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Long-Term Geometric Monitoring of the Bremen Cog: Monitoring Concept, First Results and Future Perspectives

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Abstract

The Bremen Cog, a clinker-built vessel from 1380, is an outstanding cultural asset. The preservation of the conserved and reconstructed shipwreck is an important task. This article will give an overview on the geometric monitoring for the Bremen Cog implemented in 2020. Ten measurement epochs have been held since. The geometric monitoring focusses on two main aspects: recording rigid body displacement and determination of inner changes. A ground control network is installed and observed with a laser tracker network analysis. Due to the location of the museum, tidal changes lead to an instable geodetic datum over time. For the detection of inner changes of the cog, a large-volume photogrammetric metrology concept is realized. 364 photogrammetric targets on the cog represent its structure and potential critical parts. Additional targets allow for the determination of connection in changes between the support system and the cog. Interchangeable magnetic target adapters enable to use the ground control network for photogrammetric analyses. Different adjustment strategies are carried out and are still term of research. Initial results on vectorial displacements on inner changes are given, showing that the monitoring concept could be implemented successfully.

1. Motivation

The monitoring of conserved archaeological artefacts, like e.g. conserved historic ships, is important for the preservation of their history and enabling their future presentation. One aspect of monitoring is the estimation and analysis of geometric deformation.

For the Bremen Cog as an outstanding cultural asset the geometric monitoring is an important task, as it already has been during reconstruction and directly after conservation (Hoffmann, 2011). With respect to the Bremen Cog, different investigations on spatial monitoring are known from research cooperation and literature (Wiggenhagen et al., 2004; Hoffmann, 2011; Lahn, 1992). Colson (Colson, 2023) gives a review on the work on digital documentation and monitoring of historical ships in Cultural Heritage within Europe and specifically summarizes the spatial monitoring tasks for the Bremen Cog at the German Maritime Museum. The work presented in this article represents the implementation, further development and subsequent results of the preliminary studies and concept work on the geometric monitoring of the Bremen Cog (Hastedt et al. 2019).

Regarding large wooden ships, first monitoring approaches are given for the Vasa in Stockholm, Sweden (Jacobsen, 2003). The current measuring system was developed by Horemuz (Jacobsen, 2003) and established in 2000 (based on a total station monitoring system). Since then, deformation studies (Rosewarne, 2007) are established revealing movements of several millimeters per year (Horemuz, 2025). Due to the extensive available monitoring data, the ability for long-term analysis and advanced mathematical modeling developments is given, as it is published for the strain analysis (Van Dijk et al., 2016). Based on total station and multi-sensor technology, a real-time monitoring system is implemented for the hull of the Mary Rose, the warship of Henry VIII, exhibited in Portsmouth, UK (Schofield et al., 2013; Collett et al., 2021). Photogrammetric measurements are used to monitor structural changes for viking ships at the Viking museum Oslo, Norway. Hauer et al. (2022) summarize a comparison of different measurement techniques, most based on photogrammetric approaches, applied and comparatively analysed with respect to its usability and the Viking museums' ability for long-term monitoring purposes. To have a better understanding of the wooden ships, laser scanning technology is applied to allow for 3D ship reconstruction and analysis of hydrostatic and hydrodynamic characteristics of historical ships, in Ireland and the United Kingdom (Tanner, 2013; Nayling and Jones, 2014) as well as for the Bremen Cog (Tanner and Belasus, 2021).

In general, the determination of deformation relies on the choice of the measurement system with respect to the required accuracy. For large-scale applications an overview is given in Peggs et al. (Peggs et al., 2009). "Displacement is strictly connected to the movement of a single point at different moments. Hence, the points to be monitored have to be identical and unique. Statistical tests are applied to the measurement data and its quality measure to allow for significance evaluation, e.g. of displacement given by coordinate differences. Strain analyses are standard approaches in geodesy or applied mechanics to enable predictions on deformation, referring to a segmentation of the object into parts of homogeneous deformation (Heunecke et al., 2013; van Dijk et al., 2016)" (Hastedt et al. 2019).

This article summarizes the aspects of the monitoring concept for the Bremen Cog, its first results and future perspectives. The measurement concept considers insights of different feasibility studies. By now, 10 measurement epochs were carried out and analysed for statistical tests and vectorial displacement analysis. The monitoring concept for the Bremen Cog considers accurate 3D measurements of change, allows for future derivation of strain and maintains the museum's operation during monitoring.

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2. The Bremen Cog

The Bremen Cog, a clinker-built medieval shipwreck from 1380, is presented to the public at the German Maritime Museum in Bremerhaven, Germany. It has a size of 23.27 m (length amidships with castle deck) by 7.62 m (width) by 7.02 m (height from lower edge of keel to upper edge of capstan) (Lahn 1992). The cog was salvaged between 1962 and 1965 and reconstructed out of 2000 timbers at the therefore built German Maritime Museum in the years from 1974 to 1981 (Hoffmann, 2003; Hoffmann, 2011). The conservation of the cog (1981 to 1999) followed a two-step procedure applying different molecular states of polyethylene glucol to the reconstructed cog which was embedded in a conservation bath within a tub built for this purpose (Hoffmann, 2003).

