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Resultat av posisjoneringstest

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Undertittel

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Sammendrag
Denne rapporten inneholder resultatene fra test av posisjonering i tunnel og på fortau. En av testene omhandlet posisjonering i tunnel i lengderetning og den andre testen omhandlet posisjonering i sideretning i åpent terreng. Formålet var å bygge kunnskap om løsninger i markedet som kan bidra med til å forbedre posisjon til vinterdriftskjøretøy.
Rapporten er en del av en pilot i ITS-programmet som omhandlet posisjonering.

Summary
This report contains the results from two tests on positioning in tunnels and on sidewalks. One of the tests dealt with positioning in a tunnel in the longitudinal direction and the other test dealt with positioning in the lateral direction in open terrain. The purpose was to build knowledge about solutions in the market that can contribute to improving the position of winter maintenance vehicles.
The report is part of a pilot in the ITS program that dealt with positioning.

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1 Introduction

The need for positioning in the transport system is increasing as more services within transportation rely on knowing its own and others' position. The most basic and well-known example from vehicles, is the use of navigational systems to find the way to an address. In the future it is assumed that the cooperative advanced driver assistance systems, as one of many systems, will rely on the vehicles position and report this to other vehicles to increase the safety. A platoon of vehicles can then report each other’s positioning and use it in applications like Cooperative Adaptive Cruise Control (CACC) to increase both safety and efficiency.

The most used system for establishing an absolute position at travel is GNSS. GNSS has a lot of benefits as the receivers is relatively cheap and the radio signals is free of charge to use. The downside is that the GNSS-signals are weak, and its performance is drastically reduced when sight to clear sky is reduced by either threes or urban canyons. When going into tunnels, the GNSS signals is totally blocked and GNSS is thus not a reliable source for positioning systems anymore. This can be an issue when cooperative systems need to communicate their positions to each other. It is therefore of interest for the Norwegian Public Road Administration (NPRA) to know what equipment is in the market to find absolute position in tunnels.

Since the use of cooperative driving systems isn’t widely deployed, the use of positioning within winter maintenance of roads is used as base case in this project.

Two cases have been selected:

- Longitudinal positioning in tunnels for starting of automatic salt spreader. The use of automatically controlled spreaders is widely used, but challenges have been reported when used in areas with tunnels, as the absolute position is hard to determine
- Latitudinal positioning on sidewalks. As sidewalks typically are placed close to ordinary roads, it is necessary to have a degree of certainty that the snow clearance was performed on the sidewalk and not on the main road.

2 Project organization

2.1 Project goals

The goal of the project is to test and evaluate “reasonable priced” equipment to test its performance with the two dedicated problems: Longitudinal positioning in tunnels and latitudinal positioning on sidewalks. The aim is not to benchmark vendors against each other but getting a demonstration of different equipment and its performance.

2.2 Participant selection

For being selected as a vendor for this, a set of minimum requirements needed to be fulfilled and a table of evaluation criteria needed to be answered to be able to range the different vendors.

Minimum requirements	Essential information	Answer from Univrses AB	Answer from Fixposition AG
1. Description of unit to be used	A sketch with an explanation of the various components that make up the unit and the relationship between them. The sketch must be able to make probable that the technology can solve the problems mentioned	Uses ordinary smartphone, no need for sketch	See Appendix A
2. Data from the demonstration shall be logged and delivered to customer on a machine-readable format (e.g., CSV, XML or JSON). An explanation of the different fields shall be supplied. The results shall be summed up in a final report to be given the possibility to give comment on the results.	Confirm that data will be logged, and that the customer will receive data and final report from demonstration	Confirmed	Confirmed
3. Unit must be possible to retrofit in a vehicle. The unit can be part of a system with different purpose than positioning, but must be possible to retrofit in a passengercar for the purpose of the demonstration	Confirm that the unit is possible to retrofit in a vehicle. Inform about the need of connections between vehicle and unit	Confirmed	Confirmed

