Practical Test on Accuracy and Usability of Virtual Reference Station Method in Finland

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Key words: Real-time kinematic (RTK) GPS, Network RTK, Virtual reference station (VRS)

SUMMARY

Real time GPS measurements are becoming an essential part of surveying. During the last years several real time methods have been introduced. One of the most sophisticated one, Virtual reference station (VRS) is using GPS network to mitigate errors inherent to GPS positioning. The quality of VRS was studied in such conditions that are typical in Finland and northern latitudes. The study was divided into two major parts. The main objectives were real time field measurements and density of VRS network.

Study shows that measurements can be done at centimetre-level with VRS concept if certain factors are taken into account. Reliability of measurements is high and false solutions are well proportional to initialisation reliability rate that is used. Initialisation times are short while measuring in adequate conditions. Correlation between accuracy and baseline length from nearest reference station is low and the results are quite equal within the network area. Also position of rover within the network area in terms of accuracy is negligible. However it seems to be significant for initialisation times whether rover is inside or outside the network. Number of satellites and satellite geometry are proven to have influence on measurements and therefore should be taken into account. Influence of obstructions on the accuracy was ambiguous but on initialisation times clear correlation is seen. The choice of RTK equipment seems to be irrelevant. However user should not be too trustful about the estimated accuracy values shown by the equipment because they are often too optimistic.

Network itself is one influencing factor on results. Small network (few reference stations) has not the same power against the errors that are inherent to GPS than large network. According to the study adequate mean distance between reference stations settles to 80 kilometres still having good quality on accuracy and initialisations.

As a final conclusion VRS is suitable for centimetre-level measurements but is not beatific; certain measurement procedure should be applied if reliable and accurate results are aspired.

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1 INTRODUCTION

Real time GPS measurements are becoming an essential part of surveying. During the last years several real time methods have been introduced. One of the most sophisticated one, Virtual reference station (VRS^{TM}) is using GPS network to mitigate typical errors inherent to real time GPS positioning. VRS uses a technique that calculates corrections for systematic errors based on real time data from all reference stations. The main systematic errors that affect the RTK rover performance are multipath, atmospheric and ephemeris errors. By modelling these errors from the network data and simulating local reference station with respect to rover position it is possible to diminish the errors inherent to single base RTK measurements and increase the coverage area. Ideally positioning error is independent of the rover position in the area of the network (e.g. Vollath et al. 2002).

VRS concept has been tested in Finland since 2000 and nowadays there are two different networks operational. A private Finnish company Geotrim Ltd. has started to establish a network to provide VRS service. The plans are to cover at least the generality of Finland. VRS network in Tampere region was a pilot project and it has been operational since July 2000. Since use of the VRS GPS method is becoming more and more popular in Finland it was considered important to study the quality of VRS in such conditions that are typical in Finland and northern latitudes.

The study was divided into two major parts. The main objective was to study the operation of VRS in general but also some factors affecting the measurements were studied and they are represented in their own sections. The second objective was to examine the influence of density of network i.e. the distances between base stations. Results from these two objectives are represented in chapter 3 by their nature, as measurement and network dependent factors. In addition short description about quality of differential GPS measurements is represented in its own chapter.

The author expects the reader of this paper to have certain knowledge of real time GPS measurements and therefore associated theory is omitted or only shortly mentioned in this paper. A lot of literature about the theory is available in the internet (see e.g. Vollath et al. 2000).

2 IMPLEMENTATION OF THE MEASUREMENTS

Measurements were carried out in the summer of 2003 and the main objective of the project was to study the operation of the VRS with standard configuration of the network i.e. to find out the quality of the service provided to the surveyors. Studied subjects were accuracy and initialisation times and how they are affected by different factors. Some factors that may influence on measurements are baseline length, number of satellites, satellite geometry, ionosphere activity and equipment used. Ionosphere activity, though, is excluded from this study.

In the second part of the test the objective was to examine the influence of prolonging the distances between base stations of the VRS network. This was implemented by using two overlapping but differently formed VRS networks and by taking almost simultaneous observations from both networks. By blocking the data from desired reference stations in the overlapping network we are able to create a more spaced network. Networks are introduced in chapter 2.2.

All measurements were performed in EUREF-FIN reference frame in order to study the accuracy of the VRS system itself instead of describing the possible deformations of the local terrestrial reference frames. EUREF-FIN is a national implementation of the ETRS89 reference system (Ollikainen et al. 2000).

2.1 Test Points and Observations

In order to study the operation of the VRS system three basic considerations in choosing a test points were set. Surrounding obstructions of the benchmark should not rise above 20 degrees, reflecting surfaces in the vicinity of the antenna and nearby electrical installations are not allowed to avoid signal disturbances (Hofmann-Wellenhof 2001). Foundation of the benchmarks should be on bedrock or stable rocks. Only benchmarks with known EUREF-FIN coordinates were included to the study and geodetic EUREF-FIN coordinates were transformed to Gauss-Krüger plane coordinates. To avoid unnecessary disturbances the cut-off angle for the measurements were set to 15 degrees.

