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UNIVERSITY OF TECHNOLOGY

TESTING AND EVALUATION OF A TRACKING DEVICE FOR ALPINE SPORTS

Master's thesis in Product Development

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Physical testing and market evaluation of a differential GNSS for alpine sports

A Product Development project in Sports Technology

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Testing and evaluation of a differential GNSS tracker, applied in alpine sports

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Physical testing and market evaluation of a wearable tracking device for alpine sports
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Wearable technology is a technology undergoing extensive development. Wearable technology is a 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 thesis 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 a accurately surveyed reference station, providing the rover with correction signals and thereby give a higher accuracy on tracking data.

New Century Information approached Chalmers University of Technology with an issue on evaluating the accuracy of their technology as well as the current market. The company is two-folded between a technology company and a television broadcasting company in sports. The technology company wants information on the accuracy of the product and the television broadcasting company wants to use the product for future sports broadcasts, with the goal of using the finalized technology at the world cup in Åre 2019. The technology is to be used as a complementary information for spectators, comparing athletes choice of line, time and velocity measurements, etcetera. By approaching the Chalmers Sports & Technology, the company wished for technical assistance in introducing their product on the market. The master thesis is the final project on the master program Product Development, a master program in mechanical engineering. The delivery of the project will be an evaluation of the real-time tracking accuracy in terms of mean error and standard deviation. Along with this an analysis of the products strengths, weaknesses, opportunities and threats, a SWOT analysis will be made in terms of what is happening on the market. To complete this, a SWOT analysis on the technical aspects of the product is also made. As the company will be making technical updates in hardware and software, the accuracy found in the tests is expected to improve tenfold. To strengthen and facilitate the development endeavors of the company, a proposition on a method for future testing is delivered.

Keywords: Wearable, differential, alpine, ski, tracking, positioning, technology.

First of all I would like to give a sincere thank you to my supervisor and examiner Magnus Karlsteen. Magnus is an associate professor at the department of Physics and involved in the Chalmers group Sports & Technology and the reason that this project happened. Connecting me wih the New Century Information and giving me the chance to do a project related to sports is something that I am really thankful for. Magnus did not just provide me with the contact initiating the project, he has also been providing me his knowledge and encouragement throughout the project.

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Johan Samuelsson, Gothenburg, June 2016

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1 Introduction

The company initiating the project is called New Century Information (NCI). The company is trying to make use of an existing technology and business connection. Together with a partner company that is in the business of television production of sports, called New Century Productions (NCP), the company wishes to create a positioning service that can be applied in different contexts.

Using an existing platform product, a ruggedized, portable, global navigation satellite system tracker from the Technology Provider that NCI New Century Information have choosen to cooperate with, the goal is to improve tracking and positioning in an outdoor environment. NCP wants to use the technology for television production to complement the broadcasting with information on the exact position of athletes in sports broadcasting. The company goal is to have a finished product for the alpine World Cup in 2019.

A finalized product is aiming to be used as a platform product where the technology also can be used for assisting visually impaired cross country skiers, using the accurate positioning for guiding the athlete round a surveyed and calibrated track. The company came to the sports technology department at Chalmers, to get support in proving the feasibility of the product for a new area of use. The department has also agreed to perform a competitive analysis of the product.

1.1 Background

By evaluating the current performance of the existing technology, a recommendation on future investments and development can be made. The existing technology also needs to be evaluated on the basis of current competition. NCI is a start-up company trying to break into the sports-tracking market by utilizing a connection with the Technology Provider, a company producing GNSS positioning products. This thesis work is initiated by NCI to gain support from Vinnova, in their appropriation with the scope to create smart electronic systems.

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 broadcast navigation signals. The navigation signals can in its turn be picked up by a GNSS receiver on earth to determine the position and velocity of the device. 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. The differential GNSS is using a reference station with a accurately surveyed position. The reference station is installed temporarily on an accurately surveyed position, calculating 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.[30]

The technology can be applied to several areas. The company producing the units, Technology Provider, is proposing areas of use such as surveying, flying unmanned aerial vehicles, robotics, marine applications, and motor sport. The specifications from the company are rooting for a possible application within tracking of single athletes to provide exact positioning and information. As the device in this project is using differential GNSS and has support for many different satellite systems, the accuracy of the device is of interest to understand other possible areas of application. The application of the technology is considered to be wearable. The concept where to place the device is not yet developed but given the dimensions and weight, see appendix A and B, it is considered feasible to wear while skiing.[40]

1.2 Purpose

New Century Production sees a possibility for providing spectators more information and data on the athletes performance, to complete 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.

GNSS positioning technology can be applied to gather information on the position of the athlete, velocity 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 analyze 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 by the product 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.[26]

The company has together with a partner company, Technology Provider, developed a differential GNSS that is comparatively low cost and small. Now the company wants support in evaluating and testing the product to what needs to be improved and if the technology will meet the product requirements.

As with most surveying procedures, inaccuracies and errors can occur which impair the measured data. This can be eliminated by formation of differences. In differential GNSS with a temporarily installed base station on a calibrated position, correction parameters can be calculated and sent to the mobile GNSS device.

1.3 Present research

In alpine skiing, testing and research is made using the differential GNSS for time measurements and force measurements. The differential GNSS that often are used in these contexts are often expensive and highly accurate 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. 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.[50]

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 analyze training and competition performance.[48]

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 a applicable time measurement method and will provide better opportunities for analyzing the ride than from just the use of photocells for measurements.[47]

Low cost GNSS using lower sampling frequencies have shown not to be appropriate for tracking and time measuring in sports contexts. This goes for devices using a sampling rate of 1 Hz or lower. The reason for this is the distance travelled changes to much during the sampling time.[46]

Differential GNSS using RTK has been developed to be used as a wearable by American students, in a small start up company called Radiosense. The technology is being applied as a wearable in virtual reality products. The research going on is to find a carrier phase reconstruction technique for low power mobile positioning.[31 29 34]

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.

The present research made by the company involves testing and concept proofing along with software development that is leading to the finished product. Much of the effort going down in the project have been accuracy between two or more units. Before the tests performed in this project no calibrated testing had been made. The testing performed gave numbers on exactness among the devices.

New Century Information have been running tests applying the technology on racehorses. The initial idea with the technology was to be able to track the horses on harness races. The intention of the company was to provide television broadcasting extra value in the form of horse tracking. To showcase the tracking technology, the company made graphical representations as well as some accuracy calculations.

The research and testing made by New Century Information have been lacking a proper way of handling data. The evaluation method used by the company when initiating the project was made up of using graphical evaluations of the accuracy. The graphical evaluation has been developed by the company, by calculating a graphical coefficient using a satellite photo of the current position to get a value using the latitude and longitude measurements. This called for calculations of the coefficient for each location that the tests where performed on.[28]

1.4 Limitations

The project is to investigate methods for testing the accuracy. The validation of the performance of the product is done with the goal to fortify a research application that had its due 8/3/2016. The validation will be done through product testing, where the performance of the product will be evaluated.

To further fortify the research application a SWOT analysis of the product will be made. The analysis will be made on both a market level as well as on a technical level. The market level analysis will provide New Century Information with the current status on the market of wearable technology. The SWOT should cover the strengths and weaknesses of the product along with the opportunities that the company has. The threats posed to the company will be made based on the current competitors, creating similar tracking products at the market. The SWOT analysis made on a technical basis will be covering the current product performance and characteristics that needs to be paid some attention in the development work.

The delivery for the company is an estimate of the performance in accuracy along with a proposition for a method in evaluating future developed versions of the product. The accuracy will be expressed in standard deviation and mean error. The company will be provided with a method that will be in the form of an algorithm and a recommendation on software to use for future tests. Two SWOT analyzes delivered will be made both on a market level as well as on a technical level.

2 Theoretical framework

This is the theoretical framework that comprises global positioning and different techniques that are used for positioning. Further it will also explain how the data was processed in order to investigate the accuracy.

2.1 Satellite based positioning

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.