4. The unit must be able to give a physical indication after passing a specified position, ref chapter 3. The physical indication does not have to be part of a possible product, but must be able to be offered as part of the demonstration	Confirm that it is possible to give a physical indication.	Confirmed	Confirmed
5. Cost	Cost pr unit including additional cost, for instance subscriptions etc.	Approx. 1000€	Approx. 3000€

3 Test design and test sites

3.1 Test design for testing of longitudinal precision in tunnels

Evaluation of longitudinal position in tunnels is a bit of a challenge as there is no possibility to get GNSS-coverage and alternative positioning technologies requires additional equipment in tunnel. To overcome this challenge, inspiration was gathered from athletics and their methodology with photo finish to form a low-tech solution. This is visualized in Figur 1.

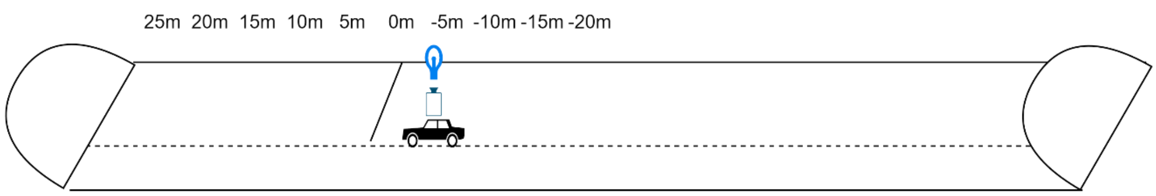
1. On the outskirt of the tunnel, a reference point has been established with land surveyor-grade GNSS-equipment with RTK. See Figur 2 with yellow markings.
2. From the reference point, it is measured a new “origo” in the tunnel using a tape measure. On every five meters, a poster is fixed on the tunnel wall with a number telling how many meters in positive or negative direction one is from the origo.
3. The coordinates of the origo are given to the equipment vendors, for them to give a physical response when they reach origo.
4. This physical response will be recorded on video together with the posters situated on the tunnel wall. This way it is possible to compare the result given from the equipment, with a ground truth in the tunnel.

One aim was to test this on different length tunnels, and therefore the following tunnels was chosen:

- Fantebrauta tunnel, 241m
- Måndalstunnelen, 2084 m
- Innfjordtunnelen, 6602m

For the Fantebrauta tunnel, origo was placed 25m from the outskirt of the tunnel, marked with a poster with a large 0 on. The posters then went from 25m to -25 meters, forming a 50m long measure to be detected on camera.

For Måndalstunnel and Innfjordtunnel, origo was placed 130m from the outskirt of the tunnel. The posters went from 130m to -130m forming a 260m long measure to be detected on camera together with the response from the equipment.



Figur 1 Sketch of tunnel with markers and car with camera and physical response

Figur 2 Measurement of fasit outside of the tunnel

3.2 Test design for testing of latitudinal precision along a line

To test the latitudinal precision for the "sidewalk"-test, the test is performed on a closed area where a straight line has been measured. The equipment is mounted in the vehicle as normal, and several test drives on the straight line is performed, comparing the results from the equipment with the static measurement of the line.

MAR2001 and MAR2007 are static RTK-measured points with cm-accuracy in EUREF89 UTM32. Several points (2002-2006) were measured at the line, between MAR2001 and MAR2007, confirming that the white dotted straight line between 2001 and 2007 can be considered as a straight FASIT-line, see Figur 3. Ordinates between the vendors "measured" points normal to the FASIT-line, will be calculated and reduced with a horizontal distance offset measured under the experiments between the GNSS/Navigation-unit and the outer edge of the wheel, see Figur 4. The driver's difficult task will be to navigate the car, so that the outer wheel edge always will be at the center of the FASIT-line. The ordinate minus offset is denoted as deviation x_i. Equations (5), (6) and (8) in NPRA's report 696[1], can be used to calculate the mean, standard deviation and root mean square (RMS), respectively.

