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# Differential GNSS for Outdoor Sports - Testing of Applicability for Alpine Sports

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Abstract: The purpose of this paper is to evaluate a differential GNSS (global navigation satellite system) tracking technology and whether it can be applied in alpine sports. Wearable technology is a technology undergoing extensive development. Wearable technology is an umbrella term for technology that can be worn, providing the user with different kinds of information. In sports, this is often related to performance of athletes. This paper is evaluating a tracking technology and whether it can be applied in an alpine environment, tracking both cross country skiers as well as down hill skiers. The technology applied in the product is a DGNSS, a differential Global Navigation Satellite System, a high accuracy positioning technology. The GNSS is using several satellite systems, providing coverage at all times. The differential part comes from the use of an accurately surveyed reference station, providing the rover with correction signals and thereby give a higher accuracy on tracking data. The technology shows promising results in accuracy in the measurement method used, but needs further evaluation using continuous measurements.

## 1 INTRODUCTION

GNSS stands for global navigation satellite system that allows the user to measure position, velocity and local time in a highly accurate way. The global navigation satellite system's signal consists of a variety of satellite systems in space that broad- cast navigation signals. The navigation signals can in its turn be picked up by a GNSS receiver on the earth to determine that receiver's position and velocity. GNSS is useful in navigational applications and provides fairly accurate position (2.5 metres) and velocity (0.03 metres/second). A GNSS receiver must have a clear signal from at least 4 satellites to function. GNSS satellite signals are weak and struggle to penetrate through buildings and other objects obstructing view of the sky. GNSS can also occasionally drop out due to disturbances in the upper atmosphere. The GNSS used in this test is a differential GNSS (or DGNSS). The differential GNSS is using a reference station with an accurately calibrated position. The reference station is installed temporarily on a known position, and calculates correction parameters and sending them to the mobile GNSS rover. This technology results in a reduction of the deviation of the measured position to the actual position of the GNSS user receivers (Granby, 2016).

The technology can be applied to several areas outside of sports. The areas of applications include for instance such as surveying, flying unmanned aerial vehicles, robotics, marine applications, and motor sports.

### 1.1 Problem

A television production company has expressed a wish for more information and data on the athlete's performance, to complement their sports event productions. This is to provide the end user with additional value information and providing the television companies with services that are giving the production company an advantage over other production companies. The linking of positioning data and live video-feed is considered as extra difficult to achieve. An increase in the precision in the positioning will provide additional features possible to combine with the viewer experience, and is thus desirable.

GNSS positioning technology can be applied to gather information on the athlete's position, velocity



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and acceleration in both team sports and individual sports. In an application in an alpine skiing environment, demands are put on the positioning technology's performance in accuracy. It should also allow large capturing volumes of data in order to be able to analyse the run. The positioning device should not restrict in motion or cause discomfort for the tracked athlete in motion, putting demands on the size of the device.

The problem to be solved is to track and position athletes in different contexts, providing athletes, coaches, and spectators with data. The data can be used by athletes and coaches to understand what improvements that can be made or as an escort for visually impaired athletes. The data can also be used to create a surplus value in sporting events for the spectators. The extra information that can be elicited can be used both for live spectators and for television broadcasting of sports. Extra data that can be provided to the audience is the trajectory of the slope, exact positions during the race, choice of line, velocity and acceleration (Spörri et al., 2014).

An evaluating and testing of the product is desirable (for different sports and accuracy) to what needs to be improved and if the technology will be meeting the requirements put on it.

## 1.2 Present DGNSS Research

In alpine skiing, testing and research carried out are using the differential GNSS for time measurements and force measurements. The differential GNSS that often are used in these contexts are often expensive and well calibrated and not built for applications where athletes are carrying it with them. In the research where differential GNSS are used, it is for proving the technology and accuracy of other positioning devices.

In research where athletes actually have carried the differential GNSS, the research performed have shown promising results in using the differential GNSS for time measurements in both alpine skiing as well as 100 m sprints. In the 100 m sprint a regular GNSS was tested and the results in the time measurements were compared to the data from a photocell. The study proves that regular GNSS can be used for time measurements of smaller segments of a slope. The technology could also be used for deciding on location comparisons between the athletes. The researchers also finds data that can be used for professional athletes and their coaches to analyse training and competition performance. (Advanced Navigation, 2015).