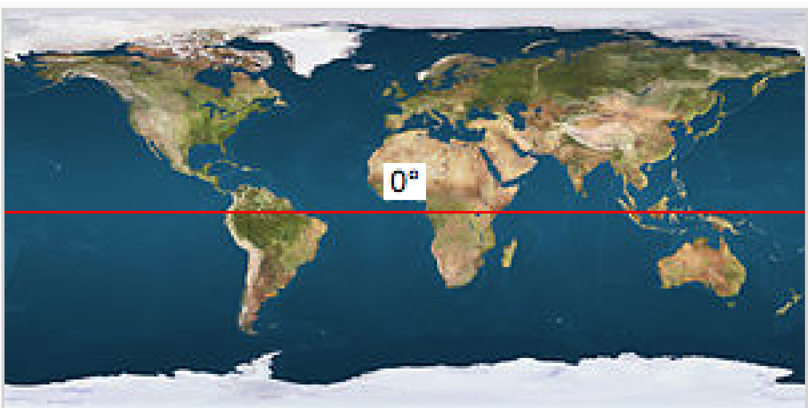

Figure 1: Position of the equator

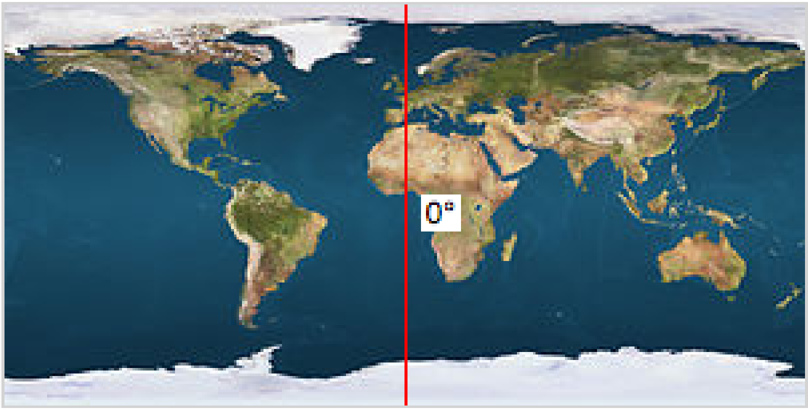

Figure 2: Position of the reference meridian

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, see figure 1. For longitude, the reference meridian is the international prime meridian, see figure 2. This way, every location on earth can be specified by a set of numbers, see figure 4. 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.[30 41]

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 3. 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 $Q = ||Q_s - Q_r||$.[30]

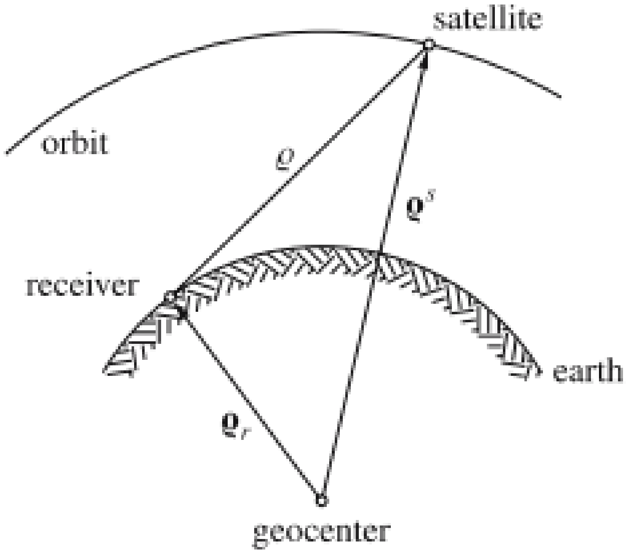

Figure 3: Principle of satellite-based positioning[30]

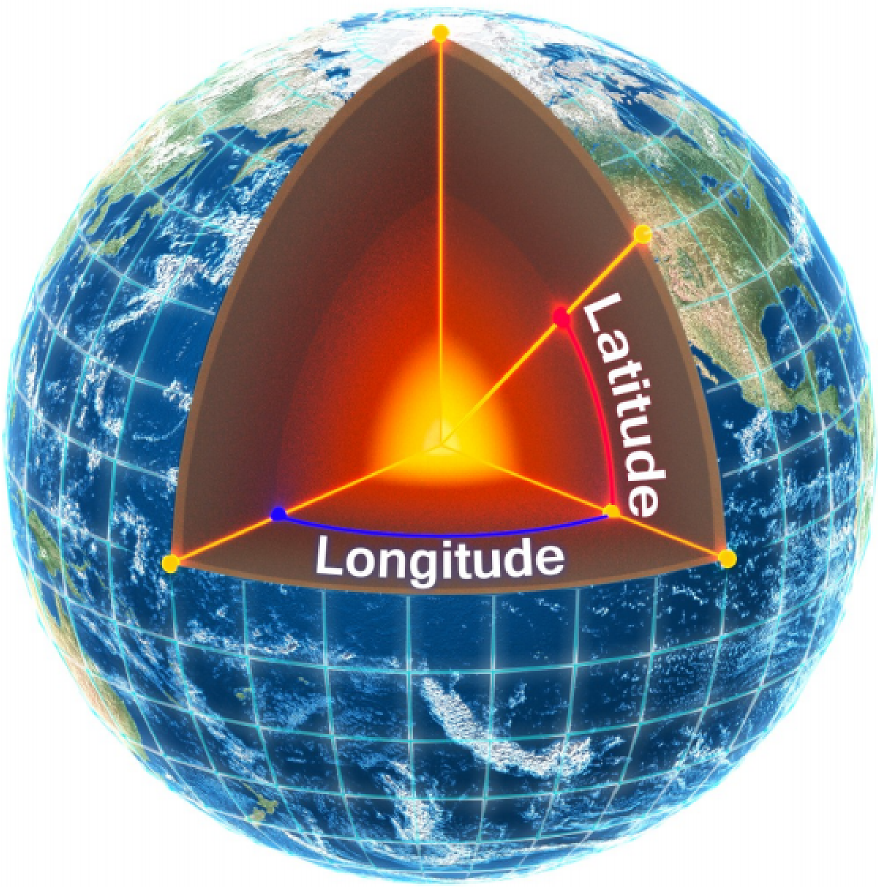

Figure 4: Latitude and longitude, represented visually to describe a position.[41]

2.2 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 orbits 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.

2.3 Differential GNSS

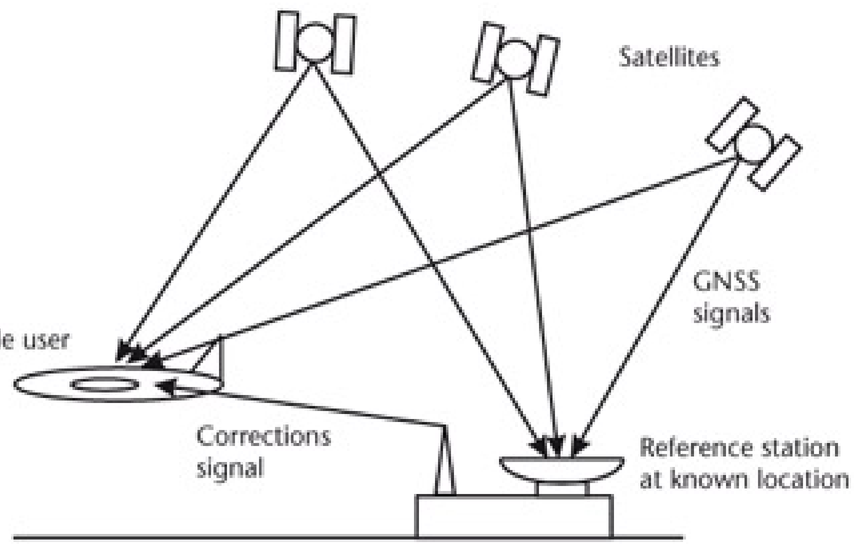

Figure 5: System overview of a differential GNSS

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 5. 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.[27,30]

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 exists, 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.

2.4 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 the Technology Provider, their procedure was to do the transformation to Earth Centered Earth Fixed (ECEF).[42]

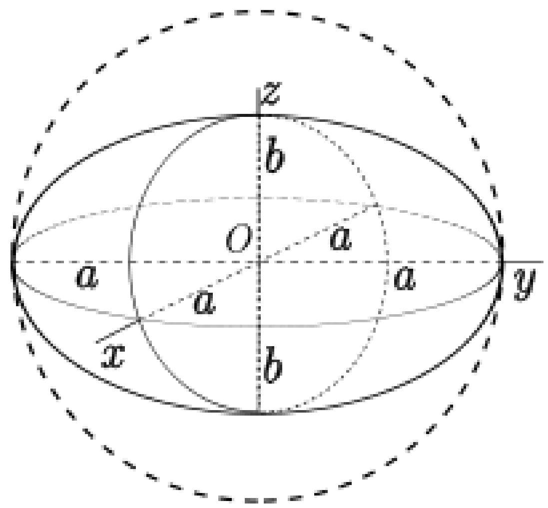

Figure 6: A sphere of radius a compressed into ellipsoid.