[1] https://vegvesen.brage.unit.no/vegvesen-xmlui/handle/11250/2725678

Figur 3 Overview of Marstein Controlstation with measurment points MAR2001 - MAR2007, verifying that the white dotted line is straight

3.2.1 Coordinate systems used

The plane coordinates in Norwegian maps as NVDB, refer to an UTM-zone in the reference frame EUREF89. RTK-measurements making use of CPOS-corrections also refer to EUREF89.

GNSS-measurements without corrections refer to “current epoch” in the reference frame WGS84. Since 1989, global dynamic frames as WGS84 have drifted some decimeters compared to EUREF89.

A numerical example performed with the transformation SkTrans-software from the Norwegian Mapping Authority for a point at Marstein in Romsdalen is shown in Table 1

Table 1 Example of transformation between EUREF89 UTM33 and WGS84 UTM33

	North	East	epoch
Euref89 UTM33	6945626.625	130556.476	1989.0
WGS84 UTM33	6945627.189	130556.976	2022.75 (early Oct.)
D	-0.564	-0.500	

WGS84-measured objects in this area (October 2022) should be shifted

$N_{Euref89\ UTM33} = N_{WGS84\ UTM33} - 0.56$ and $E_{Euref89\ UTM33} = E_{WGS84\ UTM33} - 0.50$

to match the data in NVDB.

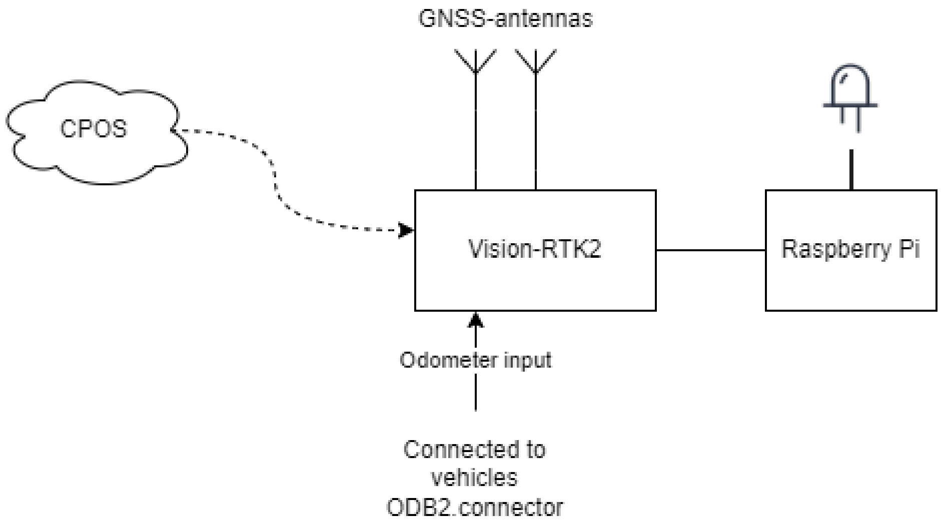
If a comparison should be made, and statistics computed only, an alternative to transform all WGS84-measured data would be to transform the measured FASIT from EUREF89 to WGS84.

Figur 4 Measurement of offset between wheel and equipment

3.3 Test equipment

3.3.1 FixPosition AG equipment

FixPosition AG used its Vision-RTK2 device for the test. It consists of two Ublox ZED-F9P receivers with helix antennas placed 30cm apart, a mono camera with global shutter, Inertial Measurement Unit (IMU) and odometer from the cars OBD2-connector. It receives correctional messages from Norwegian Mapping Authorities' CPOS-service to enable RTK.



Figur 5 Fixposition test system

For the purpose of the test, a Raspberry Pi with attached LED's was connected to the Vision-RTK2. The Raspberry Pi was programmed with a geofencing-program to light up the LED's when being close to the origo in the tunnels. A sketch over the test system is schematically visualized in Figur 5 and the equipment mounted on the test vehicle is shown in Figur 6.

Figur 6 Vision-RTK2 mounted on test vehicle

3.3.2 Univrses AB equipment

Univrses scheme for longitudinal positioning was solely based on the use of the sensors available in a smart phone and all calculations were done in an app they had developed. The system that Univrses uses is made for object detection using the built in camera, it is thus not tailor made for positioning in tunnels, but holds some features that makes it interesting to test. All interactions and feedback were done through the graphical user interface of this app. When the desired position in the tunnel was reached a white popup appeared. This event was picked up using a GoPro-camera.