Similar tests have been made using a differential GNSS to measure the trajectories of slopes and make time measurements with a regular GNSS to compare to the time measurements of photocells. Also in this study, tests proved that the data provided by the GNSS gives an applicable time measurement method and will provide better opportunities for analysing the ride than from just the use of photocells for measurements (Murray, 2014).

Low cost GNSS using lower sampling frequencies have shown not to be appropriate for tracking and time measuring. This goes for devices using a sampling rate of 1 Hz or lower. The reason for this is the distance travelled changes too much during the sampling time (Mercator, 2016).

The differential GNSS is also often used as a reference value when testing other positioning devices in surveying. The differential GNSS used in these cases are using real time kinematics (RTK) that provides high accuracies close to a base station. Real time kinematics uses a reference station and an open channel for broadcasts information in real time. With this information, the rover equipment is able to fix the phase ambiguities and determine its location relative to the base with high precision (Advanced Navigation, 2016).

What can be said overall by the current research is that not many providers on the market are testing and using differential GNSS for measurements. The technology is still under development and is considered expensive and ungainly to wear in sports and is not yet considered wearable technology.

## 1.3 Purpose of the Paper

From the above background and described problems, the purpose of this paper is to evaluate a differential GNSS tracking technology and whether it can be applied in alpine sports.

## 1.4 Outline of the Paper

The paper describes an evaluation a differential GNSS tracking technology and whether it can be applied in alpine sports. The paper is divided as follows: Section 1 introduces the problem background, current research and the purpose of the paper. Section 2 provides the theoretical framework. Section 3 describes the method used in the study, followed by Section 4, addressing the results. Section 5 progresses into the discussion of the results. Finally, Section 6 will summarise the contributions made in the paper.

## 2 THEORETICAL FRAMEWORK

Satellite based positioning is the determination of positions of observing sites. Satellites provide the user with the capability of determining a position expressed by for instance latitude, longitude and height.
Latitude and longitude can be described as the angle between where the object is positioned and the reference axis. For latitude, the reference axis is the equator. For longitude, the reference meridian is the international prime meridian. This way, every location on earth can be specified by a set of numbers. Latitude is specified as the lateral positions on a spherical shape, and the longitude as the vertical positions on a spherical shape. The latitude and longitude is measured in degrees or radians. The altitude that needs to be used when specifying positions is measured in meters over the reference ellipsoid WGS84, a model used for approximating sea level across the Earth (Hofmann-Wellenhof et al., 2008).

The process for positioning something with latitude, longitude and elevation is done by a resection process, where range differences measured to satellites are used, see figure 1. To relate this to what is happening, the vector $Q_s$ relates to the center of the earth (geocenter) of each satellite. The geocentric position of the receiver on the ground is defined by the vector $Q_r$ and is set to system time. The geometric distance $Q$ to each satellite could be measured from recording the time required for the satellite signal to reach the receiver. Using this technique would yield in the unknowns, latitude, longitude, and elevation, that could be determined from the three range equations $Q = \|Q_s - Q_r\|$. (Hofmann-Wellenhof et al., 2008).

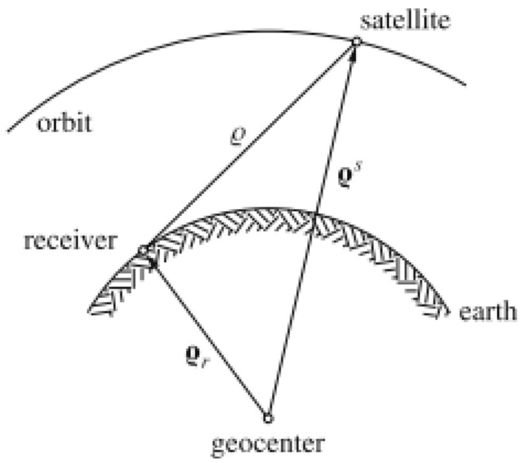


Figure 1: Principle of satellite based positioning (Hofmann-Wellenhof et al., 2008).

### 2.1 Global Navigation Satellite Systems

The most oldest and most common GNSS system is the American Global Positioning System (GPS). Other GNSS systems are the Russian system GLONASS, the European Union system Galileo, and the Chinese system Beidou. GNSS satellites orbit the earth at about 20,000 km altitude. Each GNSS system has their own constellation of satellites, providing the system with desired coverage.

