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THE GEOMETER: A NEW DEVICE FOR RECORDING ANGLES IN VISUAL SURVEYS

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ABSTRACT

The Geometer is a new handheld USB device that facilitates a relatively accurate measurement of the declination to a target with instantaneous recording of this and other data. The Geometer offers several advantages over traditional clinometers used in aerial surveys, including easier target pinpointing and tracking, more consistent angle measurements, and integration with software data collection packages. In this note we provide technical specifications for the device and its associated software, and describe a new aerial survey data collection programme that takes full advantage of the features of the Geometer. We have tested this device extensively during aerial surveys and highlight the utility of the hardware as well as ways in which the technology could be improved.

Keywords: geometer, declination, clinometer, visual survey, survey software

INTRODUCTION

Distance sampling has become a standard methodology for estimating the abundance of wildlife from observation-based spatial survey data. As the name suggests, the primary datum that is collected in all types of distance sampling is an estimate of the linear distance from the observer to the survey object. For point transects, radial distance is collected, while for line transects, perpendicular distance (i.e., the lateral distance from the transect line to the object) is sampled (Buckland et al., 2001).

While distance measurements are assumed to be exact in this methodology (Buckland et al., 2001), this assumption cannot be met in most surveys because distances are measured or estimated by human observers in real time. While line transect methods are relatively robust against random error (as long as it is not severe) in distance measurements (Buckland et al., 2001), point sampling methods such as cue counting (Hiby & Hammond, 1989) are not. Imprecise measurement can lead to positive bias if specialized analytical methods are not employed (Borchers et al., 2009, 2010). In both cases, every effort should be made to measure distance accurately and precisely, preferably by standardising and, if possible, automating measurement procedures.

Bias in distance estimation leads directly to bias in the estimation of abundance, with negative bias reducing the estimated effective strip half-width and therefore increasing abundance. While bias has been detected in many surveys, it is of particular concern for ship surveys of marine mammals, in which distances are often estimated visually or measured over a very small range of angles from the horizon using rulers or binocular graticules. Measurement error has been suspected in some surveys because of differences in measured distances between platforms using different measurement techniques to duplicate sightings (Leaper et al., 2010; Pike, Gunnlaugsson, Mikkelsen, et al., 2020). However, detection of measurement error can be uncertain and difficult, as well as impossible to correct after the survey.

An additional issue arises when observers have a tendency to round angles or distances (typically to multiples of 5 or 10), a phenomenon termed "heaping" (Buckland et al., 2001). This is problematic for fitting detection models and can result in bias, particularly if observation declinations are "heaped" near zero distance.

Placing observers on a platform that is high relative to the target objects is advantageous for measuring distances, because distance can be calculated trigonometrically using the height and the declination angle from the observer to the target. This works best when the observer height is of similar magnitude to the distances being measured, providing a wider range of angles and greater measurement precision. While similar methods are used in ship and ground-based surveys, the lower height of observers relative to lateral distance means that greater measurement precision is required to obtain accurate and precise distances.

Most aerial surveys targeting marine mammals use observers operating analogue or digital clinometers to measure the declination angle between the observer and the sighting (Pike, 2013). A widely-used example is the Suunto PM5 (Figure 1), which has been used in Icelandic aerial surveys from 1986 to 2009 (Pike, Gunnlaugsson, Sigurjónsson, et al., 2020), Greenlandic surveys (Hansen et al., 2019) and surveys off the east coasts of Canada (Lawson & Gosselin, 2018) and the United States of America (Palka, 2012). Instruments with digital displays are also available.

Hansen, R.G., Pike, D., Thorgilsson, B., Gunnlaugsson, T. & Lawson, J. (2020). The Geometer: A New Device for Recording Angles in Visual Surveys. *NAMMCO Scientific Publications 11*. https://doi.org/10.7557/3.5585

Figure 1. Suunto PM-5 analogue forestry clinometer.

While the Suunto and most similar instruments are robust and relatively simple to use, they are analogue instruments that have some disadvantages for aerial surveys. These include:

- Data are not recorded digitally, which requires recording by observers and later transcription;
- Recording of readings by the observer introduces an opportunity for error;
- Reading and recording scale readings is time consuming, which can lead to observers being overwhelmed when sightings are very frequent;
- The Suunto and some other forestry clinometers have two scales, which can lead to observer recording error;
- The observer is aware of the scale reading during operation, which can lead to angle heaping;
- Data are not directly linked to time or location, requiring post-processing; and
- Pinpointing and tracking the target while reading the declination scales can be challenging on a rapidly moving platform.

