Fit-for-purpose boundary mapping with low-cost GNSS receivers and opensource software

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Key words: cadastral surveying, low-cost equipment, opensource, adjustment, quality control

SUMMARY

The paper focuses on new methods for data capture and calculations within the field of cadastral surveying. During fieldwork in Northern Norway, two different low-cost GNSS-receivers have been tested for the purpose of mapping boundaries. These two receivers, Emlid Reach RS2 and Trimble Catalyst DA2, have been used together with smartphones and opensource software. On different types of smartphones, we have tested two different solutions based on the opensource GIS-software QGIS. One solution makes use of the smartphone-app "QField", and the other solution makes use of the smartphone-app "MerginMaps". The latter solution is cloud-based, while QField stores the data locally in the device. For both solutions, the captured data are stored within a QGIS-project. For computations in compliance with the Norwegian standards for cadastral surveying, new functionality is added to QGIS by making of a plugin called GNSSCAD. In this plugin we implement the current procedures for cadastral surveying computations in Norway. This includes weighted least squares adjustment computation, with blunder detection and reliability analysis. Also implemented is a suggested refinement of the current procedures, to make them more fit-for-purpose. The refined procedures that we propose are considered more suitable for calculations on GNSS point observations than the traditional methods, which originate from the time when total station was the main and preferred instrument for the cadastral surveyor. In addition to describing the procedures and results, the paper also presents a comparison of the results achieved with traditional equipment and software, and the results from the low-cost alternative. It is found and shown that the results produced by the low-cost alternative fully satisfy the demands concerning data quality found in the Norwegian standard for cadastral surveying. But it is also demonstrated that there are some challenges concerning data flow and assurance against blunders.

1. INTRODUCTION

Norwegian cadastral surveyors are most commonly employees of the local municipality. New properties need to be surveyed and mapped before registration. In this process, standardized boundary marks are first placed (usually) in the corners of the new property. After that, standard procedures are followed to map the new boundary. In most cases, and whenever possible, RTK-GNSS equipment is used for the surveying. If forest is too dense, or if the satellite signals are blocked by other objects, the surveyor will also use total station, and in some cases measuring tape. The accuracy demand is defined as a limit for the calculated external reliability of the coordinates. The limit is 10 cm with a probability of 95 %. This applies to the values for northing and easting, height is not registered in the cadastral map. Every boundary point is usually surveyed three times, with a time separation of at least 15 minutes between each observation to secure independency. The procedure of calculation is 1) Blunder detection, 2) Reliability analysis, and 3) Least squares adjustment. When the two first steps are passed with satisfactory results, the coordinates from step three can be registered, together with their calculated standard deviations from the adjustment computation.

The adjusted boundary points are connected by boundary lines, digitized on screen. Attribute data are added to both point objects and line objects. The resulting vector data are stored in ASCII-files, the format is the Norwegian "SOSI" (Geonorge).

To comply with the required accuracy and wanted efficiency, the GNSS receiver used for cadastral surveying must be of a type that measures on the carrier-phase and provides a solution in real time. Receivers like this has been available for several decades, at prices commonly ranging between $10 000 and $30 000. In the recent years, some different low-cost receivers have also entered the market, offering the same accuracy and efficiency for about one tenth of the price. But as far as we know, such low-cost receivers are not yet used for cadastral surveying by any of the Norwegian municipalities.

We wanted to find out if use of low-cost GNSS-receivers could be fit-for-purpose in Norway. We also wanted to find out if it is possible to use free software for the computations and production of data for the cadastral map.

