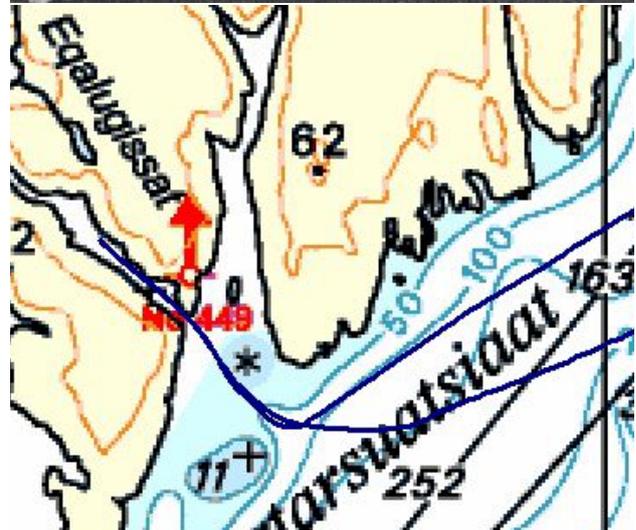
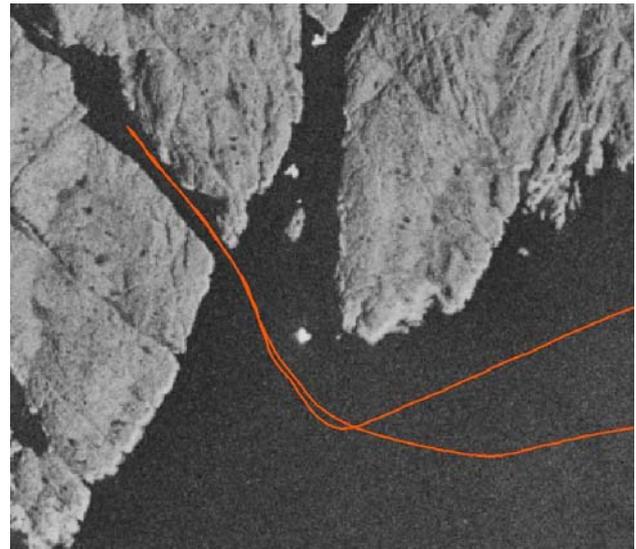


Figure 11: Test navigation exploring the accuracy of the updated version of chart no. 1212: entering and returning from a narrow fjord. At its narrowest points, the fjord is only 50 m from shore to shore. The GPS positions from the trip are plotted onto the updated chart and the orthophoto. It is seen that in this area, the new chart is certainly accurate enough for GPS based navigation.

points at a distance of less than 1 km need a residual movement of 50–60 m, in almost exactly opposite directions, while all the surrounding points have been transformed sufficiently. In order to handle such local phenomena, we need additional data.

### 4.1 Field test

The results of the pilot project are in general promising. But to ensure that the aerial triangulation and coastline production is correct several initiatives have been taken. One was a field trip inshore—with convincing results: The GPS track from (a part of) the trip is shown in figure 11 both on the electronic chart that was used directly for navigation and onto the orthophoto. The channel is only 50 m wide at the narrowest cross section and as indicated from the GPS track, the vessel was placed firmly in the middle of the channel.

### 4.2 Lidar test

The least accurate areas in an aerotriangulation are normally the areas in the outskirts; in this case the outer islands. Therefore a

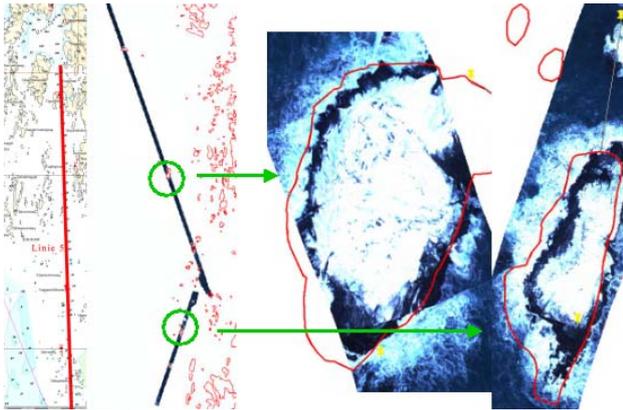


Figure 12: The new coastline compared to orthophoto from red-green lidar survey. The width of the lidar strips is approximately 100 m.

survey of red-green lidar scanning was conducted both for the interest in depth measurement from the lidar scanning itself and for positioning selected islands. As illustrated in figure 12 the islands detected using lidar fits with the coastline within a tolerance of 10–15 m.

#### 4.3 Test of homologous points

It is crucial that the correction grids are as accurate as possible. A precondition is that the homologous points are error free. This is easily controlled by transforming the digitized coastline and comparing it to the new coast line. Figure 13 shows the result of misplacing a single point and thereby erroneously shifting the surrounding nautical objects.

The real challenge is the control of how the transformation in general has affected the nautical objects. It is important to emphasize that the quality of specific rectification on the nautical object types cannot be controlled at all. All the data in the chart that need to be moved are in general of unknown origin. Hence, it may be spurious with respect to both planar position and to bathymetry. But under the given circumstances this method appears to give reasonable results.

## 5 DISCUSSION AND CONCLUSION

We have presented a method for correction of existing nautical charts. The method has proven to be functional, scalable and operational. The first chart (no. 1212) has been published May 2008 and 5 more are planned for the rest of 2008. In the following years, the remaining 59 charts from the block indicated in figure 1, representing the most busy waters around Greenland will be geometrically rectified and published. The charts will at a future date be integrated into a seamless database with nautical information from all the charts, making future updates much simpler than when using the current procedure.

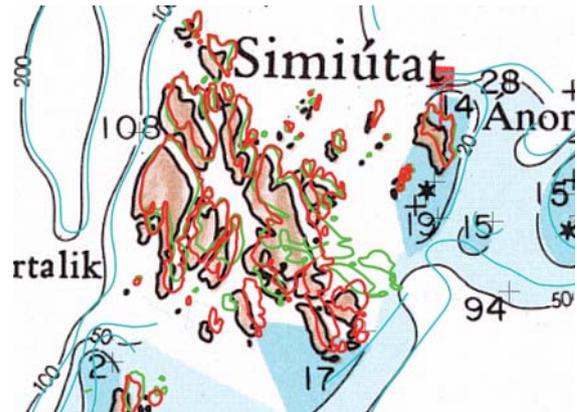


Figure 13: Erroneous placement of one homologous point. Colour code: old vectorized coastline (black), new coastline (red), transformed old coastline (green).

For the remaining 30 charts, covering the rest of the waters around Greenland we need a slightly modified procedure, since the amount of reference data is much smaller in the northern and eastern parts, than in the southwestern. A potential approach will be to integrate the use of recent and historical satellite images as a supplement to the existing aerial photos.

Currently, less than 0.01 % of the waters around Greenland have been resurveyed recently with GPS reference. Most of the waters have only sporadic bathymetric soundings of unknown origin. So the biggest challenge for this project may actually be to avoid having the new charts signal an accuracy greater than reality, despite being *much* better than the existing chart series.

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