In 2012, the Scientific Committee of the North Atlantic Marine Mammal Commission (NAMMCO) commissioned a review of aerial survey methods, to be considered by its Working Group on Survey Planning (NAMMCO, 2013a; Pike, 2013). The Scientific Committee endorsed the recommendation of the Working Group that improvements of the methods used to measure distance during aerial survey were required, stating that "Improvements in declination and bearing measurement methodology, as well as increased precision and automation of data acquisition, are important" (NAMMCO, 2013b). In 2015, NAMMCO and the Icelandic Marine and Freshwater Research Institute (MFRI) provided funding for the development of a prototype device, later named the Geometer (Figure 2), by Pi Technology in Iceland. The device was evaluated at a survey planning meeting in April 2015 (NAMMCO, 2016), and improvements in ergonomics and function were made in time for its first use on an Icelandic aerial survey in July of that year (Pike, Gunnlaugsson, Sigurjónsson, et al., 2020). Since 2015, the Geometer and its associated software have been steadily improved and it is now in use by aerial survey groups in Iceland, Greenland, Denmark, Norway, Italy, Canada, Japan, and the USA.

The Geometer offers several advantages over traditional analogue clinometers used in visual surveys. In this note, we provide technical specifications for the device and its associated software package. We also provide some results from its testing and actual use on aerial surveys, identify some areas where the technology could be improved, and describe a new software package that makes full use of the Geometer's capabilities for data input.

DESCRIPTION AND TECHNICAL SPECIFICATIONS

<u>Geometer</u>

History

The Geometer has been continually developed in close cooperation with its users. For example, the restricted working space on most survey aircraft necessitated a change in the form

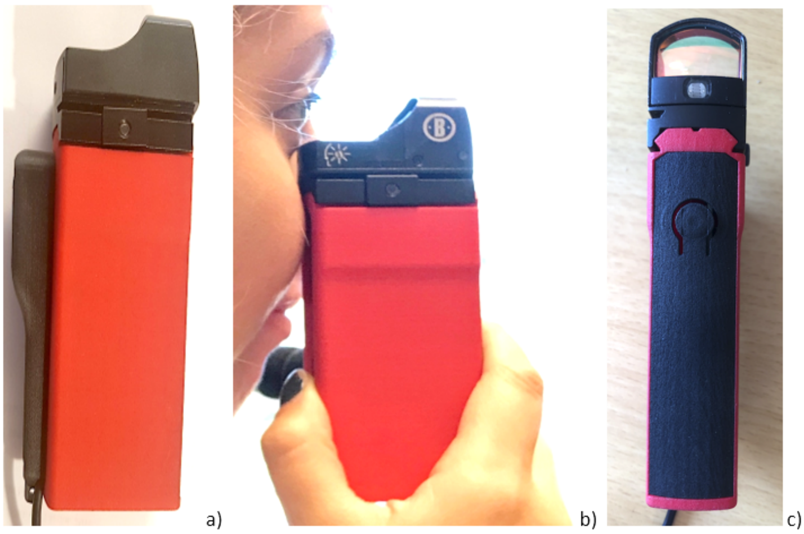


Figure 2. a) 2020 model Pi Geometer with a top-mounted red dot sight (covered) and an armoured USB connector cover; b) 2019 model held in vertical orientation, with sight cover removed; and c) front of the Geometer.

factor of the first prototype to comply with the small bubble windows.

The original demand was to replace the Suunto PM-5/360 PC Clinometer with automatic time-stamped declinations with a single click. Later, the benefit of combining this event with GPS coordinates and voice recording became clear. From these demands, the PiAttitude Windows software was created to accompany the Geometers. This software can record data from several Geometers, and a GPS unit, simultaneously (Figure 3).

When more users became aware of the Geometer, interest rose to integrate the Geometer into a survey software system called Visual Observer Recorder (VOR). Since VOR is too old to run on newer Windows operating systems, a programme called VisualSurveyor (VS) was written that combines and extends the various features of VOR and optimises inputs from Geometers. This new software is financed and managed by a user group led by one of the authors (Lawson) and, like the Geometer, is under continual development. Beside inclination, GPS, and audio recording data, VS can record manually entered metadata such as survey observer configuration, weather and sighting conditions, species sighted, group size, and other details (Figure 4). VS enters data into an SQLite (www.splite.org) database and there are plans for adding functions for preliminary summary and analysis of information that can be output from the database.

As other systems might want to integrate the data streams of the Geometer, an application programming interface (API) is available.