The reconstruction and future presentation (see Figure 1) followed a novel concept, “she was standing on her keel, but the bulk of her weight was supported from the ceiling via a number of steel rods. No outer supports or stanchions disturbed the view of the ship and her lines” (Hoffmann, 2011). The first exhibition of the cog was in May 2000. Already a year later the ship began to change its shape, first damages could be noticed e.g. as ruptures in lower hull-planks and leaning-out of both sides of the hull (Hoffmann, 2011). Due to the sagging of the hull, first additional rods were installed to stop further deformation. This, unfortunately failed to do so and instead started to pull the ship from its keel supports (Hoffmann, 2011).

Figure 1 shows the current presentation of the Bremen Cog at the Museum including its condition after reconstruction with a well-preserved starboard side while the portside reconstruction misses the upper half (Hoffmann, 2011). The current presentation includes the in 2006 added support system.

With respect to the observed damages, Hoffmann (2011) presented the development of a permanent support system which was finally installed in 2006. The requirement was to be stable over very long times, chemically and mechanically. With the installation of the permanent framework, the deformed hull was corrected to its state of reconstruction before conservation (Lahn, 1992). In total, 30 external supports with about 100 mechanical presses were constructed (see Figure 1 and Figure 11) which ended in pressure-plates being screwable to press the timbers to their correct position.

Directly after reconstruction in 1980, a photogrammetric survey was carried out by the University of Hannover under the direction of Wrobel. A laser scan acquisition of the conserved but deformed ship was conducted, and the mechanical presses were adjusted to reach the original state in accordance to the photogrammetric results from 1980 (Hoffmann, 2011). Cross-section curves on the ship were reconstructed and compared. Wiggenhagen et al. (2004) also report on the estimation of deformations with respect to the former measurements from 1980. They again used photogrammetric strategies to estimate 3D coordinates of points representing the cross-sections of 1980 and subsequently derive deformation ranging from 0 to 300 mm (Wiggenhagen et al., 2004; Hoffmann, 2011). The timbers were then pressed back based on these deformation determinations.

The self-supporting steel support system is built standing on its own legs on the floor (Hoffmann, 2011). Figure 2 illustrates the support system at current state (images are from 2017), which is anchored to the ground of the museum’s building. After reconstruction (see Figure 2 upper left) the keel was jacked up; the keel support does not show a connection to the museum’s floor. Until now, the presentation was rebuilt at least three times, without exactly knowing how the soil was filled and how this affects the support system and keel/cog itself.

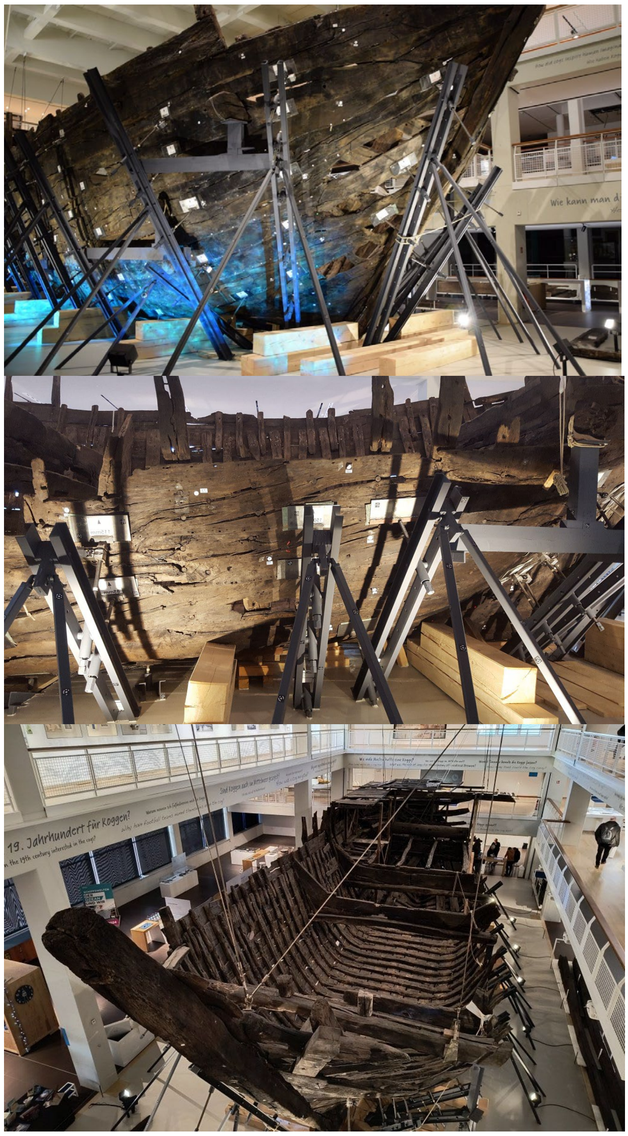

Figure 1. The Bremen Cog at its presentation at the German Maritime Museum in Bremerhaven, Germany. Upper image shows a view to bow on starboard side. The middle image shows a part of the portside reconstruction. The lower image gives an overview from bow to rear with clearly showing the well-preserved starboard side versus portside reconstruction misses the upper half (Hoffmann, 2011).