We have tested two different low-cost GNSS receivers in this research project. The Emlid Reach RS2 receiver (Emlid) has earlier been tested at the Norwegian University of Life Sciences (Øvstedal, Arnell, Ingebrigtsen, Tangen, & Roald, 2022), but not for the purpose of cadastral surveying, or making point observations by connecting to a base network service. This receiver costs around $2000. With two receivers, one of them can serve as a base station, otherwise a subscription to a base network service will be needed. The Trimble Catalyst DA2 (Trimble, 2021) is a different type of low-cost GNSS receiver. This is a software-based, and service-based receiver, and unlike the Emlid, the antenna itself doesn't contain very much hardware. The antenna is connected to the smartphone, which is turned into a GNSS receiver co-working with Trimble's positioning service. The antenna costs around $400, and a monthly subscription fee is about the same amount.

2. METHOD

As part of the annual fieldwork in cadastral surveying at Western Norway University of Applied Sciences, several parcels in Røst municipality have been surveyed by student groups under supervision by teachers. Each parcel has been surveyed twice, both by use of traditional equipment and by use of one low-cost alternative. Two separate calculations have also been made, one from each of the two observation sets. Data analysis and adjustment has been undertaken by use of commercial software, Gemini Terrain 18 (Volue, 2022), which is in regular use by Norwegian municipalities. When comparing the results, we have been looking for significant differences both regarding absolute position and estimated standard deviations for the coordinates.

We have restricted our analysis to the boundary points where physical boundary markers are placed. Some boundary points, typically along roads, but also elsewhere, has remained unmarked, and for such points we cannot be totally sure that the same position has been surveyed with both instrument types.

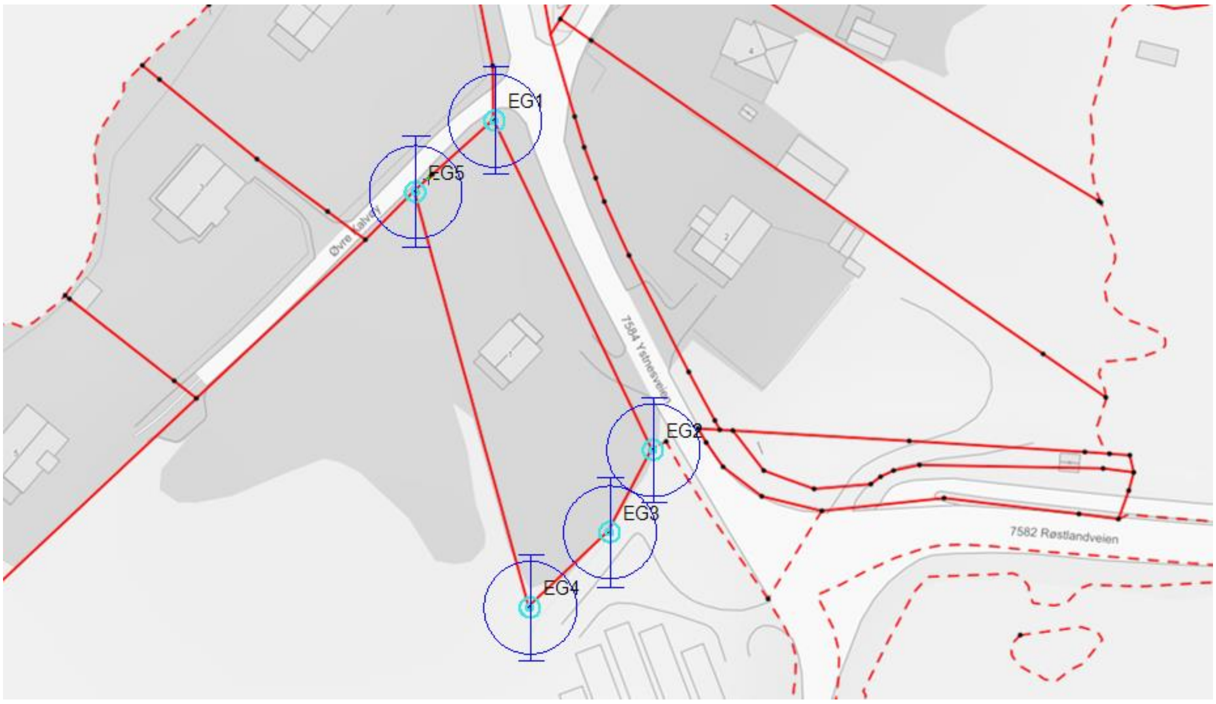

Figure 1: A parcel surveyed with high-end Leica equipment and with Emlid Reach RS2. The error-ellipses come from the adjustment of the Emlid-observations.