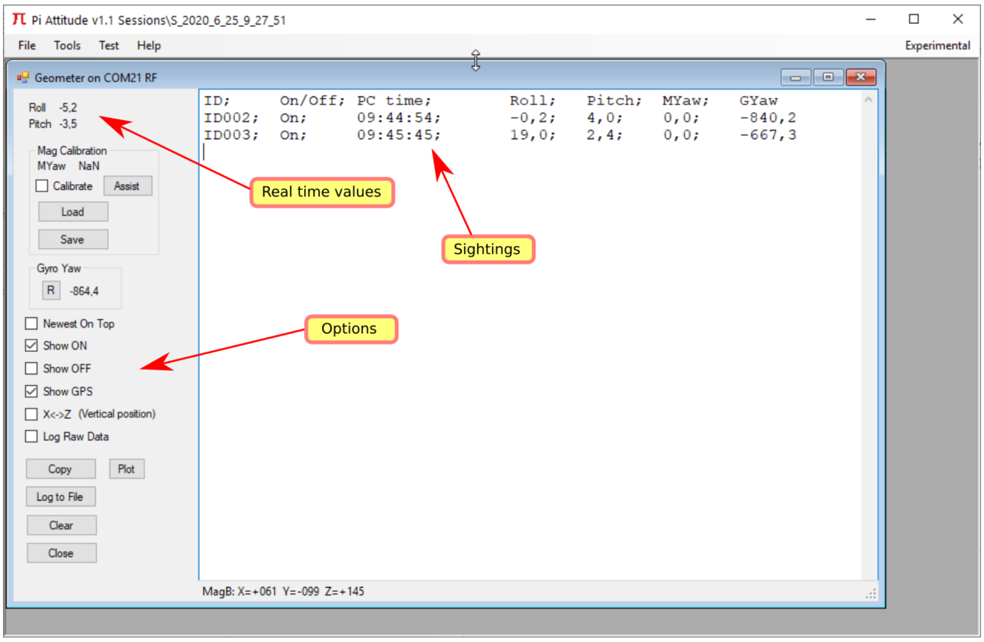


Figure 3. Pi Attitude software interface, indicating several key features, including real-time display of declination values, user-defined operation settings, and recorded sighting events.

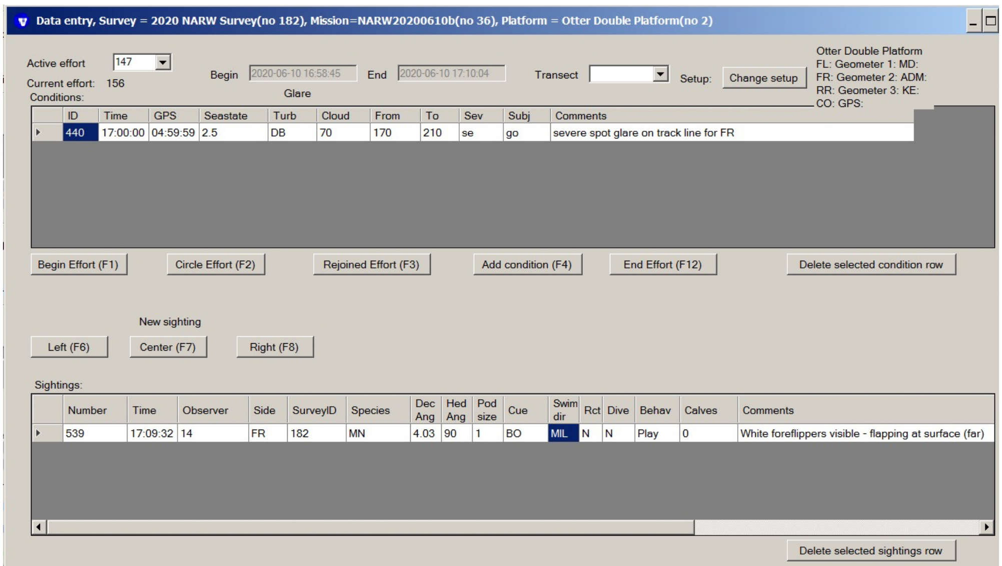


Figure 4. Visual Surveyor software data entry window, indicating several key features, including display of user-defined operation settings, observer positions, record of sighting conditions (top pane) and recorded sighting event (bottom pane).

Geometer hardware

The Geometer is based on a magnetic angular rate gravity/inertial measurement unit (MARG/IMU) electronic sensor, combined with a microcontroller on a printed circuit board mounted in a housing. The current version, V2, is connected to a PC via a USB cable that also powers the Geometer. The main function of the device is to measure declination from horizontal to the target location when abeam. This value is calculated based on measurements of the direction of earth's gravity relative to the device. As there is a non-linear relation between the gravity values and the angle estimate, the accuracy of the device is measured from the assembled unit instead of deducing it from sensor data.

When using the Geometer, the user looks through a non-magnifying "red dot" illuminated sight, aims the visible red dot at the target as it passes abeam of the platform, and presses a trigger button. This initiates reading of the declination, the GPS coordinate stream, and time. The Geometer can be used while held horizontally or vertically (Figures 2, 5 and 7).