As explained in chapter 3.1, in the last part of the tunnel the distance from the ideal point that the systems where to detect was indicated with markings every five meters. These markers were detected using a side-facing GoPro. For the Univrses trials, the measurement systems consisted of two separate GoPro cameras, mounted perpendicular to each other, that needed to be synchronized in post-production. The synchronization was done using inspiration from movie industry, a clapper, where also the date and number of the trial was indicated, see Figur 7.

Figur 7 Example of camera synchronization

The measurement scheme implemented in the Univrses app required the camera of the phone to be facing forward while driving, perpendicular to the road surface and at a known height. This meant that one of the GoPro cameras had to face forward with the smart phone in its view. The other camera was facing out the passenger window, filming the right-hand side wall in the tunnel. ISO and frame rate was adjusted to accommodate low light conditions. All tests were done in a Polestar 2 vehicle owned by the Norwegian Public Roads Administration (Figur 8 Camera setup in vehicle)

Figur 8 Camera setup in vehicle

All post-production was done in a free movie editing tool called DaVinci Resolved by Black Magic Design[2].

By using this methodology, GPS and time was removed from the experiments, the analysis consisted of visually detecting when the indicator in the Univrses app indicated when the desired position in the tunnel had been reached. The position was indicated by a big white popup on the screen, that was easily visible on-camera. By viewing the two cameras side by side, if the car was roughly in the right position, the remaining or overshooting distance could easily be read from the side-facing camera, with an accuracy of about two meters. If the position was indicated outside the marked area of the tunnel, the measured was just marked out of bounds, and not evaluated.

[2] https://www.blackmagicdesign.com/

4 Test results

4.1 Results from tunnel test

4.1.1 Results FixPosition

Eight passes were driven through the Fantebrauta tunnel, with the results presented in Table 2

Table 2 Results from test of FixPosition V-RTK2 in Fantebrautatunnel

Vendor	Tunnel	Test nr	Direction	Measurement [m]
FixPosition	Fantebrauta	1	Mot Dombås	1
FixPosition	Fantebrauta	2	Mot Åndalsnes	4
FixPosition	Fantebrauta	3	Mot Dombås	3
FixPosition	Fantebrauta	4	Mot Åndalsnes	3
FixPosition	Fantebrauta	5	Mot Dombås	3
FixPosition	Fantebrauta	6	Mot Åndalsnes	3
FixPosition	Fantebrauta	7	Mot Dombås	1
FixPosition	Fantebrauta	8	Mot Åndalsnes	3

Nine passes were driven through the Måndalstunnel, with the results presented in Table 3

Table 3 Results from test of FixPosition V-RTK2 in Måndalstunnel

Vendor	Tunnel	Test nr	Direction	Measurement [m]	Comment
FixPosition	Måndalstunnelen	1	Mot Vestnes	11,00	
FixPosition	Måndalstunnelen	2	Mot Åndalsnes	-120,00	
FixPosition	Måndalstunnelen	3	Mot Vestnes	2,00	
FixPosition	Måndalstunnelen	4	Mot Åndalsnes		No light showing, drifted to much
FixPosition	Måndalstunnelen	5	Mot Vestnes	-12,00	
FixPosition	Måndalstunnelen	6	Mot Åndalsnes	6,00	
FixPosition	Måndalstunnelen	7	Mot Vestnes	5,00	
FixPosition	Måndalstunnelen	8	Mot Vestnes	10,00	
FixPosition	Måndalstunnelen	9	Mot Åndalsnes	1,00	

For the Innfjordtunnel, 12 passes was driven and the results are presented in Table 4