This format is useful in calculation of cartesian coordinates when using a non-spherical form. Converting in to cartesian coordinates and consider the earth as a sphere will yield in a systematic error in the measurements as the earth is not spherical, see figure 6. 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 a 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, ω_e and μ, see table 1. WGS84 is globally considered accurate within 1 meter.[30]

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 ellipsiod. The input arguments for LLA2ECEF is [degree, degree, meters], which is fitting for the data set that is provided by the DGNSS examined.[36]

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

Table 1: Parameters of the WGS-84 ellipsoid

3 Research methodology

In this section the research methodology is described. The data collection design together with data handling is described. Further, the choice of doing SWOT analysis is reasoned. The section will also provide with a discussion on reliability and validity of the tests carried out.

The company wanted a swift evaluation of live tests of the products after a recent hardware update. After some investigation on testing methods, it was decided that in order to make a swift investigation the method had to conform to the data processing methods that were available at the time. The data needed to be collected and processed before 8/3/2016. This lead to a measurement method where accurately surveyed positions were calibrated on flat ground and in a ski slope. The flat ground testing was performed on Vallhamra sports facilities and the ski slope of choice was located in Ulricehamn. 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. The setup can be seen in figure 7. By putting the GNSS antenna in the zig zag 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.

Figure 7: Surveying of positions using Leica GS14 GNSS antenna and a handheld Leica CS20 controller.

Earlier testing carried out by the company involved applying the technology on horses, tracking movement around a race course. Tests also involved measurements where two of the same type of DGNSS. This was also performed in this project as tests to compare the relative accuracy. The company has, in cooperation with a programmer, constructed a program that allows the user to observe measurements live and post processing and also observe differences between the devices used. The devices were in this tests put on a fix distance between each other and the program could then give answers on how this distance varied during the tests, see figure 8.

Figure 8: Setup of the devices on Vallharma sports facilities to test relative 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.

In the middle of the project a gathering for engineers in sports technology was attended. Different smaller projects where carried out. Especially one project that was involving a Arduino-based GNSS with a barometer for altitude measurements. The measurements and the accuracy of the unit was made using a Leica GS14 RTK as a reference. The Leica GS14 has an expected accuracy of 8 mm using RTK. By using a specific Matlab code developed to fit the output data from the Arduino GNSS, the accuracy could be evaluated compared to the reference values from the Leica. The measurements where made using continuous measurements, where the data points were synced and then compared in the post-processing.[38]

The company approached Chalmers University of Technology to get support in researching the market of sports tracking devices. The choice of method was a SWOT-analysis. This was considered a good way of getting a grasp of many aspects of the product and its likes and competitors. It would also provide the company with approaches to the product that might not have been considered before. The SWOT analysis is supposed to be used as a planning tool when creating a business venture. By letting an outside connection do this, the likelihood of uncovering aspects that have not been considered yet is better.

3.1 Data collection

The physical testing have been performed on flat ground and in a slope. The flat ground tests were performed for getting a value where an 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 leveled 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.

Figure 9: Marking over an accurately surveyed reference point.

The accurately surveyed points on the sport arena were placed in a zig-zag 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, see figure 9.

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 zig zag 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. The data processing was developed after consultation with the project supervisors.

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 was 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 map-provider.projection.getDistance are the plugins and functions that are used by the program.

3.3 SWOT analysis

The current market for this device needs to be evaluated. The method for analyzing this will be a SWOT analysis where the strengths, weaknesses, opportunities and threats is investigated. This is made in order to examine the potential for a new product. The SWOT analysis can help determine the likely risks and rewards. It should also be used to face its greatest challenges and find its most promising new markets. In this analysis, factors that the company not yet might have considered can be uncovered.

3.4 Reliability and validity

When the method for post processing was created, the time was a limiting factor in reference checking the method. A swift evaluation and getting tests made before the application 8/3/2016 was considered a priority. Therefor there was a need for an easy way of processing the data.

Possible sources of errors in the measurements are corrections not being processed properly by the technical equipment. This will yield a unstable position of the reference station, that is supposed to be accurately surveyed in order to provide the GNSS with further accuracy. When it comes to the calculations, possible errors that might have occurred is whether the points that where calibrated actually where the points used in the calculations. After visually inspecting the points and data used in the calculations yielded in good results, the risk for this should be considered low. When it comes to the measurement of altitude, the reference station was the source of a possible systematic error. The height over ground of the reference station needs to be manually inserted when used. Given that the error was of systematic type, the calculations where made with this in mind. The systematic error was therefor subtracted before run in the Matlab program.

In the transformation from latitude, longitude and altitude the data can be considered valid. The aerospace toolbox from Matlab was used, and the data being put into the program had the correct syntax.

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 analyzed. 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 Δlat and Δlon.

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[32]. 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.

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

Figure 10: 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	5,36952164476987
deltalat	deltalon	deltaalt
3,33842106224904	7,14501974248680	5,36952180951862
3,33844633000937	7,14486740663269	5,36950858370217
3,33842123306515	7,14447025577357	5,36952927648440
3,33845338654232	7,14444035136472	5,36950999071411
3,33844042641703	7,14414465128158	5,36952317336498

Figure 11: ECEF values for tracker 3 at Vallhamra [m].

ECEF diff		
lat	lon	alt
0,42474535000281	0,31264249100715	0,70593960010967
0,35520482999374	-0,06013027302743	0,44273308041909
0,10936423011643	0,02801220704285	0,41405621065138
-0,52863266031267	-0,09054293901301	-0,84045827009049
-0,44831744006046	0,18240398000913	-0,71736559004165
-0,01752713805203	0,07447709320374	0,00098100620960
0,446498777	**0,170206279**	**0,722285353**

Figure 12: Difference between calibrated values and measured values tracker 2 [m].

ECEF diff		
lat	lon	alt
0,07527395995410	0,01546229597693	0,10593448962482
-0,29507358023651	-0,25158225902544	0,36994955010528
-0,07877999985695	0,55066678408267	0,13033865009504
0,82418268965157	-0,40956506000001	-0,30040316012503
-0,42581519998919	0,07890140496514	1,52859511004522
0,01995757390461	-0,00322336680014	0,36688292794906
0,486193835	**0,421209783**	**0,278048924**

Figure 13: Difference between calibrated values and measured values tracker 3 [m].

In figure 12 and 13 in bold, the values are the standard deviation in latitude, longitude, and altitude given in meters. 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.

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 14 the fluctuations in difference can be seen over the 2200 samples. The setup is shown in figure 8.

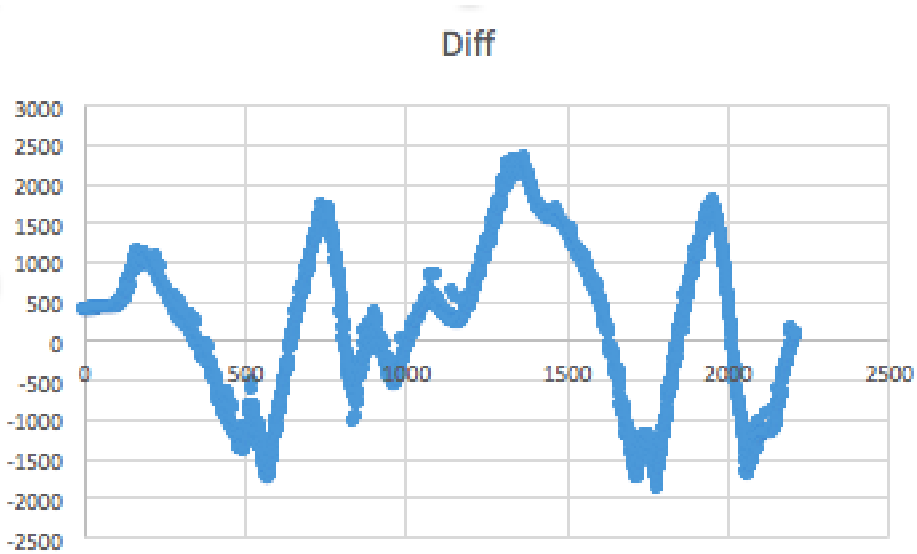

Figure 14: Positioning error, distance [mm] between two units over sample number [n].