GNSS stands for global navigation satellite system and consists of a number of satellites in space that broadcast navigation signals. The navigation signals can in its turn be picked up by a GNSS receiver on earth to determine that receiver's position and velocity. GNSS is useful in navigational applications and provides fairly accurate position (2.5 metres) and velocity (0.03 metres/second). A GNSS receiver must have a clear signal from at least 4 satellites to function. GNSS satellite signals are weak and struggle to penetrate through buildings and other objects obstructing view of the sky. GNSS can also occasionally drop out due to disturbances in the upper atmosphere.

### 2.2 Differential GNSS

The GNSS used in this test is a differential global navigation satellite system (DGNSS). Differential GNSS is an enhancement to a primary GNSS, using a reference station with a accurately surveyed position. The method takes advantage of the slow variation with time and user position of the errors due to ephemeris prediction, residual satellite clocks, ionospheric and tropospheric delays. Starting from the reference station the system broadcasts corrections to the GNSS rover, see figure 2. The rover needs to be enabled for receiving correction signals and be connected to the same satellite as the reference station in order to function (GMV, 2011, Hofmann-Wellenhof et al., 2008).

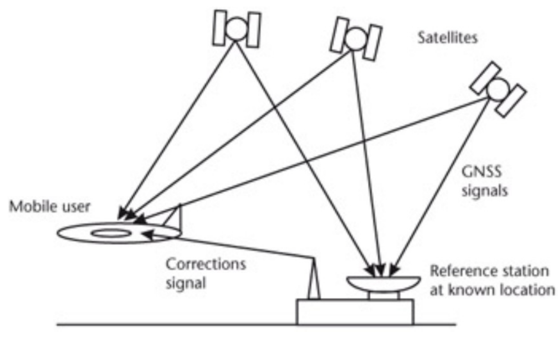


Figure 2: System overview of a differential GNSS.

This technology results in a reduction of the deviation of the measured position to the actual position of the GNSS user receivers. The reference station has the technical possibility to position itself using different satellite systems, which leads to a more accurate position. Variations of the technology exist, where multiple reference stations are used, leading to a higher accuracy for the rover. This technology can be applied in order to cover a larger area, using reference stations strategically placed in order to have coverage on the correction signals.

### 2.3 Data Processing

When processing the data coming from the units, the error and standard deviation needs to be expressed in an easy comparable unit. The unit of choice was meters, to get a physical translation that is relatable. This yields for transformations of the data. According to Advanced Navigation, their procedure was to do the transformation to Earth Centered Earth Fixed (ECEF) (Orr, 2016).

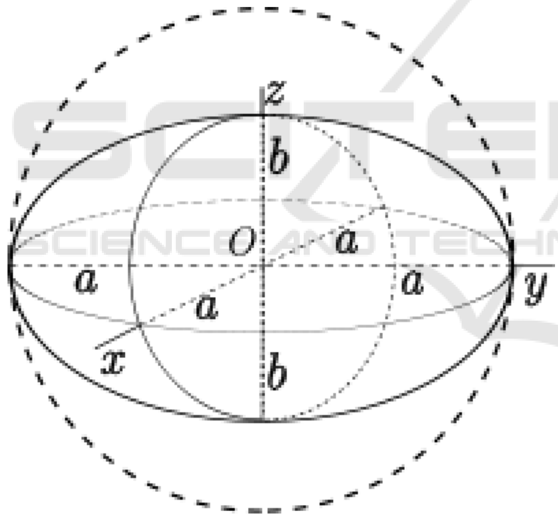


Figure 3: A sphere of radius a compressed into ellipsoid.

This format is useful in calculation of Cartesian coordinates when using a non- spherical form. Converting in to Cartesian coordinates and considers the earth as a sphere will yield in a systematic error in the measurements, as the earth is not spherical, see figure 3. This means that if calculating with Cartesian coordinates and using the same radius for all of the earth would yield in different errors at different locations. Using ECEF conversion the earth is considered an elliptical shape and the flattening of the earth will be considered in the calculations. The Cartesian coordinates calculated will have its origo in the center of the earth. The geodetic coordinates will be transformed from latitude and longitude into X and Y coordinates while the altitude will be added to the Z-component to get the altitude and the change thereof. The altitude of the Z-component will be expressed in meters above the reference ellipsoid.