Table 4 Results from test of FixPosition V-RTK2 in Innfjordtunnel

Vendor	Tunnel	Test nr	Direction	Measurement [m]	Comment
FixPosition	Innfjordtunnelen	1	Mot Åndalsnes	15,00	
FixPosition	Innfjordtunnelen	2	Mot Vestnes	15,00	
FixPosition	Innfjordtunnelen	3	Mot Åndalsnes	61,00	
FixPosition	Innfjordtunnelen	4	Mot Vestnes		No light showing in the video, short drive before entering the tunnel
FixPosition	Innfjordtunnelen	5	Mot Åndalsnes		No light showing in the video, "long" drive before the tunnel
FixPosition	Innfjordtunnelen	6	Mot Vestnes	24,00	

FixPosition	Innfjordtunnelen	7	Mot Åndalsnes		Before marking
FixPosition	Innfjordtunnelen	8	Mot Vestnes	22,00	
FixPosition	Innfjordtunnelen	9	Mot Åndalsnes	25,00	
FixPosition	Innfjordtunnelen	10	Mot Åndalsnes	63,00	
FixPosition	Innfjordtunnelen	11	Mot Vestnes	13,00	
FixPosition	Innfjordtunnelen	12	Mot Åndalsnes	60,00	

4.1.2 Results Univrses

In total 37 passes var driven through the three selected tunnels in chapter 3.1.

Twelve passes were driven in Fantebrauta, with the results in Table 5

Table 5 Results from test of Univrses' solution in Fantebrauta

Vendor	Tunnel	Test	Direction	Measurement	Comment
Univrses	Fantebrauta	1	Towards Dombås	Outside range	Too early
Univrses	Fantebrauta	1	Towards Åndalsnes	-5	
Univrses	Fantebrauta	2	Towards Dombås	Outside range	Too early
Univrses	Fantebrauta	2	Towards Åndalsnes	-25	
Univrses	Fantebrauta	3	Towards Dombås	Outside range	Too early
Univrses	Fantebrauta	3	Towards Åndalsnes	-7,5	
Univrses	Fantebrauta	4	Towards Dombås	Outside range	Too early
Univrses	Fantebrauta	4	Towards Åndalsnes	-12,5	
Univrses	Fantebrauta	7	Towards Dombås	Outside range	Too early
Univrses	Fantebrauta	7	Towards Åndalsnes	No trigger	Too late
Univrses	Fantebrauta	8	Towards Dombås	-12,5	
Univrses	Fantebrauta	8	Towards Åndalsnes	5	

In Måndalstunnel, 22 passes were driven, with the results in Table 6

Table 6 Results from test of Univrses' solution in Måndalstunnel

Vendor	Tunnel	Test	Direction	Measurement	Comment
Univrses	Måndalstunnelen	5	Towards Vestnes	No trigger	Too early
Univrses	Måndalstunnelen	5	Towards Åndalsnes	-107,5	
Univrses	Måndalstunnelen	6	Towards Vestnes	Outside range	Too early
Univrses	Måndalstunnelen	6	Towards Åndalsnes	Outside range	Too early
Univrses	Måndalstunnelen	7	Towards Vestnes	Outside range	Too early
Univrses	Måndalstunnelen	7	Towards Åndalsnes	Outside range	Did not initialize
Univrses	Måndalstunnelen	8	Towards Vestnes	Outside range	Too early
Univrses	Måndalstunnelen	8	Towards Åndalsnes	No trigger	No trigger
Univrses	Måndalstunnelen	1	Towards Vestnes	Outside range	Too early
Univrses	Måndalstunnelen	1	Towards Åndalsnes	Outside range	Too late
Univrses	Måndalstunnelen	2	Towards Vestnes	-115	
Univrses	Måndalstunnelen	2	Towards Åndalsnes	-62,5	
Univrses	Måndalstunnelen	3	Towards Vestnes	-86	

Univrses	Måndalstunnelen	3	Towards Åndalsnes	Outside range	Too early
Univrses	Måndalstunnelen	4	Towards Vestnes	-43	
Univrses	Måndalstunnelen	4	Towards Åndalsnes	-67,5	
Univrses	Måndalstunnelen	5	Towards Vestnes	-60	
Univrses	Måndalstunnelen	21	Towards Vestnes	No trigger	No trigger
Univrses	Måndalstunnelen	21	Towards Åndalsnes	No trigger	Too late
Univrses	Måndalstunnelen	22	Towards Vestnes	No trigger	Too late
Univrses	Måndalstunnelen	22	Towards Åndalsnes	No trigger	Too late