Based on the given preliminary work different tasks with respect to the museum’s location are identified. “The museum is located at the mouth of the river Weser to the North Sea and is situated on a small peninsula within the old harbour area, therefore directly influenced by the tides (Figure 3)” (Hastedt et al. 2019). The tidal influence on the museum building and the cog is present. “The impact of tides on geometric changes of comparable objects are known by the harbour authority in the order of 1-2mm. The resistance of changes on building structures or the ability to recover to its original state are unknown. In general, the water level inconsistently changes within a range of 5m between low and high tide” (Hastedt et al. 2019).

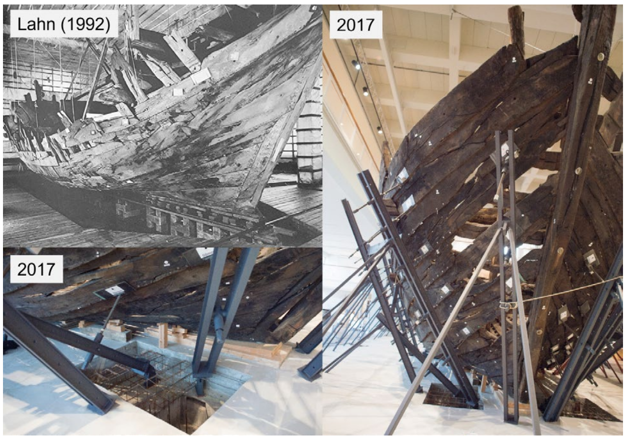

Figure 2. The Bremen Cog from its first reconstruction (Lahn, 1992) to current presentation (images from 2017).

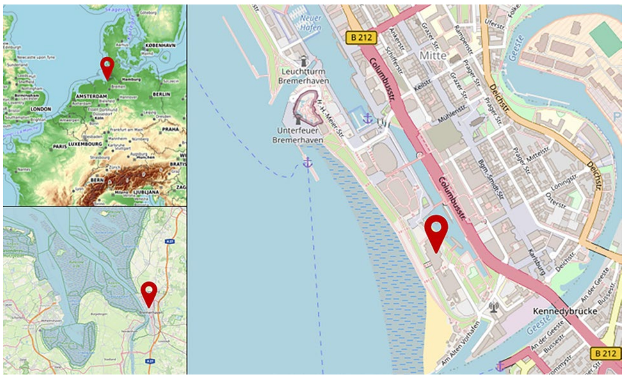

Figure 3. Location of the museum (upper left: location within Germany; lower left: location at North Sea; right: location within harbour area of Bremerhaven; image source: OSM Open Database Licence (ODbL)).

The museum hall accommodating the Bremen Cog was built with three visitor floors that enable a good view on all parts of the vessel. The influence of the relative humidity on the cog and its subsequent changes within time periods is unknown by now but kept stable within the cog hall. Impact of daylight is eliminated by an automatically controlled sun protection system and UV filters on the windows.

3. Monitoring concept

This chapter follows the findings and specifications for the geodetic monitoring concept work given in Hastedt et al. (Hastedt et al. 2019). The key features are summarised in the following and supplemented by the implementation of the monitoring and the results obtained from further research work.

3.1 Requirements and environmental conditions

For the Bremen Cog size and kind of deformation were unknown at the time of first considerations in 2017. The German Maritime Museum desired a deformation of ≥ 1mm to be detectable with the monitoring system based on the experiences of the Vasa ship monitoring in Stockholm where deformations of a millimeter within a year could be assumed at that time. Deformation should be detected for 1) movement respectively tilt of the cog due to its imbalance in reconstruction and weight and 2) inner changes of the cog identifying critical sections within the structure. Moreover, the museum’s operation should not be restricted, if possible, during the monitoring measurements and for presentation purposes to visitors. The measurements are required being short-term expenditures minimizing costs.

With the high demands defined with respect to the large-volume of the cog, and its presentation and embedding in the museum and the museum’s operation, opportunities and requirements were evaluated. For this case deformation estimation has to include rigid-body displacement of the cog as well as the determination of deformation of the cog itself. Therefore, a ground control network is required to allow for the estimation of rigid body displacement. “With respect to the measurement's minimum single point precision, the ground control network needs to be estimated with a technique of highest accuracy and stable over time” (Hastedt et al. 2019). In addition, the ground control network must be anchored to the building structure and is therefore arranged outside the cog.