Test points were observed 3-4 times under different satellite geometry and 20 observations in each session were collected. Each session contains 10 “single” (5 epochs) and 10 averaged (20 epochs) observations. Each observation has independent ambiguity resolution to diminish correlation between different observations. Total of 4000 observations were collected.

2.2 Networks and Study Areas

2.2.1 VRS Network of Tampere and Test Area

The network of the city survey of Tampere (figure 1) was chosen as the first test area because of dense network of benchmarks in EUREF-FIN reference frame. Total of 18 test points were chosen covering evenly the distances between 2 and 50 km to the nearest physical reference station, both inside and outside the network.

The VRS network of Tampere is relatively dense due to additional reference station in the middle of the network to secure the availability of the VRS service. Distances between the reference stations are 20-61 km.

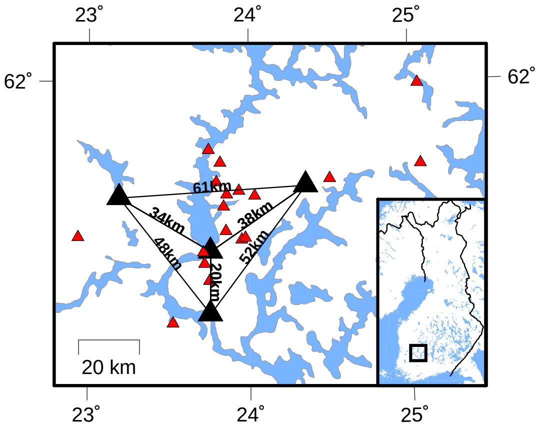


Figure 1. VRS network of the city survey of Tampere and the test points

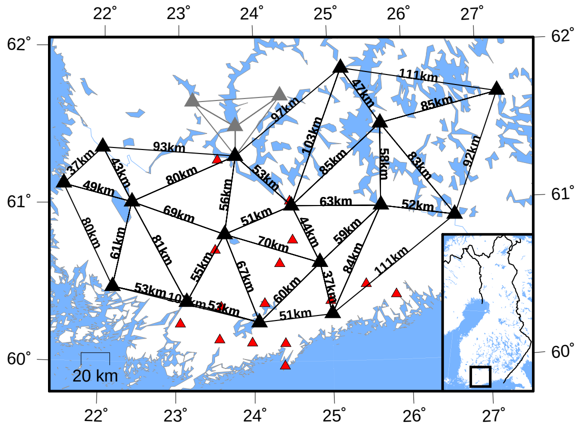


Figure 2. Primary VRS network of Geotrim Ltd. during the project (location of Tampere network is shown by light grey colour).

2.2.2 VRS networks and study areas in Southern Finland

VRS network of Geotrim Ltd. (primary network) in figure 2 is located to southern Finland and was chosen mainly to study the affect of different interstation distances. Normally the distances between reference stations are about 50-70 km according to the recommendation from the author of the control centre software (Trimble Navigation Limited 2001). However it was found interesting to study whether the interstation distances of the network could be enlarged. Therefore another overlapping network created by using the same stations that is used in the primary network. By blocking the data from desired stations, extended distances between reference stations could be studied. Different variations of newly formed networks can be seen in figure 4. Simultaneous observations from both primary and spaced networks were not possible because of only one rover equipment. Instead of simultaneous observations consecutive measurements were carried out by taking five observations in turn from each network. Measurements were performed during four weeks and the network was reconfigured at the end of the week resulting four differently spaced networks. Total of 15 benchmarks were measured four times. Distances between benchmarks and nearest network station varied between 3 and 78 km.

2.2.3 Sjökulla test field

Some smaller tests were carried out as well. FGI's photogrammetric test field in Sjökulla (figure 3) was used to study the effect of obstacles and operation of RTK equipments from different GPS manufacturers. Sjökulla is located in rural area and some of the points are surrounded by forest, single trees or other obstacles. Total of 13 points were chosen and they are classified in three categories by their surroundings from open to very disturbed terrain. Maximum distance between the chosen points is only a few hundred meters and therefore moving between points is fast and also the distance to the nearest reference station is practically the same for all the points.

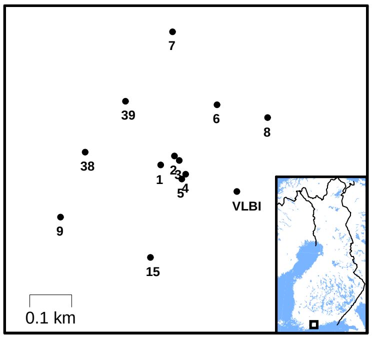


Figure 3. Measured points at Sjökulla test field.