During the tests Univrses stated that Innfjordtunnelen is too long for this measurement concept to work, so very few passes was driven there. Results for the performed tests are presented in Table 7

Table 7 Results from test of Univrses' solution in Innfjordtunnel

Vendor	Tunnel	Test	Direction	Measurement	Comment
Univrses	Innfjordtunnelen	9	Towards Åndalsnes	No trigger	Too late
Univrses	Innfjordtunnelen	6	Towards Åndalsnes	Outside range	Too late
Univrses	Innfjordtunnelen	23	Towards Åndalsnes	-77,5	

The best results were achieved in the Fantebrauten tunnel, where the instances that the system did trigger was quite close to the ideal mark. The system measured within the valid area half the time, and did not trigger or triggered outside the area the rest of the times. Since the tunnel is quite short, this was to be expected since the error due to a bias doesn't have time to grow. However, even being just a few meter off in such a short tunnel does constitute a rather large error.

Måndalstunnelen does seem to represent the limit for how long a tunnel can be before the error becomes so big that there is little point in using the application. Here the application triggered within the valid area about one third of the time, triggered outside the valid area but inside the tunnel about one third of the time and failed to trigger about one third of the time.

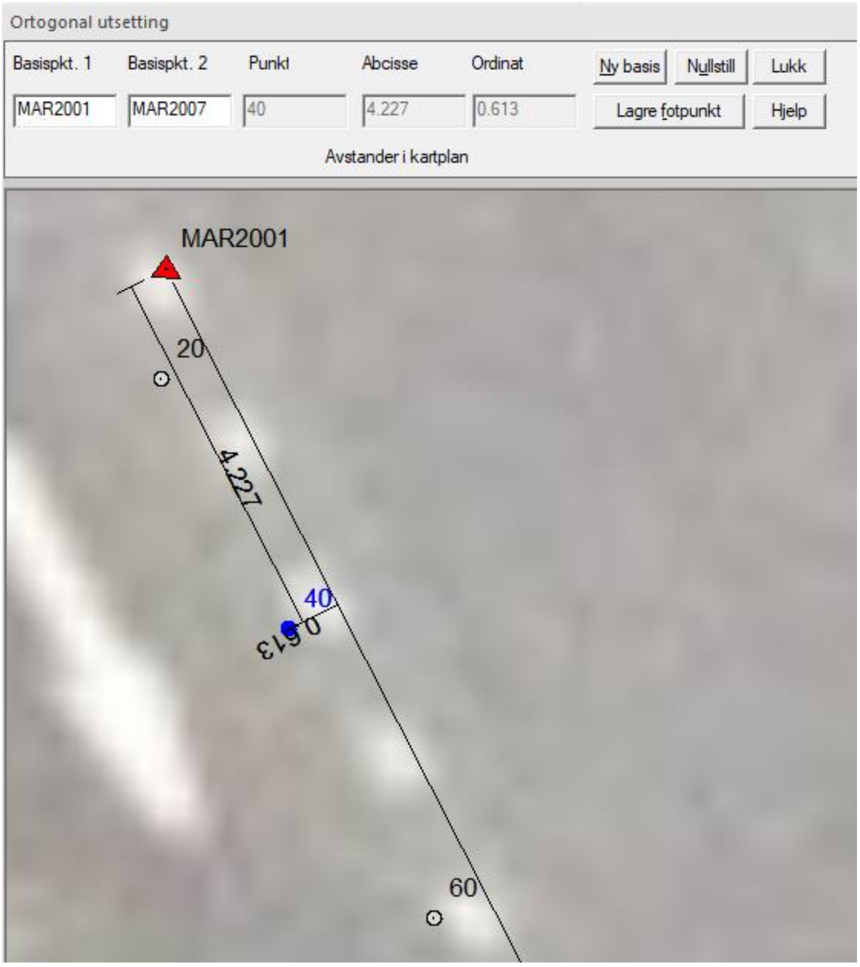
During the tests Univrses stated that Innfjordtunnelen is too long for this measurement concept to work, so very few passes was driven there.

