Evaluation of Navigation Satellite Systems for Forestry and its Precision in a Forest Environment

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Abstract:
The Swedish forestry industry is dependent of reliable positioning in the forest since much of the information in the supply chain carries positioning data. Correct coordinates are needed for the survey of the site, information of the harvesting and forwarding progress as well as positioning of road side inventory. The position data should also be able to save e.g. for planning purposes to be used throughout the forest production life-cycle. One way of providing position data is through the use of Global Navigation Satellite Systems (GNSS) where the most accurate equipment and strategies provide positions of order 1 cm accuracy in fair conditions. The GNSS equipment currently being used on the machines in the forest is however often more basic equipment that at best may provide accuracies of order 10 m under the same conditions, and often worse. In addition to the antenna, receiver and other technical equipment many factors affect the positioning quality; the forest environment itself causes uncertainty in the positioning due to tree trunk blockage of signal paths, reflections from trees, etc. Currently there are two operating GNSS systems: the American GPS and the Russian GLONASS systems. Today only GPS is being used, but with more systems emerging in the near future (e.g. the European Galileo system) the availability of satellite signals for positioning will increase significantly in the forest environment. The aim of the project is to evaluate the current accuracy of the positioning as well as compare stand-alone GPS with multiple GNSS system solutions in the forest environment. The project will also suggest techniques for improving the accuracy and robustness of the positioning suitable for the forestry field of application. The project will contribute with improvements of information flows through the whole value chain, making use of reliable positioning data. It will also provide input for ICT based systems to increase logging efficiency and minimize ground and soil impacts. Additionally, costs through misleading positioning in timber transport will be reduced and the traceability of timber and forest products will improve. The project will be ongoing during spring and finalized during the summer 2012.

Keywords: GNSS, machine guidance, positioning in forest

1 Introduction

1.1 Background

With an increasing amount of information and degree of automation follows a dependence on reliable position data. The increased digitization of information flows put higher demands on the documentation for various operations, and in the last decades, the emergence of Global Navigation Satellite Systems (GNSS) has become an increasingly important factor for positioning of all kinds. For example, it should be possible to use decision support systems based on proper coordinates as well as to reuse the coordinate sets in maps of different digital directives. The background to the project idea is born out of experience from previous forwarding optimization of forwarding routes using mathematical models (Jönsson et al. 2011) together with an increasing interest from the forestry to examine whether the positioning is generally comprehensive and adequate. What is meant by sufficient degree of accuracy and coverage varies depending on the users in forestry. Different opinions exist on this matter. For this example, to be possible to use e.g. decision support systems and re-using the coordinate set maps to find and reuse main extraction and strip roads, users in forestry will need to know that it is possible to orient themselves with sufficient precision to find and distinguish the different roads. The same is true in order to avoid soil damage and impact on sensitive land marked in digital maps. The technical equipment varies between machines, but the basic components are the same, i.e. an antenna, a receiver, and computation software that can employ the chosen strategy efficiently. Accurate positioning requires good technical equipment, but also sufficiently good reception conditions. Position determination is affected by environmental impacts on the received GNSS signals and the forest environment in the local environment is likely a dominant factor. The availability of satellite signals is also affected by the geographic position, and what is considered sufficiently good conditions is determined by the user's need today and may change in the future.

This first study is one of more coming studies to evaluated positioning precision and quality of signals as well as evaluating different conceivable systems in forestry.

1.2 Positioning systems

Various systems exist on the market and are in use in different part of the world. Below are some short explanations of different techniques.

GNSS - Global Navigation Satellite System. GNSS is a generic name for a navigation system which uses signals from satellites for positioning.

GPS - Global Positioning System. It is maintained by the United States government, is freely accessible and used world-wide.

GLONASS - Global Navigation Satellite System. Maintained and operated by the Russian government. Less known, but complements and provides an alternative to the GPS with higher satellite elevation and enhanced coverage on higher latitudes (e.g. Sweden).

Galileo - A satellite navigation system under construction by the European Union with estimated start time 2014.

COMPASS - The Chinese satellite system comparable with GPS and GLONASS.

To be able to establish a three dimensional position estimate with GNSS, signals from four satellites are required to calculate time, latitude, longitude and height. Correspondingly, to reach a two dimensional solution, i.e. latitude and longitude, three signals are needed. Today's commonly used GNSS systems have an accuracy of 30 m in real time, but often much better. In some applications 30 meters accuracy can be enough, but the decision support systems of today already claim a higher accuracy than described above. The future with its advanced decision support systems will call for a better precision and accuracy of the positioning in forest.