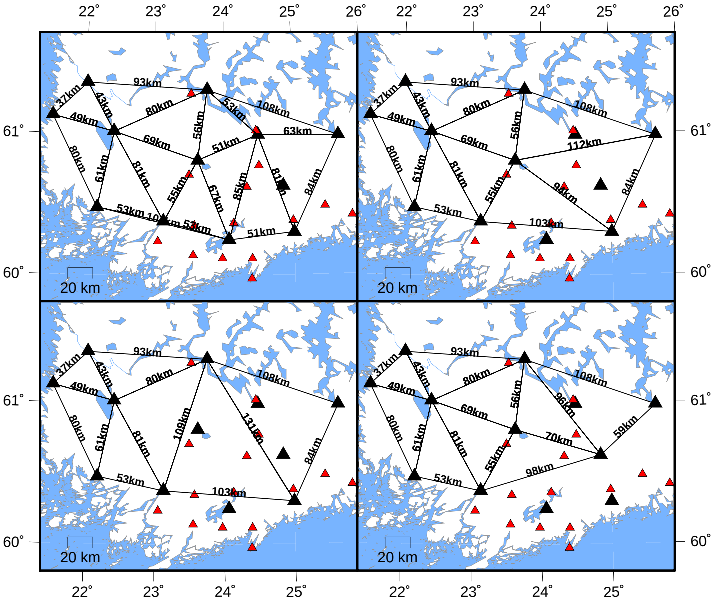


Figure 4. Spaced networks. Top left picture shows the network during first week, top right picture second week's network, bottom left the most spaced network during the week three and bottom right picture shows the last week's network. The mean distances between reference stations are 67 km, 87 km, 107 km and 77 km, respectively.

Instrument test includes RTK equipment from all major manufacturers available in Finland. Five different RTK rover set-ups were tested each having about 300 independent observations. Accuracy and initialisation times were studied.

2.2.4 Tests at the FGI

In one test we studied temporal changes in accuracy during a fixed solution. The test was performed by mounting the rover antenna on the roof of the FGI and recording coordinates at each epoch during a long fixed solution. Five different fixed solutions were implemented each lasting at least one hour.

3 RESULTS

Results are shown by the main objectives of the study. Different influencing factors are divided to own sections under the related main objective to give a better view of their influences to VRS measurements. Results are presented either by individual observations, by average or by RMS (root mean square) of the observations.

3.1 Measurement Related Factors on Results

This section gives results without classifying them by any factor. Total of 2152 observations are included and they are measured in southern Finland (15 points) and in Tampere (18 points). All disturbing factors related to terrain or surveyor himself are minimized in order to get results that reliably describe the capability of the VRS concept. Thus, the results describe attainable results while taking into consideration certain standard rules of RTK measurements i.e. minimum 5 common satellites with computing centre, maximum GDOP value of 8, obstacle-free horizon, etc.

In figure 5 we can see that results are quite well normal distributed and that accuracy of height component is worse than accuracy of horizontal coordinates. Figure 6 shows the accuracy plotted in plane (left) and height accuracy in terms of percentage from all measurements (right). Results prove the suitability of VRS for centimetre-level measurements with high reliability. Table 1 gives the same results in numerical format.

Four gross errors (few meters) occurred during the measurements without any indication of false results. Anyhow they should not be considered erroneous but statistical facts instead because they are quite well proportional to chosen reliability rate of initialisation. Low reliability rate may shorten initialisation times but reliability of solution gets also worse. User should be aware of this and the only way to prevent or diminish the possibility of gross errors is to make repeated measurements. Also the environment plays an important role when good results are expected.

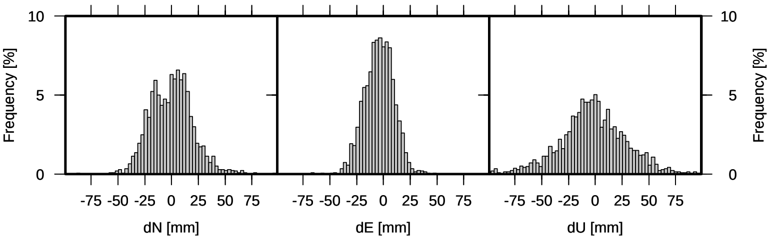
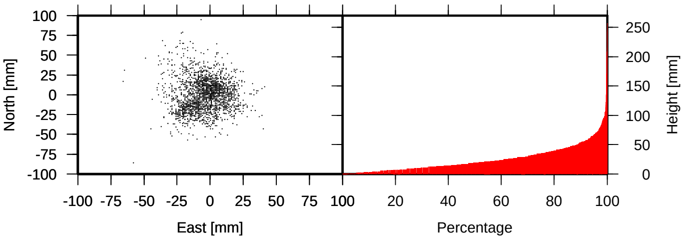


Figure 5. Accuracy of VRS from total of 2152 observations.



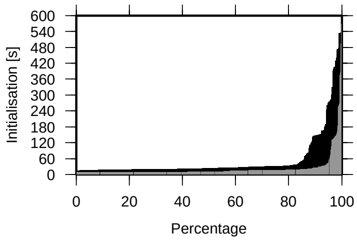


Figure 6. Accuracy of all measurements for plane (left) and height coordinates.

Figure 7. Initialisation times and the percentage of all initialisations.