The tests confirmed that the measurement method works reasonably well for short tunnels, but the error increase with the length of the tunnel. It is worth mentioning that scenario used here is not what the system originally is intended to do, and the system used during these tests is quite new and has not been optimized and tested over time. It could be that the results, especially for the shorter tunnels could be improved, but the long tunnels would still pose a problem, without input or correction from either odometry from the car, or some sort of visual update of the drive distance, for example by using the remaining distance signs inside the tunnel.

4.2 Results from sidewalk test

The FASIT-line as a baseline from basepoint MAR2001 to basepoint MAR2007 as stated in Figur 3. Abscissa is the horizontal distance along the baseline from basepoint MAR2001 in direction to basepoint MAR2007. Ordinate is the distance normal (orthogonal) to the baseline seen from basepoint MAR2001 to basepoint MAR2007. Abscissas and ordinates to measured points can then be calculated. The ordinate is defined as positive, if the considered point is on the right-hand side, and negative on the left-hand side of the baseline.

As an example, abscissa and ordinate for the measured point 40 in dataset 1 is shown in Figur 9



Figur 9 Example with measurement point 40 from dataset 1 from FixPosition V-RTK2

4.2.1 Results FixPosition

Five experiments were performed, and the original sampling was 20Hz. In the numerical analysis, the sampling rate have been reduced to 1Hz. Coordinates and calculated ordinates from the first experiment are shown in Appendix B, where the calculations have been done with GISLINE.

Ordinates were then reduced with the offset 0.630m. Then mean, standard deviation and Root Mean Square were computed in the excel. Results from the five experiments are listed in Table 8

Table 8 Calculated Mean, Standard deviation and Root Mean Square of latitudinal accuracy from 5 experiments with the Fixposition V-RTK2

Experiment No.	1	2	3	4	5
Mean [m]	0,05	0,03	0,04	0,01	-0,01
St.dev [m]	0,06	0,04	0,03	0,04	0,03
RMS [m]	0,08	0,05	0,05	0,04	0,04

Figur 10 Plot of one of the experiments from the sidewalk test. The logged data given in Appendix B

4.2.2 Results Univrses

Seven experiments were performed, and the sampling rate was 1Hz. Test No. 3 and 7 were discarded because they included too few coordinates to calculate reliable statistics. In general, the sampling started late, giving fewer coordinates to calculate the statistics .

While Univrses data refer to WGS84 current epoch, the FASIT data was transformed from EUREF89 to WGS84 respectively with the shift values ΔN=-0,56m and ΔE=-0,50m from Table 1 early in chapter 3.2.1 for calculating the results.

Ordinates were then reduced with the offset 1.2m. Then mean, standard deviation and Root Mean Square were computed in the excel. Results from the five experiments are listed in Table 9

Table 9 Calculated Mean, Standard deviation and Root Mean Square of latitudinal accuracy from 5 experiments with Univrses' solution

Experiment No.	**1**	**2**	**3**	**4**	**5**
Mean [m]	-0,04	0,04	-0,92	-0,30	-0,14
St.dev [m]	0,14	0,05	0,08	0,06	0,12
RMS [m]	0,15	0,06	0,92	0,31	0,19