Figure 1 shows one of the parcels that were surveyed. First, boundary marks were placed in the five boundary points. Then the points EG1 to EG5, were surveyed by placing the rod with the GNSS antenna on top of each boundary mark. These boundary points were also surveyed with total station for extra control. Surveying with Leica GS18 and Leica TS12 yielded the following result:

Point-ID	Northing	Easting	Height	Std. N	Std. E	Std. H
EG1	7491500.906	375712.264	4.131	0.0065	0.0065	0.0124
EG2	7491447.667	375737.892	1.710	0.0065	0.0063	0.0128
EG3	7491434.382	375730.856	1.787	0.0069	0.0066	0.0147
EG4	7491422.208	375717.968	2.061	0.0066	0.0064	0.0128
EG5	7491489.386	375699.445	2.504	0.0063	0.0061	0.0113

Surveying with Emlid Reach RS2 gave the following result:

Point-ID	Northing	Easting	Height	Std. N	Std. E	Std. H
EG1	7491500.904	375712.287	4.120	0.0116	0.0116	0.0134
EG2	7491447.688	375737.884	1.708	0.0116	0.0116	0.0131
EG3	7491434.371	375730.858	1.775	0.0116	0.0116	0.0138
EG4	7491422.193	375717.991	2.048	0.0116	0.0116	0.0131
EG5	7491489.385	375699.436	2.502	0.0116	0.0116	0.0139

Differences in absolute position and estimated standard deviations are given in the following table:

Point-ID	Northing	Easting	Height	Std. N	Std. E	Std. H
EG1	0.002	-0.023	0.011	-0.005	-0.005	-0.001
EG2	-0.021	0.008	0.002	-0.005	-0.005	0.000
EG3	0.011	-0.002	0.012	-0.005	-0.005	0.001
EG4	0.015	-0.023	0.013	-0.005	-0.005	0.000
EG5	0.001	0.009	0.002	-0.005	-0.006	-0.003

The largest differences in absolute position are 2.3 cm. The differences seem to go in every direction, except for the height. The standard deviations for the coordinates produced by the Emlid Reach RS2, is about 5 mm bigger, or about twice the size of the corresponding numbers for the Leica GS18.

For the Leica GS18, one of the point-observations would look like this:

```
05 EG1                  7491500.905  375712.268    4.126
47   0.00002484   0.00001897   0.00008083   0.00000148   0.00001547   0.00000045
46 29092022 09:21:15      1.2  0.000
```

The first line, starting with 05, contains the observed coordinates, and height above the geoid. The second line contains the full covariance matrix for the vector from the virtual reference station to the surveyed point. The last line shows date, time, PDOP and antenna height (which is here zero because it is already taken into account). This block of data is exported directly from the field controller and ready for import in the standard Norwegian surveying software packages. The name of this data format is KOF (Norkart, 2005).