Initialisation times were mostly less than one minute (average 29 seconds and 90% of initialisations under 32 seconds). However table 1 does not separate cold starts and on-the-fly initialisations. Cold start is a process that consists of the dialling to the computing centre, sending the rover position, creation of a virtual reference station and fixing the integer ambiguities of the rover. The time is clocked from the moment when GSM connection to the computing centre was established. On-the-fly initialisation consists of only integer ambiguity resolution. The difference of cold start and on-the-fly initialisations is shown in figure 7 where black colour indicates cold starts and grey colour on-the-fly initialisations.

Table 1. Accuracy (mm) and initialisation times (s) of VRS.

n = 2152	North	East	Height	Plane	Initialisation time
RMS / average	23	14	35	27	29
95%	39	28	67	43	132
99%	59	37	100	66	396

Initialisation time was limited at first to 15 minutes but after a week it was decreased to 10 minutes. This was limit to stop initialisation and consider it as a failed initialisation. Total of 40 failed initialisations from 2192 occurred during measurements i.e. 1,8% of all initialisations. These were mainly caused by poor satellite geometry, low amount of satellites or problems with GSM connection. Also majority of the failed initialisations occurred in small VRS network (see section 3.2.1), which indicates that the rate of successful initialisations is also dependent on the number of network stations.

Among 2152 successful initialisations there are only 31 initialisations that lasted longer than five minutes and this means that more than half (40 from 71) of these failed. Therefore five minutes could be considered in practice as an adequate limit of starting new initialisation. Long initialisation time may also reflect to bad accuracy. User should always be suspicious when initialisation takes long time or if there are bad satellite geometry or presence of obstructions.

3.1.1 Baseline Length

This section shows the correlation between accuracy and distance to nearest base station. Also initialisation times are studied. Distances varied from 2 to 50 km and total of 2152 observations were included in the test. Figure 8 shows the connection for horizontal and height coordinates and also for initialisation times. Distance seems not to influence on horizontal accuracy at all and only a slight degradation of height accuracy and prolongation of initialisation time can be seen either. This indicates to successful modelling of errors.

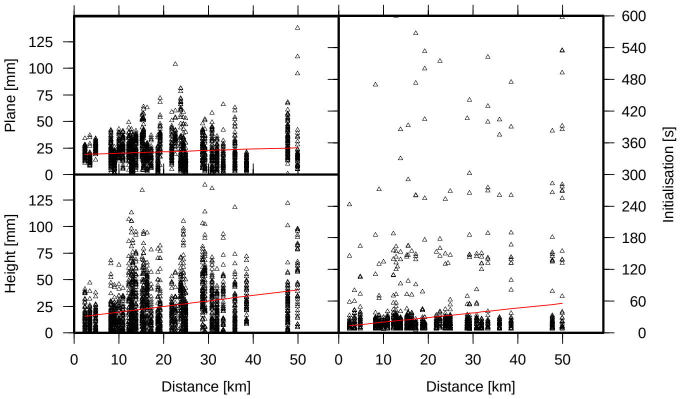


Figure 8. Connection between accuracy and distance to nearest reference station for plane (top left) and height coordinates (bottom left). Connection between initialisation time and distance to nearest reference station shown at right side.

3.1.2 Rover Position

In the figure 8 we did not separate observations in terms of rover position i.e. whether the rover is inside or outside the VRS network. In advance this was considered to influence on the accuracy because modelling of errors outside a network requires extrapolation (see e.g. Vollath et al. 2000). Influence of extrapolation is shown in figure 9 for accuracy and initialisation times. For the accuracy there is no difference whether the measurements are performed inside or outside the network. For initialisation times instead a distance correlation is seen when measuring on extrapolation area.

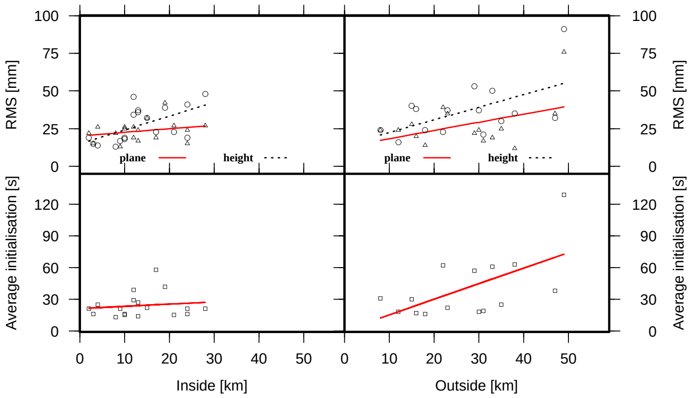


Figure 9. Accuracy and initialisation dependency on distance to nearest reference station when measurements performed inside or outside the VRS network.

3.1.3 Number of Satellites and DOP

RTK rover needs at least five common satellites with the base station to resolve the unknown ambiguities with on-the-fly technique. In general increasing number of satellites gives better results because of better satellite geometry and redundant satellites for ambiguity resolving (Hofmann-Wellenhof 2001). Lowering the cut-off angle may increase the number of visible satellites but does not always improve the results if surrounding obstacles are present. Finnish terrain is quite often forest covered and therefore adequate cut-off angle should be determined according to the measurement conditions. During the test the cut-off angle of 15 degrees was used in order to avoid signal blockage. In figure 10 we can see that increasing number of satellites decreases the RMS of observations. Also initialisation times get shorter when more satellites are visible.