World Geodetic System 1984 (WGS84) is a terrestrial reference frame, a reference ellipsoid. The reference ellipsoid is a mathematically defined way of describing the surface of a geoid. Associated with this frame is a geocentric ellipsoid of revolution, originally defined by the parameters a, f, $\omega_e$ and $\mu$, see table 1. WGS84 is globally considered accurate within 1 meter (Hofmann-Wellenhof et al., 2008).

Using the Matlab command LLA2ECEF from the aerospace toolbox, the geodetic coordinates latitude, longitude and altitude where converted into ECEF-format in meters. The LLA2ECEF command is using WGS84 as default ellipsoid. The input arguments for LLA2ECEF is [degree, degree, meters], which is fitting for the data set that is provided by the DGNSS examined (Statista, 2016).

Table 1: Parameters of the WGS-84 ellipsoid.

| Parameter and Value | Description |
|---|---|
| $a = 6378137.0m$ | Semimajor axis of the ellipsoid |
| $f = 1/298.257223563$ | Flattening of the ellipsoid |
| $\omega_e = 7292115 \cdot 10^{-11} rad/s^{-1}$ | Angular velocity of the earth |
| $\mu = 3986004.418 \cdot 10^8 m^3 s^{-2}$ | Earth's gravitational constant |

## 3 METHOD

In this section the research methodology is described. The data collection design together with data handling is described.

The measurement method where made with accurately surveyed positions were calibrated on flat ground and in a ski slope.

The flat ground testing was performed on Vallhamra sports facilities (Sweden) and the ski slope of choice was located in Ulricehamn (Sweden).

By doing post-processing calculations using Matlab and Microsoft Excel, the latitude, longitude and altitude can be translated into meters.

The used points were accurately surveyed using hired technology from Leica.

The surveyed points were then put on the form fitted for comparison with the data points from the tested product. By hiring the technology a reference value could be established, and thereby minimize sources of errors in reference.

By putting the GNSS antenna in the zigzag pattern and allowing it to collect 180 samples the point is considered accurately surveyed and the position is known with 3mm + 0.1 ppm accuracy.

The tests carried out on Vallhamra sports facilities where replicated in a slope at Ulricehamn ski center. The proceed was the same using hired technology from Leica to survey points in the slope, marking out these and thereafter make a run on skis, wearing the devices mounted on top of the helmet.

## 3.1 Data Collection

When processing the data coming from the units, the error and standard deviation needs to be expressed Physical testing have been performed on flat ground and in a slope. The flat ground tests were performed for getting a value where accuracy could be calculated. This accuracy was then applied on the tests in the ski slope as a proof of concept. The tests were made with regard to finding absolute accuracy and the relative accuracy. To get a value of the absolute accuracy, accurately surveyed points on a plane surface is being marked out using a levelled Leica Viva GNSS GS14 together with a hand held Leica CS20. Here the exact position can be compared to the value from the GNSS unit. The accurately surveyed points on the sport arena were placed in a zigzag pattern. The points were marked using orange spray paint and thereafter visited one at a time. By holding the GNSS over the point for five seconds, a visual trigger was provided for the post-processing of data, providing the possibility to see where the points are.

## 3.2 Data Analysis

Both the flat ground tests and the tests performed in a ski slope were made using a calibrated starting point and then 4 other points in a zigzag pattern. The points are calibrated with the Leica Viva GNSS GS14 mounted in the point, using averaging for 160 cycles, and thereafter marked out, using an orange spray paint. The collection of data was made after calibrating points. After this the devices where hand held and walked across the field. At each point the device was held still for five seconds to mark the position in data. This yielded, with a sample rate of 20 Hz, 100 samples at the position, making it possible to read out from the data sheet. By plotting the data, an estimation of at what sample the position is marked. This sample number is then translated from its (latitude, longitude, altitude)-form to an earth centered, earth fixed, ECEF-form. This will yield in a format of the coordinates and the movement can be given in a form of a regular coordinate system (X, Y, Z). The movement given in ECEF-form will then be used for creating a mean value around the turning point. The mean value is calculated around the minimal difference value using 90 samples. From these values a standard deviation and mean error for the accuracy was calculated.

Investigating the accuracy between two devices was made by putting two or more units on a fix distance between the units. Here the recorded distance can be compared to the actual distance. This testing was only performed on flat ground. The testing was performed using a plank attached to a bicycle holder in the back of a car. This car was then driven around a running track. The two units attached to the plank were then observed and the distance between them, 188 cm, could be observed how it differed from the reality. From this data the standard deviation and mean error can be calculated. The recording of the distance between the devices is made by using a plugin for the program recording the data. Gmap.net and mapprovider.projection.getDistance are the plugins and functions that are used by the program.