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. 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, see figure 2. This accuracy is speaking for a product that can be used with great reliability in the positioning.

1σ	2σ	3σ
68%	95%	99.7%
0.2413 m	0.4826 m	0.7239 m

Table 2: Standard deviation of the measurements from Vallhamra IP

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 figure 15 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.

Figure 15: Run from ski slope in Ulricehamn.

Figure 16: Measurements from Vallhamra sports facilities.

5 Analysis

Presented in the analysis section is the SWOT analysis, performed to support New Century Information with future business ventures. As the project went on, the SWOT analysis parted into two different SWOT analyzes, one with a pure market focus, along with a SWOT with a pure technical focus. The reason for dividing it was because of the findings in the technical aspects that were made during tests and communication with the Technology Provider was important enough to get its own section. Both of the analysis are created with regard to the future development process and covers important aspects of the product. The goal with the assays is to uncover pitfalls so that the company can keep development time down and contribute to the business venture of New Century Information.

5.1 SWOT analysis

In this section a an analysis on the ongoing development and the development being made on a competitor level is made. By identifying the strengths and weaknesses for the product as well as the outlook for the product on the market in terms of competitors and its prerequisites. To complete the current competitor analysis, the product will also be evaluated on a technical base to give the company insights in what needs to be improved before finalizing the product.

5.1.1 Strengths

The development of the product is already producing prototypes. The prototyping is in the second version testing phase. The market of today that is involved in differential positioning is limited which gives this product a head start. Connections with the producing company, the Technology Provider is established. The communication with the producing company gives possibilities for quick changes and expert input and support around the technical aspects, something that is very valuable in the prototyping of the product. This connection has also been valuable in the estimations on future accuracy of the product as they can provide with industry intel on what future satellites could mean for this product.

Similar units used in other applications. The Technology Provider is distributing similar products that are used for other applications where it shows great performance. This speaks for further extension of the product range for the Technology Provider which makes this project be of interest for them.

The technical performance opens up for a platform product, that can be applied in several sporting contexts. The goal for the product is both for real time tracking of alpine skiers and for assisting visually impaired athletes with escort. If a product proves its usability on the sports tracking market, a possibility for an early product on the market to get into new markets with the same technology and exploit its position as first on the market to create a platform product where the same technology can be used with different applications.

The accuracy with the current model is showing promising results. As the product currently supports signals from both satellite systems GPS and GLONASS. GPS has 31 satellites in orbit, and GLONASS has 24[10,9]. The product also have support for signals from Galileo and Beidou 2, satellite systems that will result in another 30 respective 35 satellites[2,7]. This will result in a better signal coverage. The devices will in the future also be used with real time kinematic, RTK, which will yield in an accuracy that is expected to increase with a factor 10 when taken into use[42]. GPS and GLONASS are currently active and the European Galileo satellite program is currently deployed.

Stakeholders from different contexts provides a wide technology base as well as knowledge in areas that will be of great importance in requirements specification of the product.

- New Century Information, technology company involved in developing the product.
- New Century Production, production company and investor in the project. Wants to reach a finalized and implemented product before the World Cup in Åre before 2019.
- The Swedish Winter Sports Research Centre at Mid Sweden University has two primary research foci: sports and performance and sports and health.
- Chalmers University of Technology, Sports Technology group.
- Zebastian Tintin Modin, Swedish cross-country skier, biathlete and Paralympian. Modin will function as specifier of requirements of the virtual escort project along with Jonas Danvind from the Mid Sweden University.
- Swedish Parasports Federation and the National Paralympic Committee of Sweden, both involved regarding the virtual escort for the visually impaired.
- Acreo Swedish ICT is a Swedish research institute within electronics, optics and communication technologies.
- Interactive Institute Swedish ICT is an experimental IT & design research institute dedicated to the creation of user experiences.
- Catapult Sports, a well established company specialized in tracking of team sports athletes. Catapult Sports have expressed interest for a possibility to join the project as a collaboration partner.

The involved stakeholders all have different incentives in the project. The development for a television broadcasting product is mainly driven by New Century Information and New Century Production while the virtual escort has a paralympian athlete for doing the requirements specification and different actors within interactive experiences and user experience to develop a solution for communicating information to the user.

5.1.2 Weaknesses

The current prototype still needs to go through some development. This will affect the time to market and a finalized product. Given the current situation on the market, many emerging companies could chose to go into the market of tracking individual athletes. There are available products already, with possibilities for visualisation. These are however not in the same range when it comes to tracking accuracy.

A technology weakness for differential GNSS is the sensitivity for buildings. Problems in having a signal reaching the base station is something that puts requirements on the base stations surroundings. Another technology weakness is the sensitivity for reflecting surfaces. This could be sheet metal such as buildings but also if the base station is in the vicinity of water. The water tends to reflect the positioning signal and could cause problems with utilizing the full potential of the differential GNSS. These two factors need to be taken account for when placing the base station.

5.1.3 Opportunities

Wearable tech, and being able to measure progress in sports is a growing market. According to Forbes magazine the market of wearable technology is estimated to be worth 34 billion dollars in 2020[35]. The technology used for collection of data used for improving performance will have a growing market the coming years. Big data sets with tools for analyzing and visualizing have been predicted to have a growing market as well[3].

The most similar product on the market comes from Catapult Sports. Catapult is currently only involved in tracking and positioning of team sports. NCI have a well established connection with Catapult Sports, that have expressed their interest in collaborating in creating a tracker for individual sports and athletes. Catapult Sports have also expressed their interest in being a part of the development process regarding this. This is a good opportunity for acquiring knowledge and an established player on the market.

Ski team Sweden alpine is involved in the project which gives the product a gateway for high level users and development input from professionals. With different stakeholders in different projects, and a platform product that can be used as a core product with many areas of application speaks for the product.

The wide distribution of smart phones opens for a product that can be used combined with a smart phone to visualize the data, not only by elite athletes but also recreational athletes.

5.1.4 Threats

Similar products are emerging on the market. Tracking and wearable technology that provides the user with information that creates additional value in the exertion of sports for the single athlete is a segment that many of the bigger sports companies have. Smaller companies are expanding in the segment. In this segment, some of the most notable tracking devices that should be considered threats are described.

Radiosense is a company out of started by researchers in the Cockrell School of Engineering at The University of Texas at Austin with Dr. Todd Humphreys. Radiosense has specialized in Carrier Phase Differential GNSS (CPDGNNS), a Real Time Kinematic (RTK) technology that is pairing data a low cost GPS with the users smart phone, creating a centimeter exact tracking device. Humphreys and his team have spent six years building a specialized receiver, called GRID, to extract so-called carrier phase measurements from low-cost antennas. GRID currently operates outside the phone, but it will eventually run on the phone's internal processor.[34,51]

ZXY Wearable tracking from Chyron Hego are producing high accuracy sports tracking devices with highly sensitive and integrated Inertial Measurement Unit as well as Bluetooth for communication to any other sensors or devices worn by the athlete. ZXY has like New Century Information been involved in horse trot tracking.[43]

Carv is a company that is launching a kickstarter campaign for a alpine skiing tracker, however with different functionality than the product developed in this case. The Carv product lacks the possibility to know where the user is positioned. The sensors are placed in the ski boot, only providing information on the stance and how the weight distribution is changing when riding. The system also have a functionality where video can be combined with the real time data provided by the sensors, opening for possibilities on refine the users technique. Carv have also developed an app that paired with the sensors can provide live coaching for the user.[44,4]

Garmin Fenix 3 is a state of the art GPS watch for multipurpose sports activities, including skiing. The watch keeps track of data such as number of runs, run distance, total descent, and speed. Combined with the GPS some similar functionality exists but does not provide any data that can match the data provided by the product from NCI.[45,8]

Recon Instruments have developed a wearable computer that projects a display in the goggles. The display provides data from a device using a dual-core, Bluetooth and wi-fi with sensors that track speed and distance, the current altitude, vertical drop and accurate airtime data. The GPS functionality in this product seems to be keeping track of the users speed and to locate friends using the same product rather than providing tracking information for improving the performance of the user. The device is equipped with 9-Axis sensors in form of a 3D accelerometer, a 3D gyroscope, and a 3D magnetometer. Together with a pressure sensor, an altimeter and a barometer application the data from the device is extensive and as the company is promising "pinpoint accuracy" on the GPS tracking function future add on functionality is possible. The promised accuracy should not pose a threat using just GPS tracking as this will not achieve the same accuracy as a differential GNSS.[18]