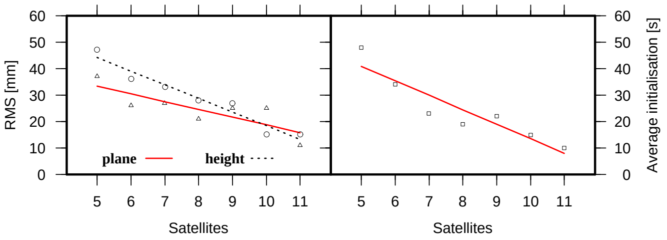


Figure 10. Influence of amount of visible satellites on accuracy and initialisation times.

DOP value describes the distribution of satellites and is important factor while planning the measurements. DOP value multiplied with standard deviation of the measurement gives an estimate of positioning accuracy (Hofmann-Wellenhof 2001). Therefore larger DOP value results worse accuracy as shown in figure 11. Also correlation between increased DOP and longer initialisation time can be seen. In the plots one obvious outlier was left out from the fitting of trend line.

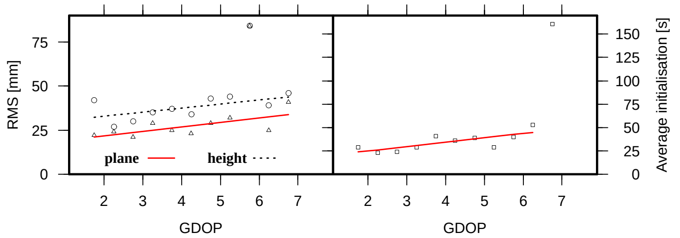


Figure 11. Influence of DOP values on accuracy and initialisation times.

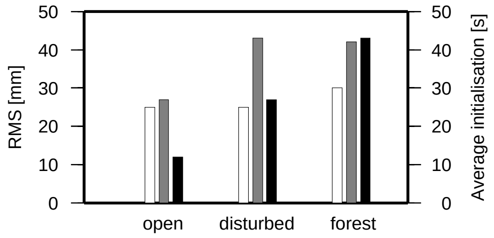


Figure 12. RMS values for plane (white) and height (grey) coordinates and average for initialisation times (black) at open or open but disturbed terrain or in forest.

3.1.4 Number of Epochs

Number of epochs used for observation is relevant in mapping applications since adequate number of epochs may have big influence in productivity of VRS measurements. For example using few epochs per observation instead of few tens of epochs may increase the number of measured points radically during a working day. We studied whether the amount of epochs have effect on accuracy. Five-epoch observations were chosen based on standard practice used by surveyors and 20 epochs were chosen just to increase the amount of epochs and study whether it has influence on the results. The study was carried out at all the test points during the whole measurement campaign. At every point 10 five-epoch and 10 twenty-epoch observations were collected.

Table 2 shows the RMS values of the accuracy for both 5 and 20 epochs. Practically no difference can be seen. As a conclusion made afterwards, it would have been more fruitful to decrease the amount of epochs to few epochs instead of five. However from the results we can say that using 20 epochs instead of 5 gives no additional value for the accuracy.

Table 2. Influence of epochs used per observation

RMS (mm)	North	East	Height	Plane
5 epochs	25	14	37	29
20 epochs	21	14	32	25

3.1.5 Surroundings

This section describes the influence of obstructions on measurements. Measurements were carried out in Sjökulla test field where 13 points were chosen as reference. Each point was measured twice under different satellite geometry resulting total of 541 successful and independent observations. Chosen points are classified as open or disturbed terrain or as forest points. Open terrain has not obstacles elevations above 20 degrees. Points classified as disturbed terrain are mainly open but some directions may have obstacles that rise up to 50-60 degrees of elevation. Points classified as forest points have obstacles all around that may rise up to 70-80 degrees. Figure 12 shows the RMS values computed from observations in plane and height coordinates and average for initialisation times.

Figure 12 shows that only slight effect of obstacles can be seen in plane coordinates but for height and initialisation times the influence is bigger. Average initialisation time is growing from 12 to 43 seconds while moving from open terrain to forest. This can be explained with signal blockages from satellites caused by obstacles. Every time signal is blocked a new integer ambiguity for the satellite need to be resolved. This prolongs the initialisation time. Though no big influence on accuracy can be seen, discretion should be used when surrounding obstructions are present.

3.1.6 Temporal Variation of Fixed Solution

Temporal variation of fixed solution is studied because in the past it had been discovered some variation of accuracy in time while having fixed solution longer periods of time. Long measurement time with a same initialisation is a normal situation while mapping and new initialisations are purposeless and time consuming. Test was carried out by mounting antenna on the roof of the FGI and performing five longer fixed solutions. Duration of the solutions varied from one hour to three hours and observations were recorded with frequency of 1 second. Figure 13 shows the temporal variation of accuracy for plane and height when amount of observations is almost 30000. Figure includes also the changes in number of satellites during the period but no clear correlation between satellites and accuracy can be seen. Instead in figure 14 clear correlation between accuracy and PDOP can be seen. Therefore measurements during poor satellite geometry should be avoided if good results are expected. However the variation of the accuracy seems to be mainly within 10 cm in both plane and height, which is accurate enough for many mapping purposes.