“Based on information theory, a significant movement of points can be identified by a signal-to-noise ratio of $q > 5$ (as approximation) if the movement is large relative to the technique's single point precision (Dupraz et al., 1979). The signal-to-noise ratio q is defined by (1):

$$q = \frac{|dl|}{s_{dl}} \tag{1}$$

The signal can be defined as the length dl of a single point measured in different epochs (vector length). The noise s_{dl}, which is the empirical standard deviation of the length of deformation, leads to a value of $s_{dl} < 0.2$ mm with $dl = 1$mm.” (Hastedt et al. 2019). With respect to this requirement a single 3D point precision has to be defined in order to allow for a high precision displacement measurement. With this, equal quality of all 3D points in all three coordinate directions within the measurement is assumed, leading to a required single point precision of $s_{XYZ} = 0.14$mm within a confidence level of 68 . With this, a photogrammetric approach is identified to be used in order to achieve high precision in 3D point measurements, allowing for short measuring times and minimal intervention to the cog. (Hastedt et al. 2019)

3.2 Basics of the monitoring concept

With respect to the defined requirements and environmental conditions, different measurement techniques are evaluated. To achieve the high single point precision of $s_{XYZ} = 0.14$mm within this large-volume metrology application, a photogrammetric approach can be used. Typical industrial photogrammetric measurement systems, providing highest precision levels, specify single point precision of 2 µm +/- 5 µm/m (RMS) which corresponds to maximum deviation of 0.142 mm within 28 m (maximum distance within ground control network). In addition, the ground control network, dealing as datum definition for all measurement epochs, needs to be of superior quality. Which will only be possible using laser tracker technology in combination with an extensive network measurement.

Measurements have to be carried out to determine the uncertainty reachable for the specific configuration, as typical settings do not consider relevant points in a backward viewing which, however, are unavoidable with the monitoring. A big advantage in using a photogrammetric method yields that this allows for short measurement time periods of about 2 – 3 hours for each measurement and for contact-less measurements of once signalised object points (non-destructive measurements for the medieval ship).

To overcome the theoretical problems with respect to the monitoring concept using a photogrammetric approach combined with a ground control network, some feasibility studies were carried out (Schmik, 2017; Schmik et al., 2018; Hastedt et al., 2018; Hastedt et al., 2019). These give insights into future practical work, technical limitations and subsequent necessary enhancements for the proposed and subsequently realised monitoring concept.

The recommended single point precision can be achieved using the proposed monitoring concept. However, some points are limited in precision such as the outer ground control points and monitoring points are difficult in access e.g. at lower hull or concealed by the support system. At this point, the influence of the tide is known, but their effect is not exactly yet.

Geometric deformation estimation in general can be divided into issues of rigid body displacement (rigid body motion) and deformation (strain, bending, torsion). A basic challenge for measurement concepts is given by the ability to separate both issues (Heunecke et al., 2013). Displacement is connected to the movement of a single point at different moments. Hence, the points to be monitored have to be identical and unique over time. Statistical tests are applied to the measurement data and its quality measure to allow for significance evaluation. Strain analyses are standard approaches in geodesy or applied mechanics to enable predictions on deformation, referring to a segmentation of the object into parts of homogeneous deformation (Heunecke et al., 2013; van Dijk et al., 2016), and will be analysed in the future, too.

Based on the basics of the monitoring concept and knowledge about the ground control network, vectorial displacements of 2 mm and more on the same point measured in different epochs can be established and are the basis for the deformation determination at this time of the monitoring process. From 2020 to 2025 ten measurement epochs E0 to E9 were carried out.

3.3 Ground control network

“The ground control network at the museum is integrated in the building structure evenly distributed around the cog. 22 bolts are fixed to the struts of the exhibition hall on three different levels” (see Figure 5)”. The female thread of each bolt can be used as socket for measuring adapters with a magnetic socket for targets of different measurement techniques” (Figure 4) (Hastedt et al. 2019) allowing for low centring uncertainties using a laser tracking network measurement for ground control point estimation and a photogrammetric approach for the cog monitoring (Hastedt et al. 2019). The measurements are evaluated within its coordinate system which has its origin in one ground control point, the positive X-axis facing along the width of the cog, the positive Y-axis facing longitudinal and the positive Z-axis facing towards the ground (see Figure 6).

The ground control points are measured every 6 months by a network measurement using a Faro Vantage laser tracker (Faro 2025) and analysed using JAG3D version 20210126 (JAG3D, 2025). The network analysis software has a length-dependent adjustment approach which is used for this large-volume application including very different measurement lengths within the network (see Figure 7).