# 4 RESULTS

For the flat ground test with calibrated points the test was made using two different trackers. The data was processed separately from that data set and thereafter analysed. The accurately surveyed latitude and longitude will be denoted CALLAT and CALLON. The values used around the turning points when doing the tests are denoted lat and the mean value around that point is denoted $\Delta lat$ and $\Delta lon$.

The columns ECEF means that the values have been converted from lat, lon, alt into earth-centered earth-fixed, ECEF-form. This was done using Matlab and converts an input of ([rad], [rad], [m]) into ([m], [m], [m]). The Matlab code uses the following values for WGS84 ellipsoid constants (National Imagery and Mapping Agency, 2004). The final column Diff is simply the difference between the calibrated value and the mean value around the turning point. This is the same as the distance from the calibrated point (Table 2).

For tracker 2 the RMS values for the different positions were 0.5274, 0.36026, 0.11289, 0.53633, and 0.484 meters for each point. This results in a standard deviation of 0.1773 m.

Table 2: ECEF values for tracker 2 at Vallhamra [m].

| ECEF | | |
|---|---|---|
| callat | callon | calalt |
| 3,33842098697508 | 7,14501958786384 | 5,36952170358413 |
| 3,33844662508295 | 7,14486992245528 | 5,36950821375262 |
| 3,33842131184515 | 7,14446474910573 | 5,36952914614575 |
| 3,33845256235963 | 7,14444444701532 | 5,36951029111727 |
| 3,33844085223223 | 7,14414386226753 | 5,36952130994464 |
| | | |
| deltalat | deltalon | deltaalt |
| 3,33842141172043 | 7,14502271428875 | 5,36952240952373 |
| 3,33844698028778 | 7,14486932115255 | 5,36950865648570 |
| 3,33842142120938 | 7,14446502922780 | 5,36952956020196 |
| 3,33845203372697 | 7,14444354158593 | 5,36950945065900 |
| 3,33844040391479 | 7,14414568630733 | 5,36952059257905 |

For tracker 3 the RMS values for the different positions were 0.0768, 0.3877, 0.5563, 0.9203, and 0.4331 meters for each point. This results in a standard deviation of 0.3053 m.

Tests on relative positioning error was also made by putting two devices on a fix distance between them and then driven around a running track with a car. The physical distance between the devices was 1880 mm and in figure 4 the fluctuations in difference can be seen over the 2200 samples.

The calculations from this gives a standard deviation of 1.003 m, a mean value of 0.215 mm and fluctuating values between -1.877 m and 2.321 m.

This means that mean of the two trackers results in a standard deviation of 0.2413 m (Table 3). So, with 68% certainty the data retrieved from the tracking device is within a span of 0.2413 meters of the observed position. With 95 % certainty the data from the tracking device the device is within a span of 0.4826 m of the observed position. With 99.7 % certainty the data from the tracking device the device is within a span of 0.7239 m of the observed position.

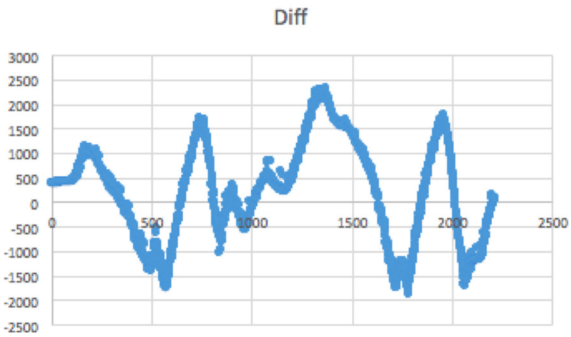


Figure 4: Positioning error, distance [mm] between two units over sample number [n].

Physical testing in the intended environment of use was also made. This was made as a proof of concept, that the device can be used for tracking an alpine skier. In figures 5 and 6, a red and a blue line can be observed. These lines are both representing a rover carried by a skier. The red line is following the track that was surveyed. The blue line is an other of the rover, that drifted away and did not provide any results of use. When riding the lift up for the ski slope test, the connection was lost when going up the lift and the devices needed to be restarted. After this, the data collection could proceed and in the peaks, the turns can be observed.