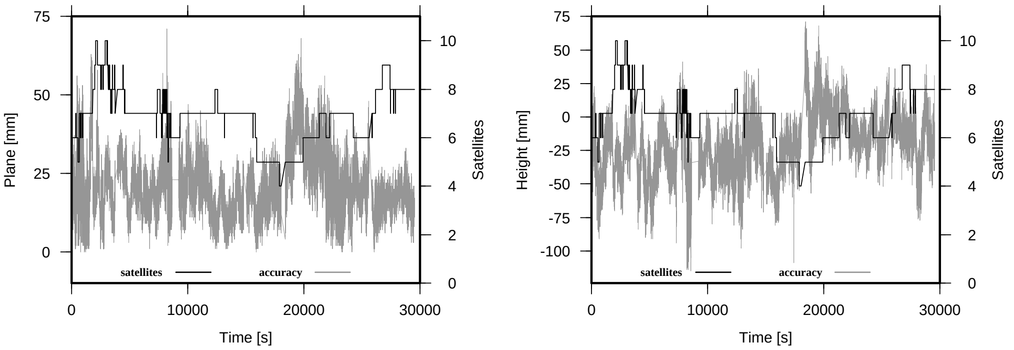


Figure 13. Temporal changes in accuracy during fixed solution. On the left side variation in plane coordinates and on the right side variation in height. Number of satellites is depicted by black colour.

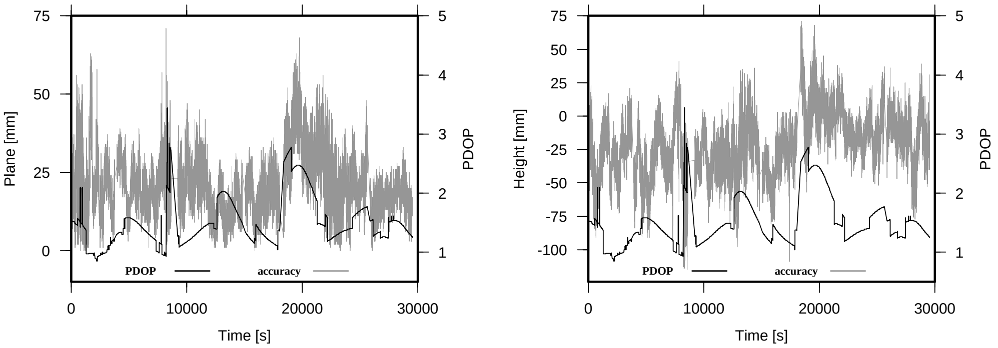


Figure 14. Temporal changes in accuracy during fixed solution. On the left side variation in plane coordinates and on the right side variation in height. PDOP is depicted by black colour.

3.1.7 Estimated vs. Real Accuracy

The aim of this test was to show the difference between the accuracy estimated by the equipment and the real accuracy. It's quite usual to trust the value shown by equipment which does only indicate to precision of the solution. In figure 16 observations are depicted by the estimates given by equipment and the real accuracy. Observations are also classified by the GDOP value and are shown with different symbols and colours. GDOP values less than 3 are depicted by black triangles, GDOP values between 3 and 5 by grey circles and GDOP values above 5 by blue squares. A slight correlation between GDOP and results can be seen but deviation of the results is large. Anyhow figure shows that the equipment gives mainly too optimistic values when compared to real accuracy of the observation. Within low demands of accuracy though the values given by equipment are satisfactory enough.

3.1.8 Different Equipments

This section gives a short overview on the influence of chosen equipment. The instrument test was participated by the major manufacturers of RTK equipments available in Finland. Tested equipments were: Ashtech Z-Xtreme, Leica SR530, Sokkia Radian-IS, Topcon Legacy-E and Trimble 5800. Study was carried out during two weeks by testing equipments at the test points in southern Finland and Sjökulla test field. Measurements are done at the same time of the day but on different days for different equipments. Therefore some slight differences caused by different atmospheric or satellites orbital conditions may be included in results. In order to mitigate this effect one equipment was kept as a reference during the measurement.

Basic settings of the equipments (e.g. cut-off angle, initialisation reliability) were equalised as much as possible but otherwise standard settings of each equipment was applied. Thus, the results are more realistic describing attainable results with standard set-ups. Table 3 shows the accuracies and initialisation times for the equipments. No clear differences between equipments can be seen except in initialisation times. Otherwise it can be overviewed that the other factors than the equipment play a bigger role on accuracy.

Table 3. Accuracy and initialisation times of different RTK equipment manufacturers.