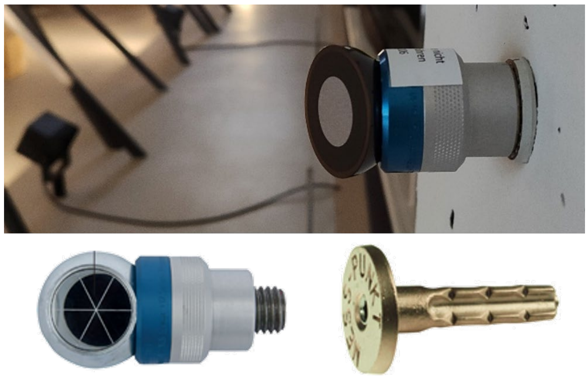

Figure 4. Female threads for ground control points with interchangeable magnetic target adapter.

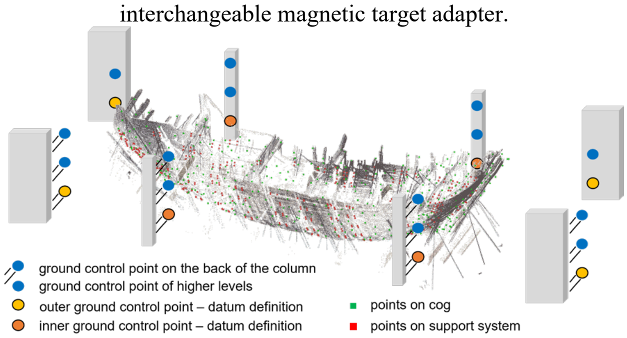

Figure 5. The Bremen Cog embedded within the building structure; the ground control points fixed to the construction columns.

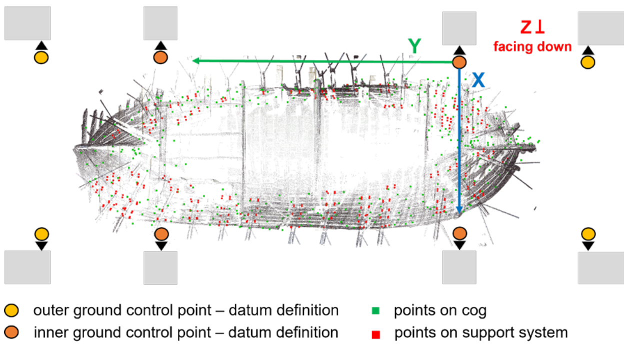

Figure 6. The Bremen Cog embedded within the building structure. The coordinate system is right-handed with its origin in one ground control point.

The network is measured using 10 laser tracker stations: 4 stations on ground level and 3 stations on each of the upper levels. The ground control network was measured and analysed with eight epochs from 2020 to 2025. After network adjustment, the RMS_{XYZ} values of all estimated 3D-coordinates are between 0.024 mm and 0.047 mm. The minimum precision of the outer ground control points used as photogrammetric datum points is given with 0.063 mm (in Y-direction). Therefore, the 3D coordinates of the ground control network are of higher precision with respect to the precision level achievable with the photogrammetric measurements. It has to be considered that the estimated ground control point coordinates are used for datum definition for the photogrammetric adjustment and subsequently for the deformation analysis. With respect to the inner ground control points location, their coordinates remain equal in quality in Z-direction compared to the photogrammetric acquisition, but of superior precision in X- and Y-direction.

The network measurement takes at least 6 hours and is therefore influenced by a full tidal change from low to high tide. The analyses of the first seven epochs (between 09/2020 and 08/2023) lead to the assumption that remaining instabilities within the network of up to 1.2 mm cannot be avoided.

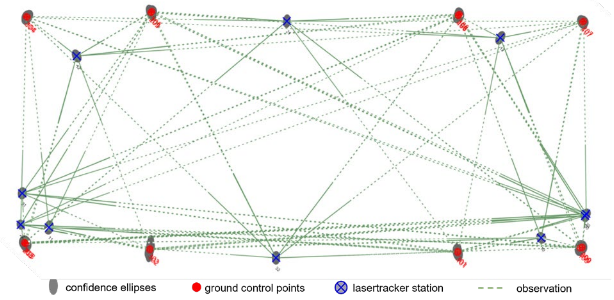

Figure 7. Ground control network illustrating all observations with respect to the laser tracker stations and to be estimated ground control points.

In a first step, the established 3D coordinates are analysed. In a second step, distances across the inner and outer ground control points are analysed. It is noticeable that epochs with an interval of 12 months (E0 - E2 – E4 – E6 and E1 – E3 – E5) show lower deviations as those of 6 months (E0 – E1, E2 – E3 etc) within these distances. Furthermore, the epochs with 12 months appear stable which leads to the decision not to add a ground control network measurement every 6 months. In order to be able to verify the observation while minimising effort and costs, the ground control network will be measured every 18 months. Therefore, the ground control network will be measured alternating in even and odd epochs (E9, E12 etc.). In 02/2025 the next epoch measurement was carried out. The results confirm the former tendencies of the instability of the ground control network. Therefore, the decision to reduce the effort was correct.