2 Material and methods

2.1 Field study

Field testing will and have been done to collect data from different harvesting conditions and geographical locations to evaluate the accuracy of current systems in the signal in terms of challenging environment in the forest terrain. The different forest types, mostly consisting of Norway spruce and Scots pine, and what kind of harvesting operation will be done can affect the quality of the possibility to reach correct signals, or observations, of today. A final felling will pave the way for the signals but in thinning, the situation will be different. The forest canopy together with reflections from the machines and trees will affect the potential number of unperturbed signals to reach the antenna. In the figures below you can see a quite common canopy on a Swedish spruce stand.

Figure 1: Crown ceiling of Norway spruce stand

Figure 2: Norway spruce stand to be thinned

The field studies examine how much of the time it is possible to make the positioning with GNSS, and when it is possible to receive a measureable satellite observation. In a field study the quality of satellite and position data over time will also be examined. The possibility to improve the position determination with two receivers and antennas with a certain separation will be evaluated.

The test performed was done in Östergötland, in the southern part of Sweden with Holmen skog as land host. The antennas were installed on the harvester machine at the front of the roof. The receivers were installed and started the collection of data. The data was collected during a double-shift working day. The harvester worked in ordinary production without yield to GNSS considerations and the signals were collected with a 5 second sampling interval. Both the antennas used in the test received signals from the GPS and GLONASS systems simultaneously.

2.2 Positioning equipment

Used in the field tests were a setup of two GPS antennas and two receivers, see figures three and four. Mounted on the antenna foot is a strong magnetic foot for an easier installation. The antenna and receiver are depicted below. By using two GPS antennas it is possible to measure both the number of received satellite signals as well as analyzing what improvement of quality is obtainable by equipping the machines with two antennas.

Figure 3: Placement of the antenna on the harvester roof

Figure 4: GNSS receiver

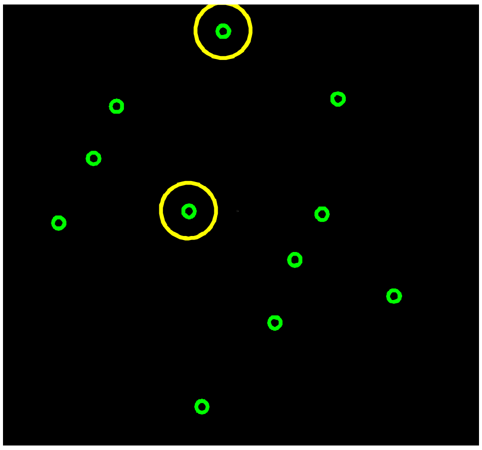

Figure 5: GNSS observation model illustration for a single antenna (black dots and numbers are the azimuth and elevation from the antenna standpoint; green circles are satellite almanac snapshot data from an arbitrary day at a location corresponding to the investigated area; yellow circles indicate unperturbed signals; the photo overlay is not calibrated to scale)

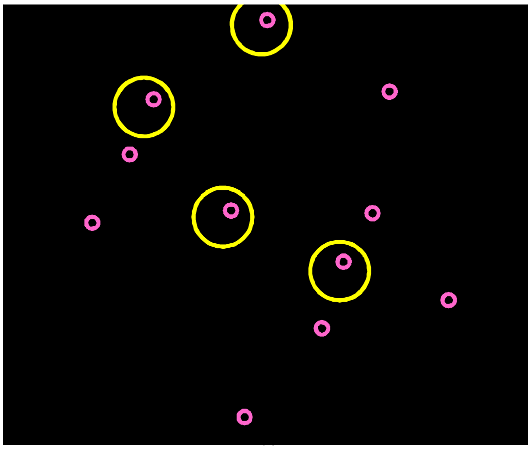

Figure 6: Corresponding observation model to Figure 5, but with two antennas (a position shift of order 1 m on one antenna makes a new relation to the near-field canopy but doesn't affect the relation to the far-field satellites (pink circles and the corresponding azimuth/elevation-grid); with this operation, more satellites appear in the canopy windows to provide the sufficient number of satellites for a position estimate)

Keeping in mind figures one and two with the dense canopy, the hypothesis that two antennas can give a better distribution under the crown ceiling to receive more signals is tested empirically. The more signals received, the higher degree of over-determination and hence the more reliable position estimate can be obtained. Below are two pictures, figure five and six, to illustrate the idea. As can be seen, comparing the right figure with the left indicates more possible signals having two antennas and better opportunities for a free sight.

This is the motivation to study whether two antennas can be utilized as a diversified antenna to receive more satellite signals in order to obtain a position estimate in adverse conditions.

3 Results

The figure 7 displays the number of observed satellites from GPS and GLONASS during the field study and shows how the number of satellite observations varies over time. The blue and red lines show the signals for the two antennas separately. The green line shows how many satellites were observed in total using two antennas. What can be observed is that using one antenna, the number of observed satellites varies significantly. No matter which one of the antennas, the number or observed satellites varies from two to more than 15 over the time studied. This indicates that the one-system single-antenna in common use is unable to provide sufficient data for a reliable position estimate. Since the quantity of observed satellites reflects the obtainable quality, this indicates a deficient precision even for today's use. Using two antennas appears to be able to improve the situation. The green lines in figure 7 shows the total number of observed satellites given from using two antennas. What can be seen is that in this field study, we reach at least five observations all times.