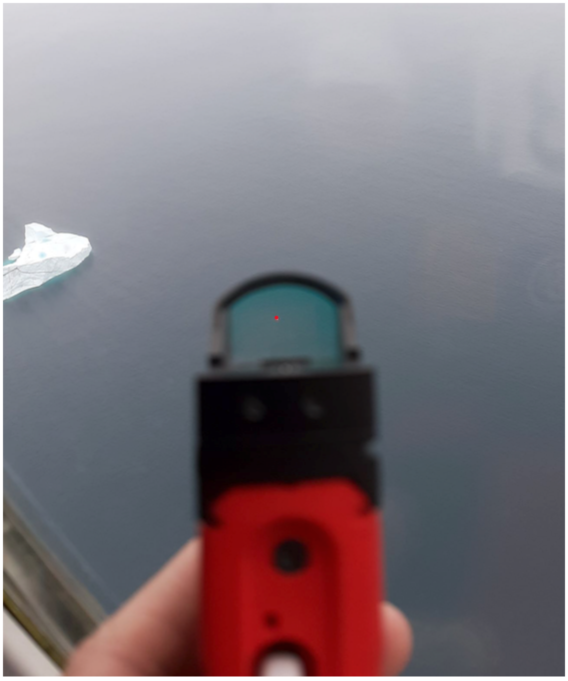


Figure 5. A Geometer used during an aerial survey in Greenland. Viewed through the reticle, a red sighting dot (enhanced here for visibility) marks the spot to where an angle will be recorded by clicking the Geometer's trigger button.

The Geometer also can measure earth's magnetic field and can estimate the aiming direction. As aircraft are metallic and deployed to various places on earth, the Geometer needs to be calibrated in the field for proper direction values. Currently, experiments are being conducted to determine the accuracy of Geometer heading estimates in different aircraft.

Software

PiAttitude

The PiAttitude software accompanies the Geometers and features a simple user interface (Figure 3). After initiating the programme, the user chooses which COM port to read the Geometer stream through. Several Geometer data streams can be monitored concurrently in PiAttitude and displayed on one computer screen. Roll (declination) and pitch values can be seen in real time and when the button on the Geometer is pressed, the current values are recorded to a text file, along with the time. If a GPS stream is also being recorded by PiAttitude, current latitude and longitude will be added to the sighting records. Every time the Geometer trigger button is pressed all readings are displayed in the software window and saved to a log file. The Geometer and associated software have the following features:

- Values are recorded in a text format so the user can edit or add comments;
- At the end of a session, all values can be saved to a text file;
- Every time the Geometer button is pressed all readings are saved as a backup;
- The data are structured with semicolon separators for easy import into analytical software.

VisualSurveyor

In contrast to PiAttitude, VisualSurveyor is strict on format and writes data streams to defined and linked fields in its underlying SQL database. Before surveying, the user defines surveys, transects, number and identity of observers, and devices inputting data streams. The user can only enter data into specific fields and data is stored in the database.

VisualSurveyor (VS) runs on 64-bit Windows computers (versions 7 and 10 have been tested) and accepts input from hardware devices like Geometers, USB buttons, keyboards, and GPS, and can present data on a moving map. VS is very resistant to data loss, and VS checks data for errors during entry.

Maps are used for displaying observations and presenting tracks. When in a location with internet, these maps can be fetched by VS from free map suppliers like Google maps or OpenStreetView. In the future, a dedicated web portal (cloud) might be beneficial to fetch previous transects, and store and share data among survey teams.

For aerial survey applications, each observer could have a headset, a Geometer, and optional other input/output devices (Figure 6). If there is a data recorder person on the platform, (s)he would also have a keyboard to control the computer running VS.

In the current iteration of VS, a sighting declination is recorded when the object is abeam. With the addition of yaw data to the clinometer, sightings can take place at other times, by pointing directly at the target and using the yaw and declination measurements to estimate perpendicular distance from the transect. Of course, the Geometer could still be used as before, taking the sightings abeam if desired.

One of the keys to understanding how VS operates is that it was designed to be transferrable and operable from a single folder, which contains all the necessary Windows components and a database. The programme configurations and data are stored in an underlying SQL database. After a mission, the data recorder can export the sightings or GPS data directly from the database.

VisualSurveyor offers flexibility in how settings can be selected and modified while it is running. The programme can be operated in one of Novice, Typical, Experienced, or Administrator mode; each offering users different levels of choice and control over settings.