Goggle company Oakley are selling their goggle model Airwave provides possibilities to review your performance stats, like max speed, total vert and max air, in detail, run by run or for the whole day. It also has functionality on navigation, where it is possible to pinpoint the user location on a resort map, find the run or point-of-interest you're looking for. It also provides possibility for tracking other users that have the same device or application on a smart phone. This technology will not provide a comparable accuracy or even functionality and will therefor not pose any threat. However Oakley is a large company that is well established in the alpine sports market and could produce improved versions or other products in the wearable technology segment that could pose a threat.[16]

The company PIQ have developed a sensor is a multipurpose sensor that can be used for many sports including alpine skiing. The sensor for skiing is shipping, February 2016. The waterproof sensor can deliver stats like edge to edge speed, air time, G-force and carving angle. The data can be viewed in real time on Android or iOS phones. This tracker lacks positioning functionality and should not be posing any threat to the tracker used by NCI.[17]

XMetrics are producing a tracking device with data analysis. The data is measured using MEMS sensors and are recorded and transferred over Bluetooth. This technology is applied on swimmers and lacks positioning functionality. The product is not in a competing area, but confirms that the wish for more data to improve the prerequisites for athletes.[21]

Zebra Technologies is in a five year deal where they have developed a location solution for the NFL. The product is developed for accessing and being able to provide both players and coaching staff but also broadcasters and in-stadium displays with data. The data collected is two-coordinate and the data retrieved is implemented today in both broadcasting and coaching.[22][23][25]

Sports Performance Tracking, (SPT), is a company working with GPS tracking for sports teams. The device is delivered with a vest or chest piece that the athlete can carry. The SPT GPS is equipped with data recording with a frequency of 5 Hz and 6.5 hours of match logging. In the software, Gametraka, the user can then view and analyze data such as distance, intensity, and top speed. Currently the technology is used by Australian rugby teams.[19]

GPSports have developed a GPS tracker that measures position, distance, and speed with a 15 Hz sampling rate. GPSports claims to have the only two-way communication system that improves the quality of the data. The provided service around the hardware gives possibilities for analysis for the coaches. The tracking system uses three transceivers that collects data and is collected through an amplified transmitter. GPSports are currently only involved in sports performed on flat ground. GPSports are since 2014 owned by Catapult Sports.[11 12]

Catapult Sports, have since 2010 a patented multipurpose sports tracker. The American ski team have already invested in this technology in order to track speed, acceleration, and G-force. This multipurpose product is also used in sports such as American football, football, rugby, rowing, ice-hockey, baseball, cross-country skiing, mountain biking, snowboarding, and tennis. With a wide implementation and variety of sports along with being awarded a 12th place at Fast Companies "most innovative companies 2015"-list Catapult Sports is undoubtedly one of the best established companies in the segment.[24 5]

Tallysman is a company producing trackers that can be used for sports. Using a multifeed antenna, the accuracy can be improved. The antenna has positioning support for using GPS, GLONASS, BeiDou, and Galileo.[20]

After winning the European Satellite Navigation Competition in 2013, a sports tracking device named JOHAN was put in production. During summer 2015 the device was tested and is now ready for taking requests. The device can measure position, velocity, distance, accelerations, and orientation for coaches, players and physical trainers to analyze. It uses state of the art satellite navigation technology from European Space Agency, (ESA), to ensure reliability and precision.[14 15]

After doing a patent landscape search in order to elicit patent information to determine filing trends and areas of interest, leading actors and intelligence on decision-making support the most viable seems to be Catapult Sports[6]. A Chinese patent was filed by Shanghai Jiaotong University in 2013 but does not seem to have been producing anything from it[13]. Some patents in differential GNSS tracking points towards having other areas of use within alpine skiing such as avalanche detection. This speaks for the product as a platform solution where an accurate device will be the core product that can be used in many different applications[1].

5.2 Technical SWOT

In this section, specific strengths, weaknesses, opportunities and threats on a technical level are presented. This way the technical aspects in the development process can be attended to, while the regular SWOT is treating the business and market aspects of the product. By identifying and precede problems and have a proactive approach in the development process, and keep the expensive late changes to the product to a minimum.

5.2.1 Strengths

On a technical level, the involved people on the company has good knowledge of how to use the product. The company also have contacts with technical competence regarding antennas. As the product is acquired from a company, the technical knowledge is coming from this company to a large extent. All the hardware updates will be manufactured and updated by professionals as soon as the technology is available. This company is also providing with software updates when needed. The company is on top of this also providing technical support, both remote and by doing hardware updates when needed. This makes the down time for a non functioning product low, which is desirable when trying to develop a product and keeping the time to market low.

It should also be considered a valuable asset that the implementation of both differential GNSS and RTK is not wide on the market of sports tracking. Harvesting the technology and being first on the market is favourable, especially when having potential customers and users wanting to be a part of the requirements specification. This will help the development process towards reaching and putting out a finalized product.

5.2.2 Weaknesses

The current technology is limited in credibility as random numbers and systematic errors occur. This calls for ongoing quality check ups to ensure that the data collected is in order.

The test data needs to go through extensive post testing processing to be able to study possible sources of error. By developing a test method, this time could be reduced and improvements can more easily be recorded. This will in its turn faster provide the company with feedback and the possibility to reach out to possible customers, presenting their technology.

The current version lacks a possibility for data recording, only live tracking is possible. The transmission of data resolution of live tracking is high in the current version is not as high as the hardware permits. The transmission rate is what limits the current version of the device. This is however a conscious decision from NCI, to keep the weight down. The products could be updated to be able to record data in future prototypes if this is considered to be of importance. As the product is going to go through hardware updates, implementing real time kinematics (RTK) during 2017, other hardware updates is still possible.

The battery time of the devices needs to be evaluated. As the devices are updated, the battery time might change. The slimmer and more lightweight a device needs to be, the slimmer the battery will need to be. Coupling this with power-intensive tasks such as position and tracking, the performance can suffer. It is also possible to change settings on what to measure. As the devices have various different sensors, the energy consumption on these needs to be taken in account. Making sure that what is measured is made use of is a way of saving energy for what is necessary for the tests and in its applications.[39]

5.2.3 Opportunities

The competition in differential GNSS trackers that are ruggedized and fit for using in sports tracking is limited. The technical opportunities are many in terms of being first on the market in tracking with this accuracy.

By taking advantage of the cooperation with the producing company the technical development and hardships occurring can more easily be resolved and the time to market can be kept short. Doing this, it will be crucial to keep good business relations with the producing company.

The company has a good opportunity to be the first on the market in differential GNSS. The accuracy that will come with implementing RTK will make them head of sports tracking if being able to finalize a product and make it reach the market in low development time.

5.2.4 Threats

The positioning of the reference station is vital for acquiring optimal signal when transcieving to a GNSS rover. The reference station itself can experience trouble in getting coverage. Factors such as the weather and vicinity to water or other reflective surfaces might cause signal disturbance. Since water and reflective surfaces previously have caused trouble in the path of the rovers, investigation on performance on ice needs to be done as the slopes in ski racing often are prepared to be icy.

The implementation of Real Time Kinematics (RTK) is a prospect development that is going to be made by the Technology Provider. This implementation itself might lead to problems arising, which needs to be taken in account in the development process.

For covering larger areas of tracks in for instance cross country skiing, the differential GNSS will need to be able to shift from one antenna to another. This functionality is according to the Technology Provider already implemented. However, the technology needs to be evaluated in the environment to ensure accuracy and flawless transitions between antennas.

The project needs to specify what accuracy is wanted in order to deploy the technology. Putting together a requirements list will help in deciding when to stop the development, when the accuracy is sufficient. Making a requirements list for both the virtual escort as well as the tracker for alpine sports will give a indication on the development effort that have to be put in the project. This can also indicate whether differential GNSS is a good investment or if an accurate regular GNSS device will be sufficient. It will also indicate whether investment in implementing RTK is necessary.

The project currently lacks a fast way of evaluating the technology, or seeing how improvements are made. A general recommendation for faster evaluations on technical software and hardware updates is to acquire a technique or a software to make swifter evaluations on the changes.