2.1 Emlid Reach RS2

The Emlid Reach RS2 receiver was connected wireless to a smartphone and was controlled from the free app called "Reachview 3" (but at time of writing this app is replaced by an updated version called "Emlid Flow") (Emlid, 2023). From within the app one can select the official Norwegian coordinate reference system which for the municipality of Røst is Euref 89 UTM zone 33. One can also download the current geoid model, and select the official height reference system, which is NN2000. After surveying, the results are exported to a csv-file:

```
Name,Easting,Northing,Elevation,Description,Longitude,Latitude,Ellipsoidal height,Easting RMS,Northing RMS,Elevation RMS,Lateral RMS,Antenna height,Antenna height units,Solution status,Averaging start,Averaging end,Samples,PDOP,Base easting,Base northing,Base elevation,Base longitude,Base latitude,Base ellipsoidal height,Baseline,CS name

EG1,375712.288,7491500.926,44.043,bnr111,12.08714622,67.51310083,44.043,0.010,0.010,0.013,0.014,1.934,m,FIX,2022-10-02 11:48:15.4 UTC+02:00,2022-10-02 11:48:15.4 UTC+02:00,1,1.5,375717.893,7491522.890,47.475,12.08725320,67.51329995,47.475,22.722,ETRS89 / UTM zone 33N
```

As there is no direct import for this data format in the commercial software packages, we chose to write a python script for converting the csv-file to a KOF-file. After conversion, the observation looks like this:

```
 50 EG1                  7491500.926  375712.288   44.043
 51   0.0100   0.0100   0.0130  1.0000  0.0000  0.0000  1.0000  0.0000  1.0000
 46 02102022 11:48:15 99  1.5   0.000   1 FIX
```

Here, the first line starts with 50, indicating that the height is above the ellipsoid. The 51-line contains standard deviations for the observed coordinates and has also room for a correlation matrix. As the correlation values aren't included in the csv, the correlations between the coordinates are automatically set to zero. Former research indicates that this has minimal effect on the adjusted result compared to the general accuracy of RTK-observations. In most cases, the change of position by adding correlation values would be within the surface of the boundary mark itself! (Nysæter, 2017).

2.2 Surveying with Trimble Catalyst

One of the student groups that surveyed the parcel with both Leica GS18 and Trimble Catalyst DA2, got the following result for the one boundary point that was marked in the field.

2.2.1 Group 1

Result with Leica GS18:

Point-ID	Northing	Easting	Height	Std. N	Std. E	Std. H
15NY	7491481.501	375691.578	2.317	0.004	0.003	0.009

Result with Trimble Catalyst DA2:

Point-ID	Northing	Easting	Height	Std. N	Std. E	Std. H
15NY	7491481.490	375691.559	4.110	0.008	0.008	0.011

Difference

Point-ID	Northing	Easting	Height	Std. N	Std. E	Std. H
15NY	0.011	0.019	-1.793	-0.004	-0.005	-0.002

The differences in northing and easting lie well within the limits of what is expected on basis of the estimated standard deviations. We notice a huge difference in height, and we also notice that this difference is only 7 mm away from exactly 1.8 meters. For the Trimble Catalyst DA2, the antenna height could only be set at either 1.8 meters or 2.0 meters.

2.2.2 Group 2

Another student group surveyed a parcel using Leica GS14 and Trimble Catalyst DA2. Three boundary markers were placed on one side of the parcel, and thereafter surveyed with both instruments.