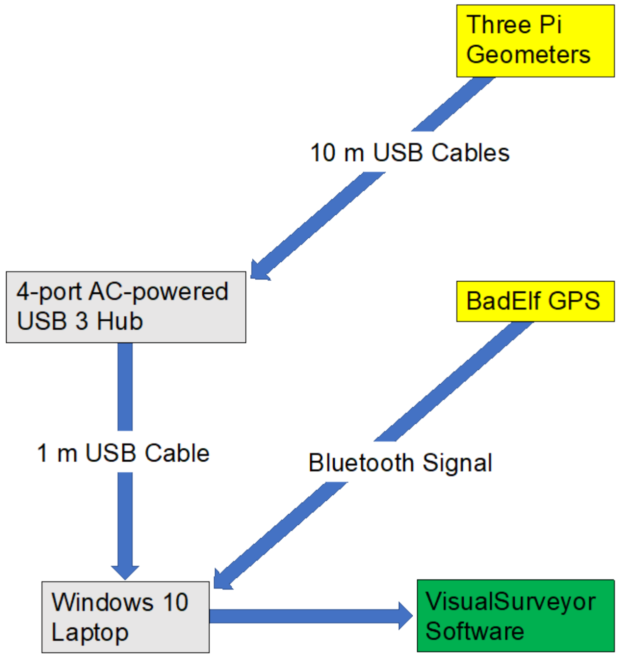


Figure 6. Signal connections for the multiple Geometers used to input declination measures from three observer positions to the VisualSurveyor software aboard a Fisheries and Oceans Canada chartered Twin Otter.

PRE-SURVEY TESTING

After installation of the red-dot sights atop the Geometers, and prior to any testing or survey use, Geometers were "sighted in" by recording declinations to a single target from a known height at a measured lateral distance from the unit, and the sight was adjusted as per directions until the measured and actual declinations were equal (Figure 7). A prototype Geometer was tested in May 2015 prior to a survey planned for July of that year, and again prior to and during a survey carried out in July 2016. Testing was carried out by holding the Geometer on top of a tripod at a measured height from the floor, and sighting on targets (coins) at known lateral distances from the unit (Figure 7). Actual declination angles to the target were calculated trigonometrically for comparison.

Linear regression was used to determine the relationship of actual versus measured declination angles. In 2015, the unit was left running for about 5 hours (a typical flight duration) and declination measurements were repeated every hour. In 2016, the 4 Geometers used on the survey were tested individually to determine if the units differed. In addition, the units were tested in the horizontal and vertical orientations to determine if that affected measurement accuracy.

Results

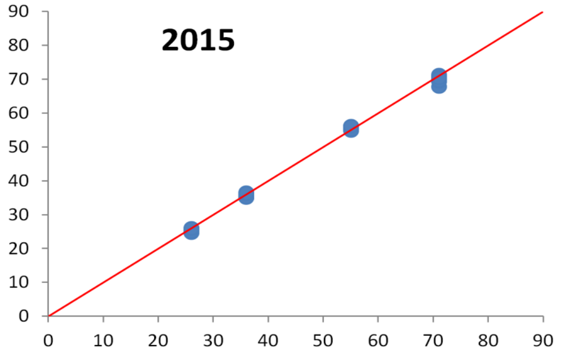
Regression of measured against actual declinations had a slope close to 1 in all cases (Table 1, Figure 8). In 2015, the intercept term was not significantly different than 0 ($P>0.05$) and there was no significant effect from the length of time the instrument had been running (i.e., no instrument drift). In the 2016 regression, the intercept term was significant ($P<0.001$) but had a magnitude of less than 1 degree. There was no significant effect of Geometer identity or Geometer orientation. Using measurements from both years, the intercept term was not significantly different from 0, slope did not differ significantly from 1, and there was no effect from the year of measurement.

Yaw measurements were also tested but were found to be too inaccurate for use in 2015-16. However, the hardware and firmware have been updated and the yaw function is improved. Development and testing are still ongoing.

Figure 7. Geometer "sighting in", by making declination measurements from a known Geometer height on target coins at a known distance from the Geometer.

Table 1. Linear regressions of actual to measured declination to targets. A-R^2- adjusted R^2; *P* - significance; *** - *P*<0.001; *M* - regression slope; INT - intercept.