6 Discussion

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

6.1 Discussion of measurements

Early in the project, there was a wish for the testing to be made to verify the accuracy of the product as soon as possible. This was to ensure that data could be provided for the research application that was made to Vinnova. After some research on methods of how to translate the data available, it was after consultation with both supervisors from Chalmers and New Century information 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 measurements 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 by the company. 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 as the projects not yet have translated their requirements and future areas of use into a value to aim for. By doing this, the company can decide when the development process can be considered ready for the market.

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 by the company. Earlier measurements performed by New Century Information 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. No where in earlier research have a product proven itself using a technique like this, and neither will 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 to remember from the testing in the ski slope 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 15 can be because of this problem. The rover have 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. This was something that was updated during the project span. After this software update, the data collection have been considerably better. Data collected and inspected visually suggests that the accuracy has improved since, see figure 17.

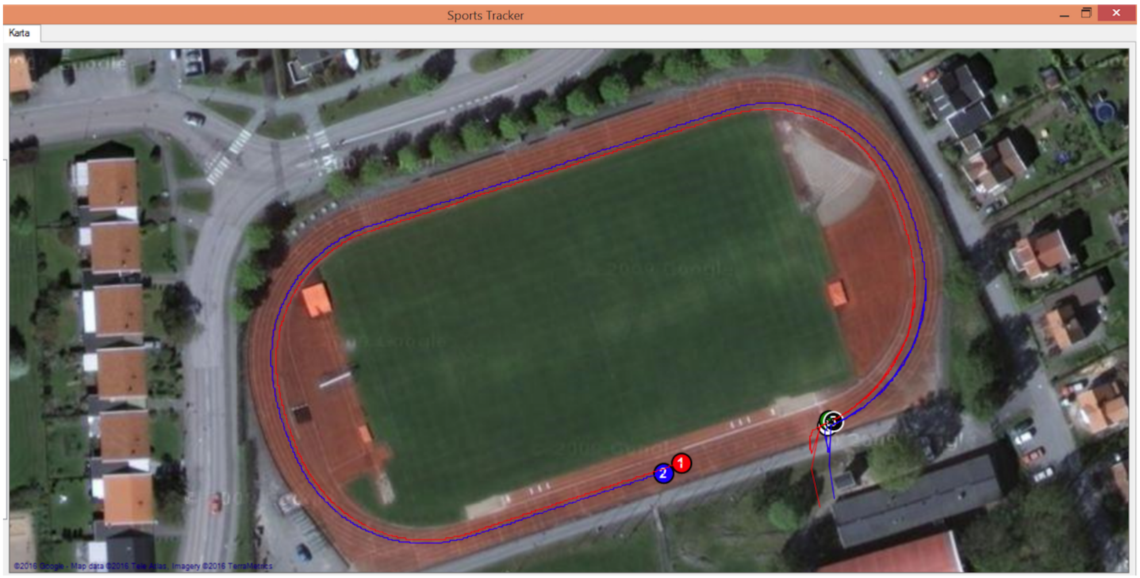

Figure 17: Measurement from Vallhamra sports facilities after software update to resolve problems with differential fix.

After taken part in ISEA winter school, where prominent researchers within positioning in sports assisted, alternative methods for measuring occurred. 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 3500 dollars = 30800 SEK.[37][33]

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 a 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.

6.2 Discussion SWOT

Wearable tech is an expanding market and the rate of emerging companies is high. Given how far New Century Information has come with the development and the contacts made with key players in the business and expert personnel, the chance of reaching a finalized product should be considered good. Threats such as time to market for a finalized product is of course impending. However, involved contacts in this project speaks of no current development on the Swedish market which is increases the possibility of getting a good start in Sweden. Both hardware and software development needs to be propelled, along with accessory products around the technical platform.

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. Many of the wearable technologies found in the SWOT could all be a competitor to the product of New Century Information on one market or the other. These products are finalized and on the current market which puts demands on having a technological edge on the product from NCI.

the Technology Provider have communicated an increase of the accuracy when additional satellites are deployed. This speaks further for the fact that the technology will satisfy the future requirements on accuracy. By specifying the requirements this update could be made while the rest of the development process continues. By being able to perform the different development processes in parallel will facilitate a shorter time to market. Evaluating the accuracy will not be the only part of realize a product, but when needed the evaluation should be possible to perform smooth and easy. Once again, the importance of having a way of evaluating the accuracy becomes evident.

7 Conclusion

Wearable tech is an expanding market and the rate of emerging companies is high. Given how far NCI has come with the development and the contacts made with key players in the business and expert personnel, the chance of reaching a finalized product should be considered good. Threats such as time to market for a finalized product is of course existing. However, involved contacts in this project speaks of no current development on the Swedish market which increases the possibility of getting a good start in Sweden. Both hardware and software development needs to be propelled, along with accessory products, such as virtual escort technology, around the technical platform.

the Technology Provider have communicated an increase of the accuracy when additional satellites are deployed. This speaks further for the fact that the technology will satisfy the future requirements on accuracy. Along with the technology update in form of real time kinematics, the accuracy is expected to improve further. The question that New Century Information needs to ask themselves is when the accuracy can be considered to be enough for its intended area of use.

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.

8 Managerial implications

This section will address how the researcher believes how the future development of the product should be done in order to reach a finalized product that can be utilized in the different contexts suggested by the company.

The study was supposed to provide the company with an analysis of the accuracy of the current technology, along with a SWOT-analysis. The method for evaluating the accuracy in this study was considered sufficient by both the tutor and the company supervisor. After documentary research and conferring with prominent researchers in the field, it was established that there are methods that are more recognized. In order to have an investigative approach to future development, it is proposed to use a established method for future tests.

8.1 Recommendations

The project will enter new phases where the technology is going to be used in different ways. By establishing a wanted accuracy in these different projects will make it possible to realize when the development is ready to be taken into the next phase. To strive for good accuracy without an aim will make it possible to never stop try to improve the accuracy. To ensure an early market introduction, it will be crucial to get the technology sufficient for the intended purpose and thereafter move on.

If one of the intended areas of use shows to have a higher demand on the accuracy, the development of the product can be made in parallel, cutting development time. Therefor it should be considered crucial to make the requirements specification for both of the separate parts of the project. In all development projects it is important to translate demands and wishes on a finalized product into a requirements specification made up of numbers or factors that can be measured and verified. By getting a number on how accurate the technology needs to be, it will be tangible when the development of the positioning technology is finished. This requirements specification will also provide the development project with a physical representation of what the accuracy will mean practically.

An investment in a software for evaluations of accuracy. Dedicated softwares for this can provide a fast evaluation. the Technology Provider are using Matlab, but a more reasonable investment to do in this case is probably to use a dedicated software for GNSS evaluation. Justin Javad, RTKLIB, GPSTk, trackRT, Bernese and Trimble are all examples of softwares that can be used to evaluate accuracy of GNSS devices. Among them are several open source softwares, as well as license software that can be used for this application.[49] This consideration needs to be made on a basis of what software proficiency that is available in the company. If choosing Matlab, development costs will follow with the investment. On the other hand, using an open source software might put demands on further software development. These numbers are just put as an example for the company to chose side. The main focus from the company is to have someone who have knowledge in the technology they choose.

In order to maintain the technical advantage, New Century Information should consider making the investments in updating their technology to Real Time Kinematics. As many of the competitors have tracking possibilities with varying accuracies, it should be considered a profitable investment to be first in the area of sports tracking using differential GNSS with RTK, improving the accuracy and creating a product that currently lacks competition on the market. the Technology Provider have lobbed for this update and it will be made during Q1 in 2017 if everything goes according to plan.

In order to facilitate the technical support from the Technology Provider, New Century Information should consider establishing a formal business relation. In order to to ensure feedback and technical support from the Technology Provider, and to faster resolve technical difficulties. The current proceed where a question takes one-two weeks to get answered does not facilitate a fast development process. A formal business relation where technical support is a way of faster moving forward in order to not grow stagnant in the development process.

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. In the next section a specified algorithm will be presented. 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 analyzed 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.

8.2 Proposed method

1. Always use the data of a calibrated differential GNSS RTK as a reference value. The calibrated differential GNSS RTK can be carried in a backpack

and the while the unit for instance can be put on the head.

2. When doing the actual tests it is favourable to have a trigger signal, to be able to identify the starting point. It could for instance be to walk, run or ski perpendicular to the slope one way and then back in the same tracks, to indicate that the data collection has begun.