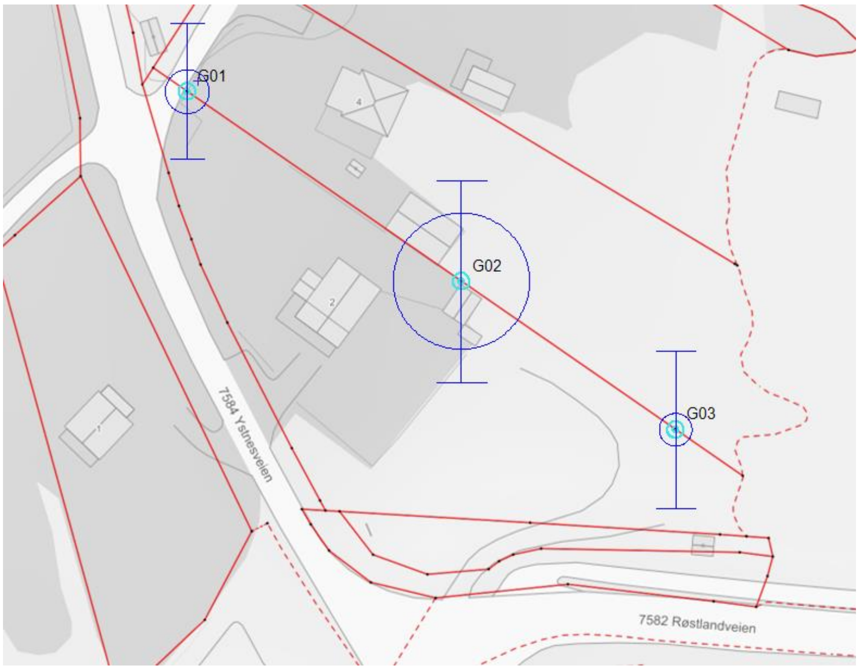

Figure 2: Parcel with three boundary points measured with both Leica GS14 and Trimble Catalyst DA2. The error-ellipses come from the adjustment of the Trimble-observations.

Results obtained with Leica GS14:

Point-ID	Northing	Easting	Height	Std. N	Std. E	Std. H
G01	7491513.737	375728.100	5.190	0.003	0.002	0.006
G02	7491485.279	375769.184	1.423	0.004	0.003	0.009
G03	7491463.042	375801.261	1.206	0.003	0.002	0.007

Results obtained with Trimble Catalyst DA2:

Point-ID	Northing	Easting	Height	Std. N	Std. E	Std. H
G01	7491513.718	375728.107	7.348	0.007	0.007	0.021
G02	7491485.270	375769.176	3.578	0.021	0.021	0.030
G03	7491463.024	375801.257	3.278	0.005	0.005	0.024

In the results above, we observe that the heights are all totally different for the two instruments. Differences in absolute position and estimated standard deviations are shown in the following table:

Point-ID	Northing	Easting	Height	Std. N	Std. E	Std. H
G01	0.019	-0.007	-2.158	-0.004	-0.004	-0.015
G02	0.009	0.008	-2.155	-0.017	-0.018	-0.022
G03	0.018	0.004	-2.072	-0.002	-0.003	-0.016

The differences in northing and easting lie well within the limits of what is expected on basis of the estimated standard deviation. The differences in height is here not close to a possible value for the antenna height, which could be set to either 1.80 or 2.00 on the pole that was in use. For these measurements it has not been possible to resolve the height issue with any certainty.

2.2.3 Group 3

Still another student group surveyed two adjacent parcels with both Leica GS14 and Trimble Catalyst DA2.

Figure 3: Two parcels surveyed with different instruments.

The point HP served as a setup point for the total station and was surveyed with GNSS just like the boundary points. The results below are obtained solely with GNSS, without any TS measurements.

Results with Leica GS14

Point-ID	Northing	Easting	Height	Std. N	Std. E	Std. H
HP1	7491612.185	375785.762	2.470	0.003	0.002	0.006
P1	7491614.933	375791.446	2.370	0.004	0.003	0.008
P2	7491602.595	375815.213	0.830	0.006	0.004	0.014
P3	7491580.659	375803.765	2.005	0.003	0.002	0.006
P4	7491595.914	375780.072	2.521	0.004	0.003	0.013
P5	7491568.350	375797.933	2.229	0.003	0.003	0.008
P6	7491585.079	375771.508	3.182	0.004	0.003	0.009

Results with Trimble Catalyst

Point-ID	Northing	Easting	Height	Std. N	Std. E	Std. H
HP1	7491612.185	375785.768	5.5	0.003	0.003	0.003
P1	7491614.935	375791.451	5.4	0.003	0.003	0.003
P2	7491602.583	375815.205	3.8	0.003	0.003	0.003
P3	7491580.656	375803.768	5	0.002	0.002	0.002
P4	7491595.899	375780.074	5.5	0.002	0.002	0.002
P5	7491568.341	375797.931	5.2	0.003	0.003	0.003
P6	7491585.063	375771.515	6.2	0.003	0.003	0.003

In the dataset from Trimble Catalyst we observe that the measured heights are shown with no more than one decimal. The precision that we would expect seems to have been lost in some step of the data transfer process.