The significant influence of the tidal changes due to the museum’s location are still term of analysis in order to provide appropriate interpretation for the results of the geometric measurements. As the ground control network builds the basic datum definition for the geometric monitoring of the cog, the instabilities due to the tidal changes are important in terms of measurement precision and reliability of the deformation analysis as this recommends a stable datum definition. With JAG3D, deformation analysis based on the original observations of the network measurement can be estimated (Lösler et al., 2017) and will be term of future analysis.

To better understand the instabilities of the ground control network, one approach could be to analyse the ground motion by radar interferometry. The European Ground Motion Service (EGMS, 2025) provides velocity data for rasterised persistent scatterer. Figure 8 shows the location of the closest point of the EGMS with its corresponding vertical velocities (Figure 9) for the period from 01/2019 to 09/2023. As a first indicator, the mean velocity of -0.8 mm per year gives an idea on the ground motion influencing the monitoring. The displacement graph in Figure 9 indicates the variety of results for the acquisitions, corresponding to the satellite revisits for the specified location. The remaining instabilities of up to 1.2 mm depending on the tidal cycle appear correct and reliable. A closer analysis of the ground motion by radar interferometry might give a close insight for the monitoring, even though there is only low ground motion and the method is limited in resolution and precision with respect to available radar data.

Figure 8. Excerpt of the European Ground Motion Service (EGMS, 2025) for the location of the German Maritime Museum (labelled).

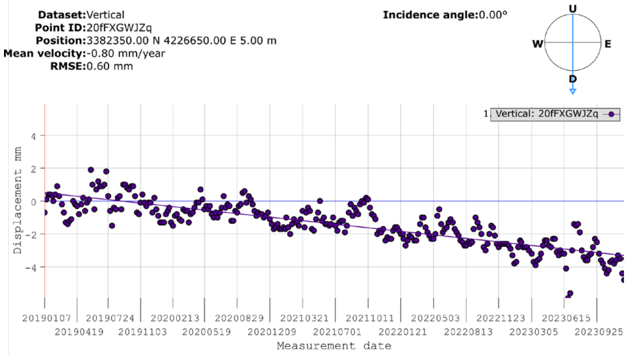

Figure 9. Corresponding vertical velocities of ground motion for location of the German Maritime Museum (Figure 8).

3.4 Geometric Deformation Monitoring

For the geometric monitoring of the Bremen Cog a photogrammetric method is chosen (Hastedt et al. 2019). Therefore, different photogrammetric targets are arranged within the measurement volume (Figure 10). On the cog, 364 retro-reflective targets are glued residue-free on Japanese paper (Figure 11). “The monitoring points are distributed irregularly 1) because of the local visibility situation based on the objects shape and the cradle and 2) to enable a good representation of the volume by applying a triangulation network over all object points for future deformation analysis” (Hastedt et al. 2019).

On the pressure-plates of the support system, 358 self-adhesive retro-reflective targets are used, mainly representing the outer corners of each plate. This allows for the determination of connections of deformation between cog and support system. Different movements of the pressure-plates compared to the cog itself might be detected. In addition, the behaviour of the support system and the keel support are unknown due to the museum’s reconstructions (Figure 2). For the photogrammetric measurements about 500 coded tie points are placed around the cog for automatic processing of the photogrammetric image bundles (Hastedt et al. 2019). For the photogrammetric acquisition a Hexagon DPA Professional (Hexagon, 2025) camera system is used with a multi-image bundle and simultaneous camera calibration using the corresponding software package AICON 3D Studio. The photogrammetric acquisition scheme is shown in Figure 12.

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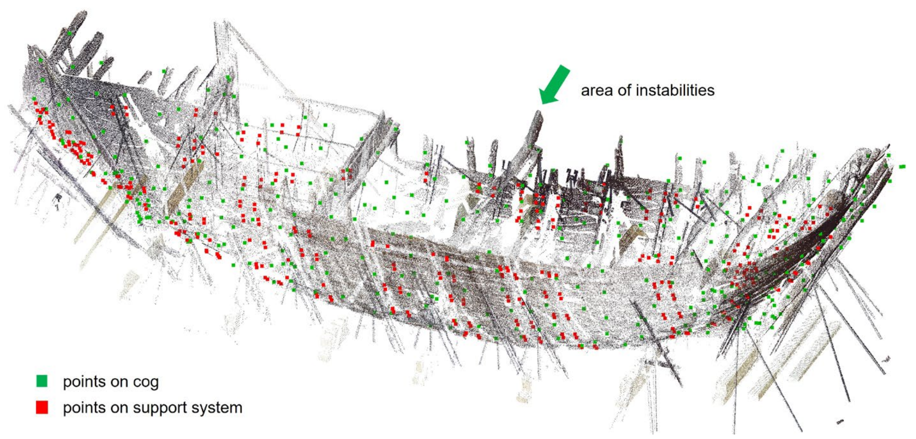

Figure 10. Schematic view on the cog (scan illustration) with blended monitoring points on the cog and the pressure-plates.