Plane	Ashtech	Leica	Sokkia	Topcon	Trimble	Height	Ashtech	Leica	Sokkia	Topcon	Trimble
RMS	30	25	30	33	24	RMS	37	31	40	35	27
<95%	51	43	48	57	44	<95%	68	71	81	61	55
Initialisation	Ashtech	Leica	Sokkia	Topcon	Trimble						
average	13	16	19	20	48						
<95%	54	33	52	36	152						

3.2 Network Related Factors on Results

3.2.1 Number of Network Stations

The study was performed in two different VRS networks that have different number of reference stations. The network in Tampere consists of four reference stations while the second network in Southern Finland consisted of 16 reference stations (network has expanded since the test measurements). This made it possible to compare results between small and large networks and their capability of modelling the errors.

Figure 15 show the accuracy and initialisation times with respect to baseline length from nearest reference station. The difference in accuracy of plane coordinates seems to be insignificant but in height the difference is seen clearly. The same trend is seen in initialisation times, too. Figure does not show percentages of failed initialisations (see chapter 3.1). While the overall percentage of failed initialisations was 1,8% the values for small and large networks are 3,50% and 0,34%, respectively.

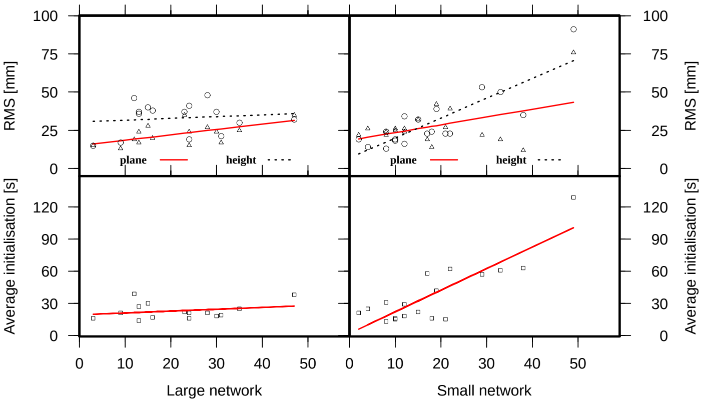


Figure 15. Accuracy and average initialisation times of small and large VRS network vs. baseline length.

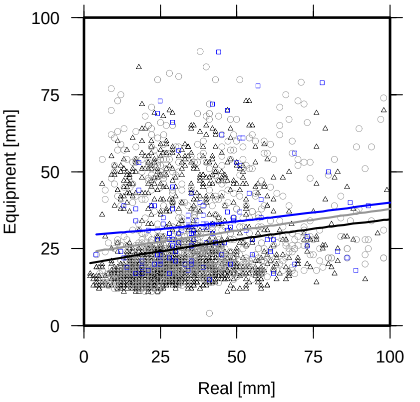


Figure 16. Comparison of estimated accuracy given by equipment and real accuracy.

3.2.2 Distances between Network Stations

Usual distance between reference stations (interstation distance) is between 50 and 70 km according to the recommendation of the author of the computing centre software (Trimble Navigation Limited 2001). We studied how sparse the network can be without degradation of quality of measurements. In order to study this, we used another spaced VRS network. This network was created by choosing a subset of stations from existing primary VRS network.

Both networks were used parallel to each other. The study was carried out during four-week period with four different configurations of the network. Mean distances are averages calculated from the interstation distances in the measurement area and resultant mean distances for the spaced networks are 67 km, 87 km, 107 km and 77 km (for the primary network 61 km). The networks are represented in figure 4. Total of 1147 observations from the spaced networks were collected.

Figures 17 and 18 show the influence of spacing the network. Dark bars represent the observations collected from the primary network and light bars observations from the spaced networks. The difference between the adjacent dark and light bars shows the influence. Each pair of dark and light bars is interrelated because of almost simultaneous observations from both networks. The pairs instead are not comparable to each other because of measurements done during different weeks. In addition measurements are not done under same satellite geometry at each point from week to week. This explains the variation of absolute values. However absolute values tell something about the success of each week's measurements.

It is clearly visible that mean distance over 100 km cause degradation of accuracy. Mean distance less than 90 km, however, seems not to affect the accuracy of horizontal coordinates but still deteriorates the accuracy of height coordinates. Mean distance under 80 km seems to be quite safe and no differences in results are visible.

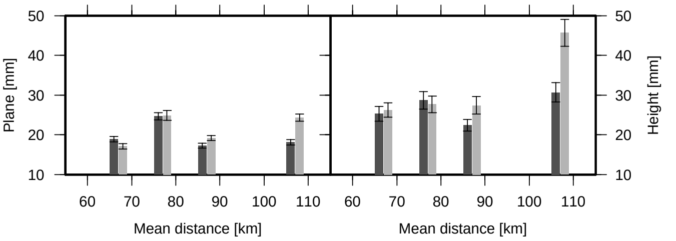


Figure 17. Comparison of simultaneous observations on accuracy from primary and spaced networks. One bar represents of 300 observations.

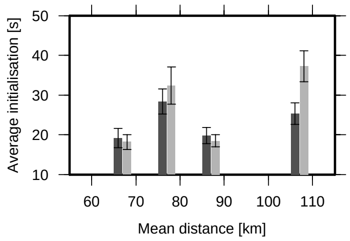


Figure 18. Comparison of simultaneous observations on initialisation times from normal and spaced networks. One bar represents of 300 observations.