3. Analyze the data using a specified software. This could also be created in matlab. The proposal is to calculate standard deviation and mean error as values of comparison.

4. Run a similar track every time. It is a good idea to perform tests at the same time of the day and in the same geographical location in order to keep the uncertainties from satellite coverage and change in measurements of the reference ellipsoid to a minimum.

5. Using the same track every time, for instance a specified line on a sports track, will make it possible to run the same evaluation programme every time.

Create a reference track using an accurately surveyed differential GNSS with RTK. This track could be created along the line of a track on Vallhamra sport facility, see figure 18. Surveying the track could be made by Leica for hire, in order to get the data on the right format. The measurements should be made continuously.

Figure 18: Lines along a running track.

When comparing the collected values it should be considered to have a visual trigger signal for when the comparing should begin. The synchronization between the measurements can then be made by identifying the visual trigger and also the data from measurements of satellite clock.

The data collected is synced and then transformed into ECEF form. By using ECEF form, the most correct representation of the earth, see figure 6. This transformed data will then be compared. The difference between the two values will be extracted. In the comparison the value is saved. The code will come to a gate, asking whether all data available is processed. If there still is data to process, the algorithm will be put back in the loop to before the synchronization. This way, the data-sets will be synchronized using satellite clock once again. This way, if the data-points are collected using different sampling frequencies, the data-sets will always be in sync. If all data is processed, the algorithm will break and the output of the comparisons will be a set of data with differences, expressed in meters. From this data-set mean error and standard deviation is easily extracted. The flow diagram of the algorithm can be seen in figure 19.

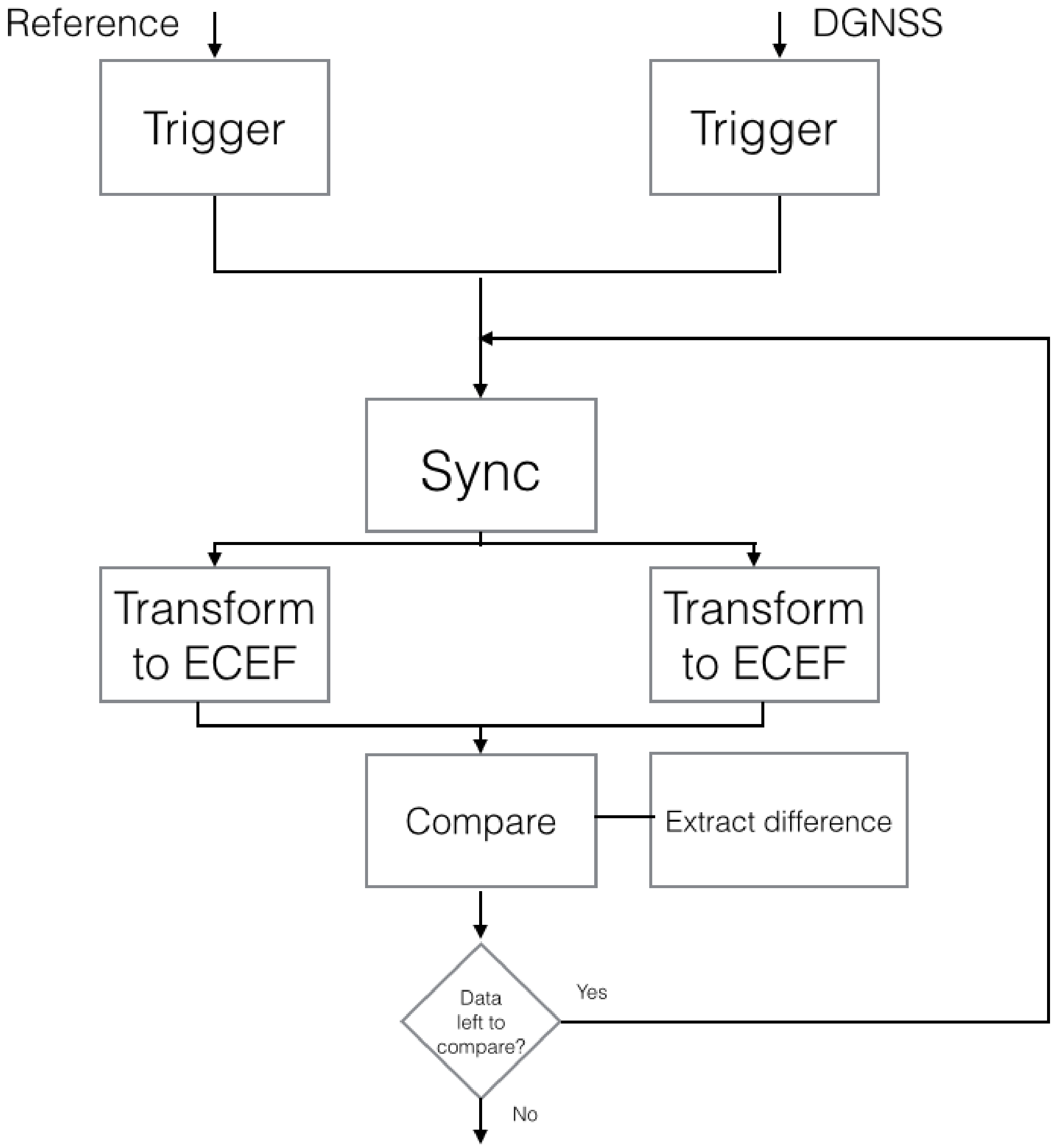

Figure 19: Algorithm for evaluation of accuracy in future tests.

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A Spatial Data Sheet

ADVANCED NAVIGATION

POSITIONING EVERYWHERE

SPATIAL

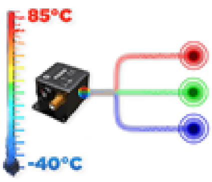
Spatial is a ruggedized miniature GPS aided inertial navigation system and AHRS that provides accurate position, velocity, acceleration and orientation under the most demanding conditions.

It combines temperature calibrated accelerometers, gyroscopes, magnetometers and a pressure sensor with an advanced GNSS receiver.

These are coupled in a sophisticated fusion algorithm to deliver accurate and reliable navigation and orientation.

WWW.ADVANCEDNAVIGATION.COM.AU

CALIBRATED DYNAMIC RANGING SENSORS

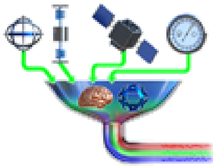


Spatial contains some of the highest performance MEMs inertial sensors currently on the market. These are put through Advanced Navigation's intensive calibration process to increase their performance further still and provide consistently accurate data over an extended temperature range of -40°C to 85°C. Advanced Navigation's custom calibration process is the only full sensor calibration that can provide dynamic ranging, allowing the user to select a sensor range for high accuracy or high accelerations on the fly. As part of this calibration, every Spatial unit spends 8 hours in our specially built rotating temperature chamber.

RELIABILITY

Spatial has been designed from the ground up for mission critical control applications where reliability is very important. It is built on top of a safety oriented real time operating system and all software is designed and tested to safety standards with fault tolerance in mind. The hardware is protected from reverse polarity, overvoltage, surges, static and short circuits on all external interfaces. The GNSS contains RAIM, which excludes both malfunctioning, and tampered satellite signals.

ADVANCED FILTER

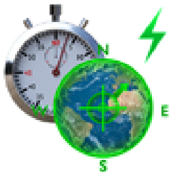


Spatial contains Advanced Navigation's revolutionary sensor fusion filter. The filter is more intelligent than a typical extended kalman filter and is able to extract significantly more information from the data by making use of human inspired artificial intelligence. It was designed for control applications and has a high level of health monitoring and instability prevention to ensure stable and reliable data.

MULTI CONSTELLATION GNSS

Spatial's next generation GNSS receiver supports all of the current and future satellite navigation systems including GPS, GLONASS, GALILEO and BeiDou. These additional satellite constellations allow Spatial to provide accurate position and velocity data in environments where GPS only units can't, such as urban canyons and indoors. When Spatial can't get a satellite fix, it continues to navigate using inertial navigation.

HOT START



Spatial contains a next generation battery backup system that allows it to hot start inertial navigation from its last position in 500 milliseconds and obtain a GNSS fix in approximately 3 seconds. The battery backup system lasts for the lifetime of the product and will provide backup for 48 hours without power. Spatial is the first GNSS/INS in the world to provide hot start navigation.