About 1200 images are taken for each epoch, including measurements of the 14 ground control points of the lower two exhibition levels being observed with each epoch (Hastedt et al. 2019). With the use of a high-quality metric photogrammetric system the recommended single point precision of 0.14 mm for the large volume environment is achieved for most points. Restrictions are given for some ground control points and monitoring points due to limited access. The evaluation is based on a photogrammetric bundle adjustment, minimizing the residuals over the whole bundle by adding specific weighted datum observations or scaling information.

3.5 Analyses

For the geometric monitoring different datum definitions and scaling observations are tested and analysed. Ground control points are introduced as pseudo observations to define the geodetic datum with their related standard deviations in order to have soft constraints in the adjustment and allows for the determination of all deformation aspects (Hastedt et al. 2019). Within first analyses based on E0, rigid-body motion could not be detected so far. Further analyses are necessary for all epochs applying equal datum definition based on E1 as the monitoring points were supplemented after E0. Therefore, E1 is chosen being the base epoch for geometric monitoring analyses. In addition, it has to be evaluated which datum (inner or outer ground control points) would be best with regard to the given requirements and conditions.

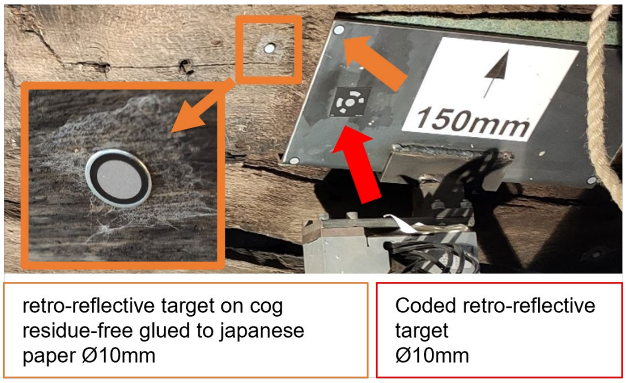

Figure 11. Overview on photogrammetric target types and targets residue-free glued to Japanese paper.

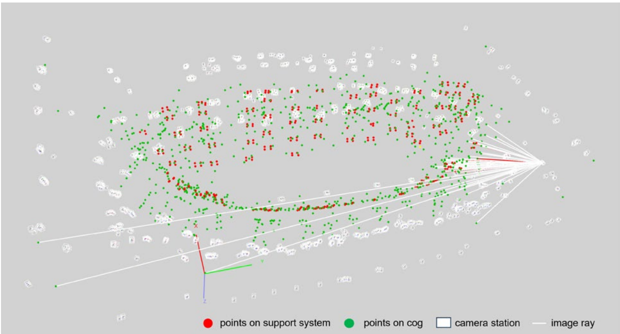

Figure 12. Photogrammetric bundle illustrating the camera stations with respect to the cog and the monitoring points; image rays are exemplarily visualised for one camera station.

From a geodetic point of view, the outer ground control points (see Figure 5) are preferable as they cover the whole measuring volume (Hastedt et al. 2019). But, from a photogrammetric point of view, they are disadvantaged as these points are in general behind the measurements field of view. Nevertheless, the outer ground control points are detectable with a 1σ precision of $RMS_{XYZ} = 0.16$ mm to $RMS_{XYZ} = 0.22$ mm while the inner ground control points lead to a precision of $RMS_{XYZ} = 0.08$ mm to $RMS_{XYZ} = 0.11$ mm (E9) applying a free bundle adjustment using scales from the ground control network from E1. Theoretically, deformation could be detected within the required value of ≥ 1 mm. But the instabilities of the ground control network have to be considered.

In the following, analyses with respect to relative deformation of the cog itself are given. In this case, scaling information is used within a free bundle adjustment of each epoch, applying scales with their related standard deviations from E1. The 3D coordinates of each epoch are transformed to its corresponding points in E1, using the inner ground control points. Almost all 3D changes in terms of displacements refer to a stable object with a displacement of < 2 mm since 2020. The comparison of different datum definition and adjustment procedures indicate a slightly lower displacement estimation for relative deformation analysis as it is given for geodetic datum definition using pseudo-observations for absolute deformation. Further analyses using E1 as base epoch will lead to further answers.

4. First displacement results

The vectorial displacements are calculated for each observed point in every epoch with respect to its position in the first epoch using the same processing method. By now, a vectorial movement of ≥ 2 mm can be defined as significant and reliable in terms of measurement precision and ground control network results. Two points were identified with movements ≥ 2 mm over all measurements. Figure 13 shows a section of the schematic view on the cog (from Figure 10) with exemplary displacement vectors as an overview of the resulting movement of two observed points.