Year	n	A-R^2	*P*	*M*	95% CI		INT	95% CI	
2015	43	0.976	***	0.996	0.990	1.001	NS		
2016	32	1.000	***	1.012	1.006	1.018	-0.663	-0.953	-0.373
All	75	0.986	***	0.997	0.994	1.001	NS		



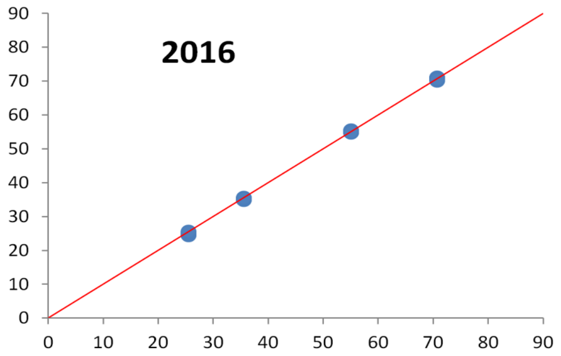


Figure 8. Actual (x-axis, degrees) versus measured declinations using the Geometer in 2015 and 2016. X=Y line shown for comparison.

USE ON SURVEYS

Iceland 2015

The Geometer was used for the first time on an aerial survey carried out in July 2015 around Iceland (Pike, Gunnlaugsson, Sigurjónsson, et al., 2020). Observer training was simplified because observers did not have to learn to rapidly read and report analogue clinometer readings. Experienced observers commented that simply pointing and clicking the Geometer was a much easier task. The red dot sights were found to be functional and reliable, and easy to point under all light conditions encountered. Data transcription was greatly eased as the primary data (time, location, declination) were available for copying and backup immediately after every flight. No significant issues with hardware or software were encountered.

Iceland 2016

In 2016 the Icelandic survey was repeated using a de Havilland Twin Otter with a full double platform configuration (Pike, Gunnlaugsson, Sigurjonsson, et al., 2020). As the bubble windows on the Twin Otter are somewhat smaller than those on the Partenavia Observer used in 2015, observers found the Geometers awkward to use in the horizontal configuration. However, the developer immediately revised the control software so that they could be used in a vertical configuration; this was found to be more comfortable for most observers. The Geometer sights were "sighted in" after switching configurations. Again, no significant issues with hardware or software were encountered during this survey.

Greenland 2016

In Greenland, a de Havilland Twin Otter with 4 observers has been the standard platform and configuration for aerial surveys for cetaceans since 2005. Observers used Suunto inclinometers to manually record declination angles to cues and/or whales to be used for cue counting and/or line transect analysis. The Geometer was first used on an aerial survey in Greenland in 2016 where all observers participating in the survey were experienced marine mammal observers (Figure 9). There was a positive consensus regarding the digital output of the Geometer because the time used to transcribe data post survey was substantially reduced. The digital readings seemed especially useful in areas with clumped distribution of animals where observers, in the past, had to manually read many declination angles in a short timeframe. When reading declination angles in such a situation, observers tend to either heap angles together or to group smaller groups of animals into larger groups making it difficult to separate out double sightings. All observers agreed that declination measurements were made easier by using the Geometer and there was a common understanding that more

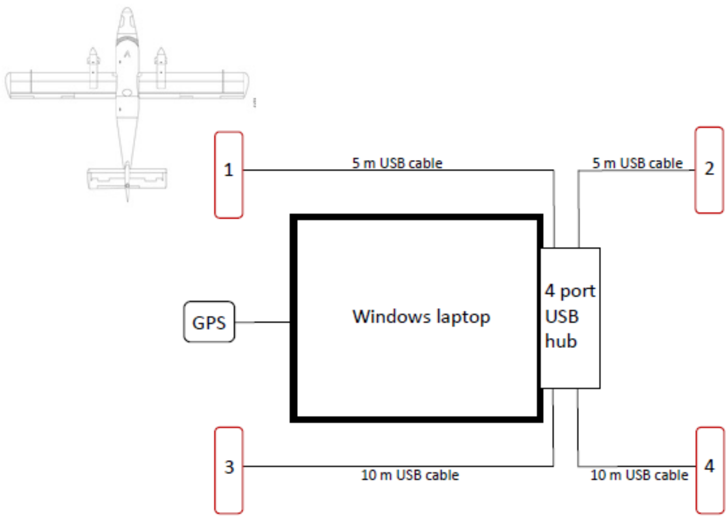


Figure 9. Geometer setup for four observers on board a de Havilland Twin Otter used for aerial surveys in Greenland. Numbers refer to Geometers 1-4.

animals/group of animals were sighted in large scattered groups because observers did not have to spend time manually reading the declination angle. Also, the time stamp at the time the declination angle was measured was more precise than on previous surveys. This was especially the case when there were many sightings close in time.

Heaping

We compared declination measurements made by primary platform observers to sightings of common minke whales, white-beaked dolphins, humpback whales and harbour porpoises from: a) surveys carried out around Iceland in 2007 and 2009 using a Suunto clinometer, and b) surveys carried out around Iceland in 2015 and 2016 using Geometers (Figure 10). Heaping is apparent in measurements using the Suunto, with a higher frequency of observations at multiples of 10 and to a lesser extent 5 degrees. There is no obvious heaping evident in measurements made using the Geometer. The same pattern was true for data collected during Canadian aerial surveys.