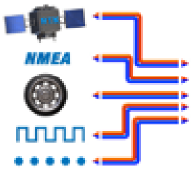
MINIATURE RUGGED ENCLOSURE

Spatial's precision marine grade aluminium enclosure is waterproof and dirtproof to the IP67 standard and shockproof to 2000g, allowing it to be used in the most extreme conditions. A sophisticated venting system allows the unit to measure air pressure whilst keeping water out. Its minimal size, weight and power requirements allow for easy integration into almost any system.

HIGH UPDATE RATE

Spatial's internal filter runs at 1000Hz and data can also be output at this rate over high speed RS232. This allows for control of dynamically unstable platforms. Spatial is also highly tolerant of dynamic movement and vibration with a very advanced custom navigation filter.

PERIPHERALS



Spatial features two general purpose input output pins that support an extensive number of peripherals. Including odometer based input for ground vehicles, RTK GPS systems, DVLs and USBLs for underwater navigation, NMEA input/output and more. For an integration fee, custom peripheral devices can be added.

NAVIGATION

Horizontal Position Accuracy	2.0 m
Vertical Position Accuracy	3.0 m
Horizontal Position Accuracy (with DGNSS)	0.6 m
Vertical Position Accuracy (with DGNSS)	1.0 m
Velocity Accuracy	0.05 m/s
Roll & Pitch Accuracy (Static)	0.1 °
Heading Accuracy (Static)	0.5 °
Roll & Pitch Accuracy (Dynamic)	0.2 °
Heading Accuracy (Dynamic with GNSS)	0.2 °
Heading Accuracy (Dynamic, Magnetic Only)	0.8 °
Heave Accuracy	5 % or 0.05 m (whichever is greater)
Orientation Range	Unlimited
Hot Start Time	500 ms
Internal Filter Rate	1000 Hz
Output Data Rate	Up to 1000 Hz
Latency	0.4 ms

GNSS

Model	u-blox M8
Supported Navigation Systems	GPS L1 GLONASS L1 GALILEO E1 BeiDou L1
Supported SBAS Systems	WAAS EGNOS MSAS GAGAN QZSS
Update Rate	10 Hz
Cold Start Sensitivity	-148 dBm
Tracking Sensitivity	-167 dBm
Hot Start First Fix	1 s
Cold Start First Fix	26 s
Horizontal Position Accuracy	2.5 m
Horizontal Position Accuracy (with SBAS)	1 m
Velocity Accuracy	0.05 m/s
Timing Accuracy	30 ns
Acceleration Limit	4 g

COMMUNICATION

Interface	RS232
Speed	4800 to 1M baud
Protocol	AN Packet Protocol or NMEA
Peripheral Interface	2x GPIO and Auxiliary RS232
GPIO Level	5 - 20 V
GPIO Functions	1PPS Odometer Stationary Pitot Tube NMEA input/output Novatel GNSS input Trimble GNSS input AN Packet Protocol input/output Packet Trigger Input Teledyne DVL input Tritech USBL input Custom (contact us)

HARDWARE

Operating Voltage	5 to 36 V
Input Protection	±40 V
Power Consumption	100 mA @ 5 V(typical)
Hot Start Battery Capacity	> 48 hrs
Hot Start Battery Charge Time	30 mins
Hot Start Battery Endurance	> 10 years
Operating Temperature	-40 °C to 85 °C
Environmental Protection	IP67, MIL-STD-810G
MTBF	> 50,000 hrs
Shock Limit	2000 g
Dimensions (excluding tabs)	30x30x24 mm
Dimensions (including tabs)	30x40.6x24 mm
Weight	37 grams

SENSORS

SENSOR	ACCELEROMETERS	GYROSCOPES	MAGNETOMETERS	PRESSURE
Range (Dynamic)	2 g 4 g 16 g	250 °/s 500 °/s 2000 °/s	2 G 4 G 8 G	10 to 120 KPa
Noise Density	150 ug/√Hz	0.005 °/s/√Hz	210 uG/√Hz	0.56 Pa/√Hz
Non-linearity	< 0.05 %	< 0.05 %	< 0.05 %	-
Bias Instability	20 ug	3 °/hr	-	100 Pa/yr
Scale Factor Stability	< 0.05 %	< 0.05 %	< 0.05 %	-
Cross-axis Alignment Error	< 0.05 °	< 0.05 °	< 0.05 °	-
Bandwidth	400 Hz	400 Hz	110 Hz	50 Hz

B Spatial Reference Manual

8 Specifications

8.1 Mechanical Drawings

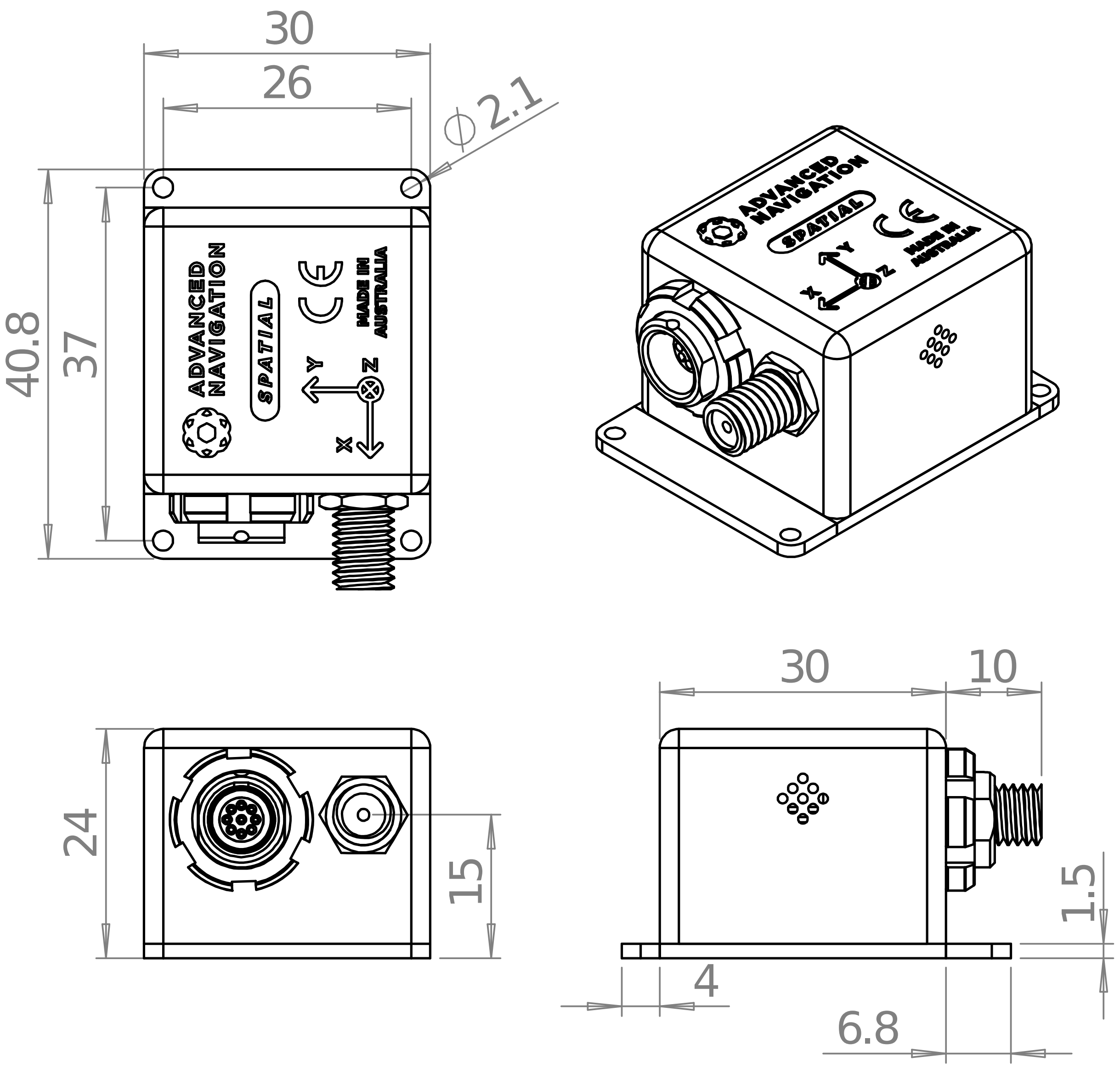


Illustration 14: Mechanical drawings of Spatial

8.2 Navigation Specifications