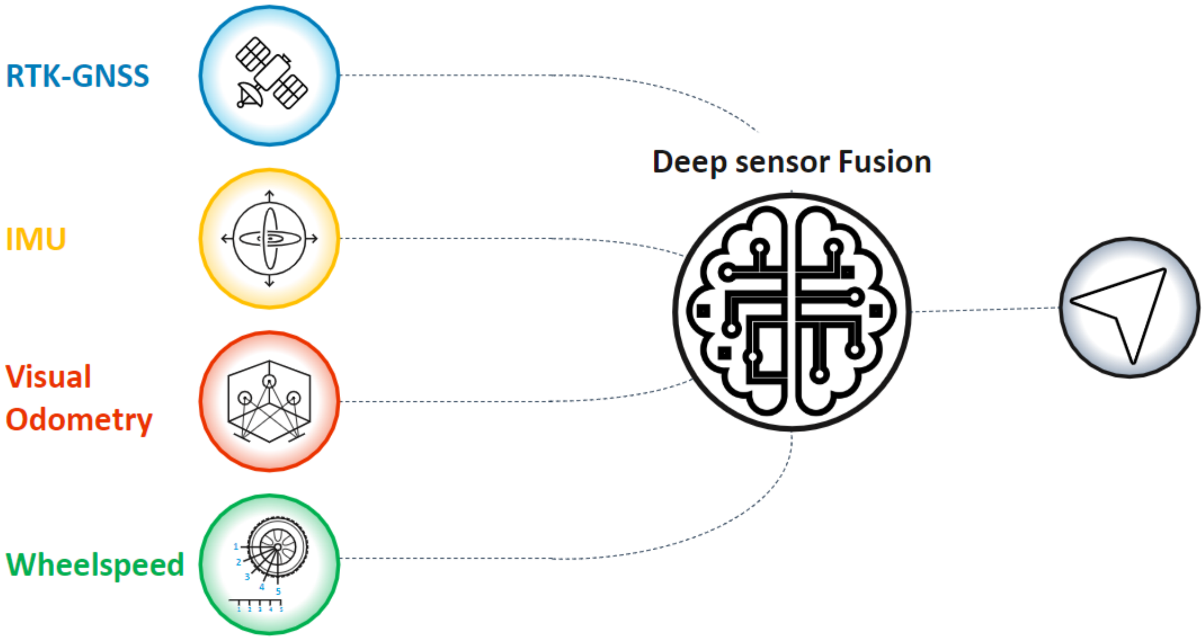
5 Conclusion

This report sums up the results from the test in Åndalsnes where longitudinal positioning in tunnels and latitudinal position with GNSS coverage was tested. The results show that establishing an accurate longitudinal position in tunnels is a challenge and that the challenge increases with the length of the tunnel.

For latitudinal positioning in open sky, the results are good for both solutions tested and within what to expect for a winter maintenance vehicle doing snow clearance on the sidewalk.

6 Appendices

Appendix A System sketch Fixposition



Appendix B Example of data from GISLINE

```
Prosjekt: FIX_TVERR_01                              G/L-Land

            *ORTOGONAL UTSTIKKING*  Avstander i kartplan

Punkt 1:  MAR2001     X =  6945626.625  Y =   130556.476

Punkt 2:  MAR2007     X =  6945534.738  Y =   130603.540

Avstand:   103.239 meter     Retning:  169.8653 gon
```

Punkt	Kode	X-koordinat	Y-koordinat	Absisse	Ordinat
0		6945627.940	130555.137	-1.781	0.592
20		6945625.393	130556.433	1.077	0.600
40		6945622.583	130557.857	4.227	0.613
60		6945619.336	130559.494	7.863	0.637
80		6945615.674	130561.314	11.952	0.686
100		6945611.565	130563.374	16.549	0.726
120		6945607.359	130565.495	21.259	0.756
140		6945602.964	130567.713	26.182	0.785
160		6945598.532	130570.002	31.170	0.768
180		6945593.954	130572.399	36.338	0.722
200		6945589.176	130574.897	41.729	0.677
220		6945584.353	130577.400	47.163	0.647
240		6945579.505	130579.866	52.602	0.663

260	6945574.776	130582.295	57.918	0.657
280	6945569.968	130584.687	63.288	0.720
300	6945565.212	130587.099	68.621	0.741
320	6945560.561	130589.491	73.851	0.732
340	6945555.952	130591.919	79.060	0.672
360	6945551.359	130594.330	84.247	0.620
380	6945546.805	130596.702	89.381	0.585
400	6945542.473	130598.892	94.235	0.611

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