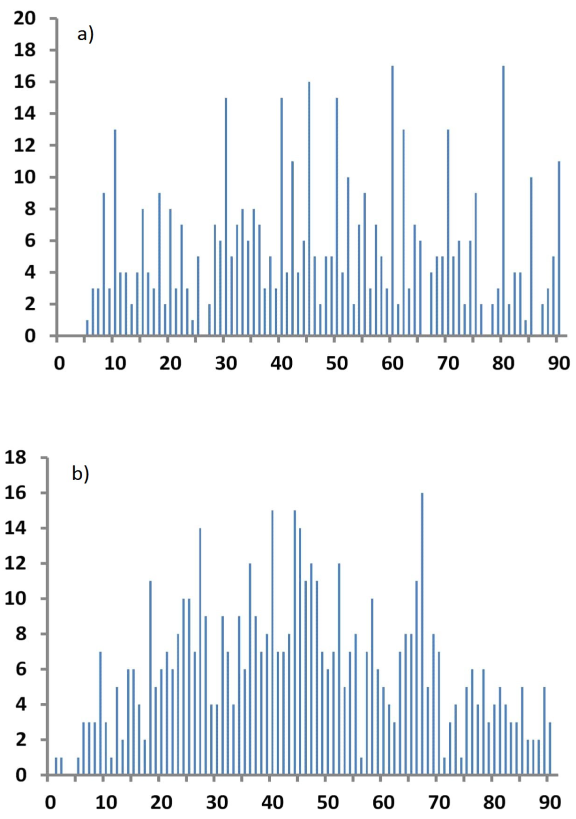


Figure 10. Frequency distributions of beam declinations to sighting from a) surveys in 2007 and 2009 around Iceland using Suunto inclinometers, and b) surveys in 2015 and 2016 around Iceland using Geometers.

Duplicate identification and measurement precision

Survey data from two visual aerial surveys of narwhals in Northwest Greenland (in 2014 and 2019) were used to test for difference in angle measurement and timing precision for duplicate identification using Suunto inclinometers (2014) and Geometers (2019). Sightings from same side observers were identified as duplicates if the difference in time was less than 20 seconds and in degrees less than 15 (in 2014) and less than 6 seconds and 10 degrees (in 2019). For the purpose of testing the precision of the Geometer, sightings with a time difference of 5 seconds or less and differing no more than 15 degrees in declination were classified as prospective duplicates for both surveys. The total number of prospective duplicates identified this way were 18 and 102 in 2014 and 2019, respectively (Table 2). The average difference in time (in seconds) between same side sightings was significantly different between the 2 sets of angle measurements (t-test, P<0.001). The average difference in declination angles measured with the Geometer (1.76 degrees) was significantly smaller than angle measurements using the inclinometer (4.42 degrees), which ultimately led to a more reliable procedure of assigning sightings as single or double sightings (Table 2). Narwhals are mostly found in groups and observers need to determine the midpoint of a group of animals. It is possible that the variance in this determination between same side observers causes some of the variance in the measurement precision. It would be ideal to make a comparison of inclinometer and Geometer precision on a data set with sufficient duplicate sightings of single animals.

Table 2. Duplicate sightings from visual aerial surveys of narwhals in Northwest Greenland 2014 and 2019. N is total number of sightings, N (s) is the number of sightings made by same side observers within 5 seconds, N_{dup} is the total number of duplicates, N_{dup} (s) is the number of duplicates within 5 seconds and $\bar{x}_{dec}$ is the average difference in declination angles of duplicate sightings within 5 seconds with standard deviation (sd) in parentheses.

Year	N	N (s)	N_{dup}	N_{dup} (s)	$\bar{x}_{dec}$ (sd)
2014	89	19	37	18	4.42 (4.58)
2019	159	103	102	102	1.76 (1.42)

Atlantic Canada 2007, 2013-2020

Fisheries and Oceans Canada flew a number of aerial surveys for marine megafauna around Atlantic Canada (mainly Newfoundland and Labrador) in 2007 and in 2013-2020, with 3 or 4 observers using Geometers on a Twin Otter at 600- or 800-feet altitude. In 2019, the Canadian teams began using Geometers, with previous surveys using handheld Suunto clinometers. Observers used the Geometers, equipped with red-dot sights, connected by 10m USB cables to a single Windows laptop that was monitored by the flight leader/data recorder. The Geometers were integrated with VS for triggering each sighting record and the measurement of observation time, GPS location, and declination angle. The Geometers performed well over the course of the survey and in combination with VS provided an efficient and consistent means to collect real-time sightings data into a digital database. No calibration drift was noted in the declination measurements over time. During mark-recapture effort there was rarely much difference in the angles between declinations collected by front and rear observers of the same targets (see next section).