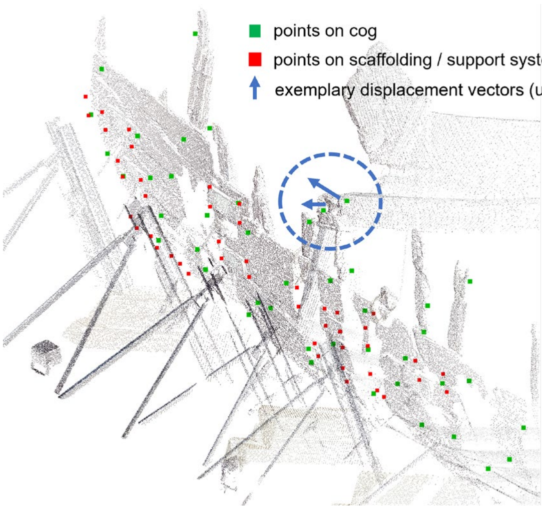

Figure 13. Section schematic view on the cog with points of significant vectorial movement.

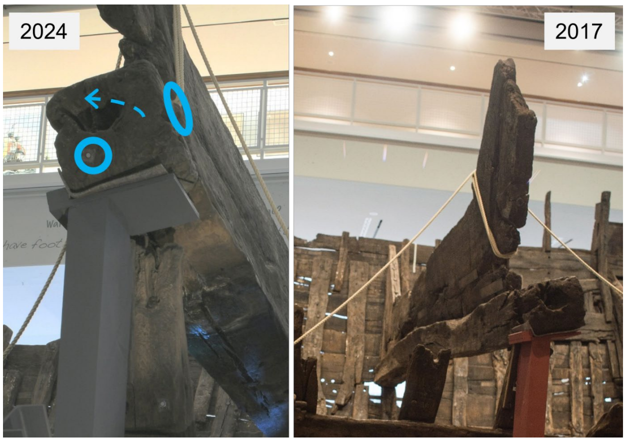

Figure 14. Section detail of significant vectorial movement.

The highlighted points in Figure 13, respectively their three-dimensional displacement vectors have a maximum of 4.3 mm till now. Figure 14 shows the section as photographs in more detail. The observed points are situated to the front and side of a horizontal beam on portside. The beam seems to be fixed within the starboard reconstruction so that the movement can only be identified on portside. The three-dimensional displacement vectors lead to the assumption that torsion affects the beam as the point on the side of the beam experiences greater movement at all, but also in Z-direction while the front point experiences movement mostly in Y-direction. The assumption seems to be confirmed when looking at Figure 14. The beam is only stored with its bottom side to a support bar and probably influenced by its overlying weight of additional reconstructed ship timber (see Figure 14 on the right).

5. Conclusions and future perspectives

For long-term geometric monitoring of the Bremen Cog, a monitoring concept was developed and successfully implemented. The monitoring consists of photogrammetric measurements observing the cog and its support system and laser tracker network measurements to determine the ground control network. Every 6 month an epoch is measured and analysed with respect to coordinate changes in 3D space so far. The monitoring has been carried out since 2020. By now, 10 epochs are measured and preliminary analysed to relative deformation. First displacement results provide comprehensive insights into changes over time. Thus, critical parts with changes > 2 mm are identified, torsion of one beam appears to be present.

Nevertheless, the successful implementation of the monitoring and data analysis emphasise the need for further investigations. The ground control network needs to be evaluated with respect to its instabilities and subsequently its influence on the deformation analysis has to be identified. Additional statistical tests should be applied, too. Ground motion will be evaluated in order to verify the measured instabilities. For the photogrammetric monitoring datum definition is required, being stable over time and equal to all epochs. Appropriate analysing methods are necessary with respect to the ground control network. A key point remains to examine the extent to which the inner and outer ground control points affect the deformation analysis. Additional statistical tests, strain analysis and significance tests have to be applied to the monitoring points in order to separate rigid-body motion from deformation as well as to identify inner changes and critical sections. Moreover, it would be of interest if the pressure-plates experience different movements as given for the monitoring points on the cog.

Furthermore, the Bremen Cog needs to be cleaned due to dust. The conservators need to apply different cleaning techniques to further preserve the cog. For the photogrammetric targets, investigations are performed to establish the cleaning procedure, to evaluate their long-term stability in reflectivity and to determine the influence on further measurements.

As the first geodetic measurements from 1980 (Lahn, 1992) were the basic geometric information during preservation, it would be of interest, how nowadays measurements fit to former results from 1980. It should be evaluated, if the old data can be reconstructed and digitally evaluated in order to identify identical parts for a comparison evaluation.

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