Differences in absolute position and estimated standard deviations are shown in the following table:

Point-ID	Northing	Easting	Height	Std. N	Std. E	Std. H
HP1	0.000	-0.006	-3.030	-0.001	-0.001	0.003
P1	-0.002	-0.005	-3.030	0.000	-0.001	0.005
P2	0.012	0.008	-2.970	0.002	0.001	0.011
P3	0.003	-0.003	-2.995	0.000	-0.001	0.003
P4	0.015	-0.002	-2.979	0.001	0.000	0.010
P5	0.009	0.002	-2.971	0.000	-0.001	0.005
P6	0.016	-0.007	-3.018	0.001	0.000	0.006

The biggest difference for the northing is 1.6 cm. The estimated standard deviation for same northing value is 4 mm and 3 mm. The difference in height seems to be close to exactly 3 meters.

2.3 Trimble catalyst DA2 dataflow

The Trimble Catalyst DA2 antenna is used together with two companying apps made by Trimble. The “Trimble Catalyst Service” (Trimble, 2022), which runs in the background, and the “Trimble Mobile Manager” (TMM) (Trimble, 2023) which provides the user interface. These apps are free, but none of them provide functionality for storing points or observations. For this purpose, one can buy different Trimble-apps for data collecting or use other third-party apps. Since our purpose was to evaluate a low-cost alternative, we decided on choosing a free third-party application called “MerginMaps” (Lutra Consulting, 2023). We could also have chosen av very similar app called “QField” (OPENGIS.ch, 2023). We have tried it, and it works very much like MerginMaps. But at the time of our fieldwork, QField was only available for Android devices and most of our students had Iphones. At time of writing, QField has also become available for IOS devices. Both MerginMaps and QField works together with QGIS (QGIS Development Team, 2023).

2.4 MerginMaps

MerginMaps lets the user store point observations made by the smartphone, within a QGIS-project stored in the cloud. For small amounts of data, this is a free service. The QGIS project is setup on the computer in beforehand and must contain a point vector layer where observations can be stored. For this layer, some settings have to be made to make sure that the standard deviations are stored together with the observed coordinates. For cadastral surveying in Norway, it is also mandatory to store the observation time. This to be able to document that observations in an adjustment are sufficiently independent. The vector point layer should have an attribute field for antenna height. It is also possible in QGIS to set a default value for this. Attribute fields for cadastral information is also easily added when setting up the project.

When using an Android smartphone, one will have to activate developer settings in the phone to be able to pass the position data provided by TMM over to MerginMaps. Otherwise, the smartphone’s internal GNSS will act as the position source. For Iphones, this goes automatically when it comes to the position itself. But it turned out that the standard deviations were not taken from TMM, but rather from the phone and indicating meter-accuracy. If this was the case for every Iphone-survey, or if some of the students found the settings to fix the issue, we are not sure. But for those who experienced the problem, the surveyor had to check the TMM app to make sure the fix-solution was found. This issue also occurred on some of the Android smartphones.

In MerginMaps, the surveyor may synchronize the data back to the cloud project at any time, and we experienced that the four students in one group could easily work in the same shared project.