The same trend is seen also in initialisation times. Within the error bars it is seen that mean distance over 100 km is affecting the time needed for initialisation but for shorter distances the differences are insignificant. However increasing the interstation distance causes three times more failed initialisations (1,12%) when compared to primary network (0,34%).

3.3 DGPS

Accuracy of differential GPS was studied besides the main study and was not our main interest. Test was carried out during two weeks by measuring all 15 testpoints twice. Networks were formed differently at different weeks and they are shown in figure 19. Measurements were done with Trimble GeoXT handheld DGPS receiver and total of 291 observations were collected.

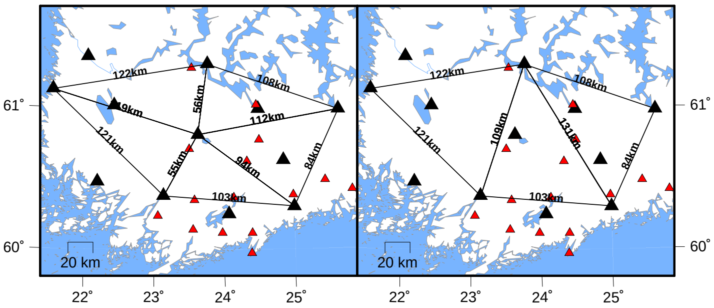


Figure 19. DGPS networks during two weeks measurements.

Figure 20 shows the accuracy plotted in plane and in height by percentage of all observations and the same results in numerical format are shown in table 4. As a conclusion few meters accuracy is achievable with DGPS measurements.

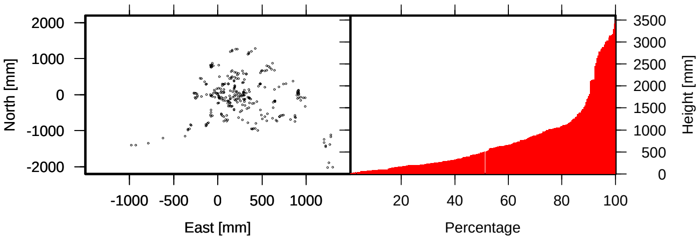


Figure 20. Accuracy of DGPS measurements in plane (left) and height (right).

Table 4. DGPS accuracy in meters

n = 291	North	East	Height	Plane
RMS	0,58	0,47	1,09	0,75
95%	1,23	0,94	2,86	1,32

3.4 Problems occurred during the study

In most cases measurements succeeded well but some minor problems were encountered. GSM connection was stuck few times needing a manual reset of GSM modem in computing centre. This may be caused by GSM modems themselves or weak GSM signal. Another subject that caused problems was missing satellite data from distributed correction. This was caused by unsuccessful modelling or resolving of satellite data in computing centre. Also loss of fixed solution occurred few times causing a need for new initialisation. Losses may be caused by obstacles, sudden changes in atmosphere or multipath.

4 CONCLUSIONS

Measurements can be done at centimetre-level with VRS concept if certain factors are taken into account. Also reliability of measurements is high and false solutions are well proportional to initialisation reliability rate that is used. Initialisation times are short while measuring in adequate conditions.

Correlation between accuracy and baseline length from nearest reference station is low and the results are quite equal within the network area. Also position of rover within the network area in terms of accuracy is negligible. However it seems to be significant for initialisation times whether rover is inside or outside the network. Number of satellites and satellite geometry are proven to have influence on measurements and therefore should be taken into account. Obstructions and their influence on the accuracy was ambiguous but on initialisation times clear correlation is seen. The choice of RTK equipment seems to be irrelevant according to the test. However user should not be too trustful about the predicted accuracy values shown by the equipment because they are often too optimistic.

Network itself is one influencing factor on results. Small network (few reference stations) has not the same power against the errors that are inherent to GPS than large network. According to the study adequate mean distance between reference stations settles to 80 kilometres still having good quality on accuracy and initialisations.

As a final conclusion VRS is suitable for centimetre-level measurements but is not beatific; certain measurement procedure should be applied if reliable and accurate results are aspired.

5 REFERENCES

Hofmann-Wellenhof, B., H. Lichtenegger and J. Collins (2001): GPS Theory and Practice. Fifth, revised edition. Springer-Verlag. Wien New York.

Ollikainen, M., H. Koivula and M. Poutanen (2000): The densification of the EUREF network in Finland. Publ. of the FGI, No. 129. Kirkkonummi.

Trimble Navigation Limited (2001): Trimble Virtual Reference Station VRS. VRS Brochure. (http://www.trimble.com/vrs_bro.html)

Vollath, U., A. Buecherl, H. Landau, C. Pagels and B. Wagner (2000): Multi-Base RTK Positioning Using Virtual Reference Stations. Technical Paper – September 2000 (http://www.trimble.com/vrs_tp.html).

Vollath, U., H. Landau and X. Chen (2002): Network RTK – Concept and Performance. Technical Paper published in Nov. 2002 (http://www.trimble.com/vrs_tp.html).

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