Table 3: Standard deviation of the measurements from Vallhamra IP.

| 1‡ | 2‡ | 3‡ |
|---|---|---|
| 68% | 95% | 99.7% |
| 0.2413 m | 0.4826 m | 0.7239 m |

Figure 5: Run from ski slope in Ulricehamn.

Figure 6: Measurements from Vallhamra sports facilities.

## 5 DISCUSSION

The data collected, the collection method and the handling of the data will be discussed. Along with this, problems that manifested themselves during the tests will be discussed. Technical outcomes from the testing will be discussed.

### 5.1 Discussion of Measurements

After some research on methods of how to translate the data available, it was decided to take the approach using accurately surveyed points. Holding the rovers laying flat in the palm of the hand, the accurately surveyed points were marked one at a time by holding the rover still for five seconds. Mean error and standard deviation was than calculated by taking the difference between this point and the points close to the point. This could yield in a better accuracy than reality, since the data collection was allowed to run while being close to the point. When calculating the mean error in this case, the measurement is assumed to reach a steady state with close to zero error. Therefore the outcome from these results should be approached with caution as they might leave a too promising prognosis.

The accuracy from the tests was better than expected. As earlier stated, the accuracy should be approached with caution, as the method is not verified. It is hard to further discuss whether the accuracy is good enough or not, regarding what requirements and future areas of use into a value to aim for.

After performing the tests it was found that the calibration of altitude should have been made before commencing the collection of data but was not made properly which resulted in a systematic error of 5.4 meters. This calibration is made with regard to the height above the ground that the reference station is put. This was handled when doing the post processing of the data. The calculations were performed with the systematic error subtracted in order to not affect the data. The subtraction was made in order to get a proper value of the altitude measurements, as these are important when measuring in a ski slope.

The values on the relative positioning error was not as good as expected. Earlier measurements performed by a company had shown more promising results. The reason for this could be that there have been a problem with getting a differential fix between the reference station and the devices, something that was experienced during the tests. Earlier tests have shown standard deviations and mean errors that were more in the range of 0.7 m and 0.003 m in mean error according to the company contact. This method of testing should however be considered to be discarded. To calculate the error between two unsure sources should not be considered as a scientific way of proving performance for a product like this. The way errors occur for two rovers among them can be random and if interference of the satellite signal occurs, it will do so for both of them, causing unreliable results.

It is important outcome from the testing in the ski slope, is that when connection is lost for the device it is crucial to restart it and allow it to get a differential fix before commencing the tests. Reasons for the blue line in figure 5 can be because of this problem. The rover has failed to get differential fix and the collected data is useless. The problem can also have appeared because of problems with the software causing multi-path errors. After the study, a software update has been performed, targeting a number of weaknesses. A follow up study showed considerably better results.

Alternative methods for measuring are present. The most used method is continuous measurements using a calibrated differential GNSS. Post measurements data processing then needs to be made using Matlab or software such as Justin from Javad, where one can evaluate data from two different input sources in double differential mode. In a comparison of cost between choosing to go with Matlab versus investing in Justin it differs 2800 SEK between getting Justin from Javad. Matlab 18500 SEK + aerospace toolbox 9500 SEK = 28000 SEK versus Justin from Javad 30800 SEK. (Javad, 2016, Matlab, 2016).

The method using accurately surveyed points put demands on post processing data handling that was time consuming. The time consumption is not in parity with the power of the results, as the method is not verified when evaluating GNSS accuracies. This is an other reason for investing in software for facilitate quick evaluations of future updates in the product.

The tests showed that the units where non robust to rotation, something that caused the unit to loose the differential fix. This needs to be evaluated in a future requirement specification whether it will be a problem when using.

## 6 CONCLUSIONS

Wearable tech is an expanding market and the rate of emerging companies is high.

The similar products in the segment are many. Ranging from GPS watches to ungainly differential GNSS, the competition is extensive. By getting a differential, wearable GNSS to show stable results, it would be a completely new segment of tracking and positioning devices. The wearable technology, using differential GNSS with an accuracy that could pose a threat to this product has chose to direct their development focus towards virtual reality products. It should be kept in mind that this kind of technology is growing in many different areas of technology and more spread.

By specifying what the product is going to be used for, whether it is time measurement, line choice of the skiers or measurements of velocity, etcetera.