2.5 QGIS

In QGIS, we chose to make a python-script to export the point observations to a KOF-file. In this process, it was necessary to check whether the standard deviations were at the centimeters level or at the meters level. If the latter was the case, we replaced the stored values with estimated accuracies from the GNSS base network provider. A point observation in the resulting KOF-file would look like this:

```
50 G02                  7491485.256  375769.162   43.301
51   0.0141   0.0141   0.0300  1.0000  0.0000  0.0000  1.0000  0.0000  1.0000
46 02102022 12:37:59           0.000
```

Here the height value is ellipsoidal, and this is caused by (lack of) settings on the phone. Standard deviations have successfully been transferred from the TMM app. We notice that the standard deviations on the northing and the easting are both the same. This is because TMM provides horizontal accuracy, not separated into northing and easting. Decomposing of the horizontal standard deviation is done by the python script. Last in the 46-line, antenna height could have been inserted if a value for this had been included in an attribute field. But antenna might be inserted in both TMM and in MerginMaps and might thereby already have been taken into account. So here one needs to be careful.

2.6 The process of adjustment computations

A priori standard deviations of the point observations determine the weighting in the least-squares adjustment. If standard deviations are not available or get lost in the data flow, estimated values from the base network provider will be used, as already mentioned. The consequence of the latter is that every observation in one boundary point gets the same weight in the adjustment.

As a result of the adjustment computation, estimated standard deviation values for the adjusted coordinates are calculated. These values are rounded to the nearest centimeter (above zero) and registered as accuracy in the cadastral map. It is therefore of some importance that these standard deviation values correctly represent the real accuracy of the point.

The commercial software packages in Norway calculate these standard deviations from one common adjustment for the whole survey. Related to our fieldwork, this would mean that all the point observations in our last example above are adjusted together. In this process, only one common sum of squared residuals is computed, and this sum in turn effects all the calculated standard deviations for the coordinates of all the surveyed boundary points. Inconsistent observations in one boundary point will lead to increased estimated standard deviations in every other point.

While the above is undisputable in theory, we decided that we wanted to investigate the effect in practice. This is done by comparing the standard deviations from an adjustment computation of alle the points bordering a parcel, with the standard deviations from several adjustment computations for one point at a time. The point-by-point adjustment has been made using the same commercial software. It is actually possible to calculate this way using standard software, but the process is tedious and generates a lot of reports.

For the two parcels in figure 3, we get the following results:

Trimble Catalyst DA2, common adjustment:

Point-ID	Std. N	Std. E	Std. H
HP1	0.0034	0.0034	0.0034
P1	0.0034	0.0034	0.0034
P2	0.0034	0.0034	0.0034
P3	0.0024	0.0024	0.0024
P4	0.0024	0.0024	0.0024
P5	0.0034	0.0034	0.0034
P6	0.0034	0.0034	0.0034

Trimble Catalyst DA2, point-by-point adjustment:

Point-ID	Std. N	Std. E	Std. H
HP1	0.0056	0.0056	0.0056
P1	0.0024	0.0024	0.0024
P2	0.0028	0.0028	0.0028
P3	0.0020	0.0020	0.0020
P4	0.0026	0.0026	0.0026
P5	0.0015	0.0015	0.0015
P6	0.0040	0.0040	0.0040

The first thing to notice, is that all the standard deviations after both computation methods are below one centimeter. This means they will all be rounded up to the same value (1 cm) when being registered in the cadastral map. To better display the differences, we have calculated the change in percent for the standard deviations as a result of change of method.

Point-ID	Std. N	Std. E	Std. H
HP1	65 %	65 %	65 %
P1	-29 %	-29 %	-29 %
P2	-18 %	-18 %	-18 %
P3	-17 %	-17 %	-17 %
P4	8 %	8 %	8 %
P5	-56 %	-56 %	-56 %
P6	18 %	18 %	18 %

From this table we see that the change exceeds 50 % for two of the points, and we see that the changes go both ways. For the three points in figure 2 we get the following results:

Trimble Catalyst DA2, common adjustment:

Point-ID	Std. N	Std. E	Std. H
G01	0.007	0.007	0.021
G02	0.021	0.021	0.030
G03	0.005	0.005	0.024

Trimble Catalyst DA2, point-by-point adjustment:

Point-ID	Std. N	Std. E	Std. H
G01	0.003	0.003	0.008
G02	0.004	0.004	0.006
G03	0.008	0.008	0.040

After the common adjustment, 5 out of 9 standard deviations exceeds 2 cm, but after the point-by-point adjustment, only one of nine standard deviations exceed 1 cm. In this case, the two different computation procedures would cause different standard deviations to be registered in the cadastral map for one of the surveyed boundary points (G02).