Measurement precision

Survey data, for cetaceans only, from the nine visual aerial surveys were used to test for difference in angle measurement and timing precision for duplicate identification using Suunto inclinometers (2007, 2013-2018) and Geometers (2019 and 2020). Sightings from same-side observers were identified as duplicates by the team during flight, or if the difference in time was less than 5 sec and in degrees less than 15. The total number of duplicates identified this way were 650, a proportion that varied amongst years (Table 3). A t-test found that the mean difference between paired observers' declination angles measured with the Geometer (3.27 degrees) was significantly smaller than between observer angle measurements based on the Suunto (5.07 degrees) ($t = -5.403$, $df = 249.3$, $p < 0.0001$). As for the Greenland experience, the variance in declination values between same side observers causes some of the variance in the measurement precision. To further test this possibility, the inclinometer and Geometer precision was compared on a subset of this data with duplicate sightings of single animals. Again, the mean difference between paired observers' declination angles measured with the Geometer (3.28 degrees) was significantly smaller than between observer angle measurements based on the Suunto (5.22 degrees) ($t = -3.635$, $df = 113.8$, $p = 0.0004$).

Table 3. Duplicate sightings from visual aerial surveys of cetaceans in Atlantic Canada in 2007 and 2013-2020. The data were collected by 2 observers in bubble windows on the right side of a Twin Otter aircraft, with a data recorder sitting between the bubbles. *N* is total number of cetacean sightings, N_{dup} is the total number of duplicates, and $\bar{x}_{dec}$ is the average difference in declination angles of duplicate sightings with standard deviation in parentheses. The 2020 survey is ongoing.

Year	N	N_{dup}	$\bar{x}_{dec}$ (sd)
2007	712	50	6.18 (4.44)
2013	66	16	3.44 (2.28)
2014	46	23	5.26 (3.70)
2015	183	15	5.80 (4.72)
2016	1,286	187	4.26 (3.98)
2017	240	25	4.24 (3.94)
2018	3,595	209	5.68 (4.53)
2019	774	66	3.39 (3.05)
2020	896	59	3.13 (3.18)

CONCLUSIONS AND DISCUSSION

The Geometer and associated software have the following advantages over the analogue clinometers traditionally used in surveys:

- The Geometer eliminates observer error in reading or transcribing the declination, yaw, and time measurements. Furthermore, without display of the declination value, there is no chance of "heaping" in declination readings by observers;
- The differences between declination angles and re-sighting times collected by paired observers (double platform data collection) is less with Geometers than with analogue clinometers;
- More accurate time stamps on all observations;
- Faster to use in areas of high-density sightings, with the observer simply sighting the "red dot" on each group centroid and pressing the button – even with keyboard entry of sightings metadata, the VS data collection system kept up with this data stream;
- The observer can use both eyes to make the sighting, allowing better observation effort to be maintained while with analogue clinometers, the sighting can only be seen with one eye when using the instrument;
- With the VS software, Geometer data are recorded into a SQL database that can easily output desired variables for use in subsequent analyses, eliminating transcription errors and data handling time;
- When the Geometers can also produce reliable yaw measurements, the observers could collect sighting angles anywhere in the viewing field, rather than just abeam, which would be a real advantage. For instance, VS could then automatically calculate exact target positions and distances based on altitude and the two declination and yaw measurements.

There does, however, remain room for improvement. This includes:

- Improving precision and collecting accurate yaw measurements, making it feasible to use the Geometer on ship surveys;
- Integrating a microphone into the Geometer to allow for the input of audio data (previous surveys have used separate microphones and voice recorders);
- Waterproofing the Geometer for use on outdoor platforms exposed to weather, such as large vessels and elevated terrestrial observatories;
- Creating an option for Bluetooth data connection with the Geometer (which would then be battery powered);
- Adapting the Geometer to provide audible or visible feedback if a trigger press has been sent.

The future

The Geometer has been displayed at various international conferences (e.g., in Halifax, Canada 2017, Middelfart, Denmark 2018, and Barcelona, Spain 2019). Users have suggested new functionality such as Bluetooth connectivity, built-in voice recording, and integration with software on IOS and Android devices. Every modification must be undertaken with care as some users report limitations such as not being allowed to use a Bluetooth instrument on some aircraft. In the future, the Geometer will feature increased functionality both in the hardware and software integration.

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COMPETING INTERESTS STATEMENT

Except for the manufacturer, Baldur Thorgilsson, the other authors of this technical note have no financial interest in the development of the Geometer nor the accompanying software.

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