The recommendation for the company when pursuing the market of differential GNSS tracking of athletes, is to standardize their testing method. Since the product has not yet reached its final technology and the implementation of real time kinematics, it should be considered favourable to have a standardized method for testing where improvements can be confirmed. The standardized method needs to be created in order to be able to process data in a reasonable way where improvements can be easily recorded. When using a standardized method, it will also be easier to evaluate the different settings and additional functions that are available in the technology.

The next step when reaching a prototype that is reaching the requirements for the product and testing in different environments and possible sources of error and most favourable conditions for testing. The technical possibility for switching between antennas is already implemented but not yet evaluated and should therefor also be evaluated. This will be vital to provide signal range for a full ski slope or a cross-country ski slope.

At present there are several factors with the devices that are not making it robust enough for using. Tilting of the devices, calibration of height over the ground and loss of differential fix when put in a skip zone are all problems that is pointing towards an unfinished product. These findings should be put in the requirements specification if they pose a threat to a functioning problem. The earlier these problems can be resolved, the cheaper it can be fixed rather than having to do late changes in product development process.

### 6.1 Recommendations

When performing future accuracy evaluations, a reference track should be used in order to continuously evaluate updates. By having a consistency in the evaluation method, the evaluation gets reliable. The creation of the reference track should be made simultaneously with the data collection of the differential GNSS. There are two reason for this, to be able to synchronize the data sets and to ensure that the circumstances of the earth is the same for the two different data sets.

When performing tests, it is important to make everything at the largest extent possible, replicable. Therefore it is suggested to use the same algorithm for the process every time.

Other factors that might affect the measurements that should be considered when collecting data are the following:

- Collect data in clear weather in order to ensure satellite coverage. Cloudy skies might prohibit signal coverage.
- Collection of data to be analysed should be made continuously, instead of around accurately surveyed points.
- The rovers needs to be restarted and get differential fix before commencing data collection.
- The rovers must be carried with the right side up, and with the correct side in front. The rovers should not be rotated over 40 degrees in order to not loose contact with the reference station.
- The reference station needs to be calibrated in height over ground every time when performing tests. This is important to remember, otherwise it will result in a systematic error in the altitude measurements, something that is important to do as accurate as possible when tracking alpine skiers.

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## REFERENCES

Advanced Navigation (2015), Spatial,. URL http://www.advancednavigation.com.au/product/spatial#applications. Accessed: 2016-05-26.

Advanced Navigation (2016) Spatial,. URL http://www.advancednavigation.com.au/product/spatial#documentation. Accessed: 2016-05-30.

Bernhard Hofmann-Wellenhof, Herbert Lichtenegger, and Elmar Wasle. *GNSS – Global Navigation Satellite Systems*. Springer-Verlag Wien, 2008.

GMV (2011) DGNSS fundamentals,. URL http://www.navipedia.net/index.php/DGNSS_Fundamentals. Accessed: 2016-05-12.

Granby, P. (2016) Unpublished MSc. Thesis, Chalmers University of Technology

Javad. Justin, (2016). URL http://www.javad.com/jgnss/products/software/justin.html#. Accessed: 2016-06-05.

Matlab (2016). Pricing and licensing aerospace toolbox,. URL http://se.mathworks.com/pricing-licensing/index.html?prodcode=AT&s_iid=main_pl_AT_tb. Accessed: 2016-06-05.

Mercator, P. (2016). Leica viva gs14 – gnss smart antenna,. URL http: //leica-geosystems.com/products/gnss-systems/smart-antennas/leica-viva-gs14. Accessed: 2016-05-16.

Murray, S., (2014) Putting wearables into context with low-power GNSS, URL http://www.broadcom.com/blog/wireless-technology/putting-wearables-into-context-with-low-power-gnss/. Accessed: 2016-05-09.

National Imagery and Mapping Agency (2004) World geodetic system 1984. *Technical Report NIMA TR8350.2*, Department of Defense.

Orr. X., (2016) Nci sports tracker project - the road ahead... unpublished company material.

Statista (2016) Big data market size revenue forecast worldwide from 2011 to 2026 (in billion U.S. dollars). http://www.statista.com/statistics/254266/global-big-data-market-forecast/. Accessed: 2016-02-29.

Spörri J., Limpach P., Geiger A., Gilgien, M., and Müller E. (2014) The effect of different global navigation satellite system methods on positioning accu- racy in elite alpine skiing. Sensors, 14 (10), 18433-18453.