3. RESULTS

Our investigation shows that the two different low-cost alternatives can be used to obtain data that satisfy the standards of cadastral work in Norway. The differences between the measurements from the different receivers are at the same level as the differences between individual observations from expensive receivers. While the many issues with height errors could be critical for other purposes, they don’t affect the quality of cadastral surveying, as height coordinates are not registered for boundary points in the cadastral map.

We have also seen that it is possible to get the data from the low-cost receivers into standard software packages by use of free software and some scripting in Python. At the same time, using many different apps with many different settings can cause problems. We can especially see this in all the height observations with big errors.

The choice between an effective common adjustment and a point-by-point adjustment has of course zero effect on the adjusted coordinate values, but has a clearly significant effect on the computed standard deviations of the same coordinates. At least, the effect is significant when viewed as percentwise change. Related to the purpose of registering accuracy in the cadastral map, the significance is perhaps less obvious.

4. DISCUSSION AND FURTHER WORK

The data that his research is based on, are collected in the municipality of Røst, on a nearly flat island without trees that are large enough to block any satellite signal. As a consecuence, we have found out that the low-cost alternative is a working alternative under ideal conditions. One cannot rule out that the more expensive GNSS-receivers will prove significantly better in more demanding environments.

While we have seen that one can get the job done using low-cost equipment and free software, we have also seen that there are a lot of things that can go wrong. On the other hand, this fieldwork is undertaken by unexperienced students, not professional surveyors. Among other errors, many of the groups ignored the advice to start with measuring a known position. If this had been done, wrong antenna height settings could have been discovered and corrected.

As for the data flow, it is complicated, and our solution requires some programming skills. Some professional surveyors would probably not feel comfortable with this task, and rather be willing to pay more for the equipment than to learn python-scripting.

To meet with these obstacles, we have undertaken to develop a plugin in QGIS for cadastral surveying with GNSS-antennas connected to smartphones. The plugin is still under development, but we hope to present a working beta-edition at the FIG working week in Orlando, 2023. This plugin will have functionality to automatically set up empty data layers for cadastral surveying in Norway, ready for use on the smartphone. After the data collection, it will be possible to export the data to a KOF-file, if the surveyor prefers to do the quality control and adjustment computation in another software. But we also plan to implement this functionality in our QGIS plugin. The standard for cadastral surveying in Norway (Kartverket, 2011), requires a blunder detection analysis and a reliability analysis prior to the adjustment computation. This will be implemented in our plugin as an automatic point-by-point calculation. Possibly, we will also implement the traditional method of calculating the points in common, for the purpose of comparison.

We were on beforehand quite convinced that what we have named the “common adjustment” is an incorrect way of handling point observations. In such a calculation process, the most accurate points will appear as less accurate, and the less accurate points will appear more accurate than they really are. The method is a remnant from the time when points were connected by observations between them or from the same stations, and no one had heard about point observations. We now find that the data supports this view, and this motivates us to develop a plugin with the computation method which we believe is a more correct one.

Lastly, one could object that the expensive equipment isn’t that expensive after all, when all costs are considered. This is probably correct, especially for a big Norwegian municipality with several employed land surveyors. Surveying equipment and software licenses will then probably represent a relatively small cost compared to the surveyors salaries and will also be compensated by the fee paid by the landowners. But this would probably be different in a small municipality with only one engineer who undertakes some cadastral surveying in addition to many other tasks. Municipalities are also free to hire private surveyors for cadastral surveying. With low-cost GNSS receivers and free software, less investment will be needed to get started as a private cadastral surveyor.

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