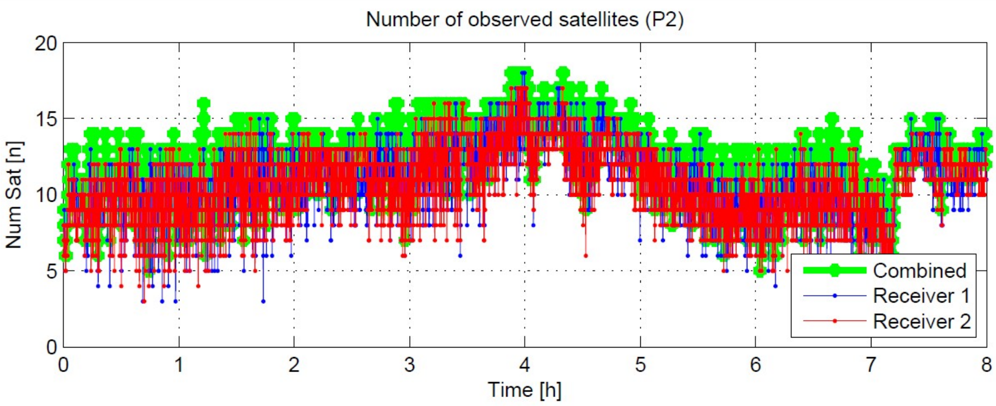

Figure 7: Number of observed satellites over time

Most of the time a relatively good observation can be reached compared to using only one antenna remembering that a minimum of four signals are needed for a three dimensional position. Given the adverse signal reception conditions and the fact that the combination of two separate systems sacrifices one satellite to sync the two system times, we assume that six satellites are needed in order to obtain a position with a minimum of over determination. What can be seen is that two antennas actually gain more observations for positioning at almost every instant and that the hypothesis of improved signal reception appears to be valid.

Looking into the figure 8, which represents the number of extra satellites observed using two antennas, it can be seen that for a larger portion of time, two antennas contribute with more satellite observation than one does. Here the comparison is done with antenna "one".

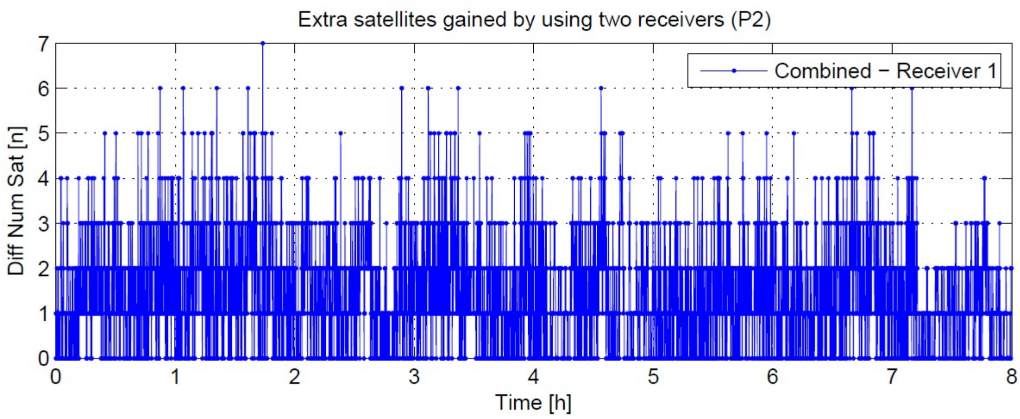

Figure 8: Number of extra satellites gained using two receivers

The figures 9 and 10 show the number of satellites in percent of time. The black lines show the GPS observations for each antenna, Rx1, in one figure per antenna. The red lines in the figures show the combination of GPS observations and GLONASS observations for each of the antennas separately.

In figure 9, the current forest machine situation with a single system GPS receiver (Rx1, black line) is compared to an improved situation with dual system receivers (GPS and GLONASS combined) for the two individual receivers Rx1 (blue) and Rx2 (red). Additionally, the combined receiver system is indicated in green. Critical are the cases with a small number of satellite observations. Given the assumption that position needs to be determined with some redundancy, and those 6 satellites therefore is a reasonable request, it can be seen that for the current forest machine, this is obtainable at only 75% of the time. Should the system be complemented with GLONASS receiving capabilities, this 6 satellite requirement can be obtained at 98% of the time. Should the diversified antenna concept be used, 8 satellites would be available 98% of the time, to improve the position redundancy situation further.

Looking at figure 10, another development scenario is depicted. The reference situations of a single-system one-antenna receiver (black) and a dual-system double-antenna receiver (green) are the same as in figure 9. Here however, the blue line indicates the potential of a single-system dual-antenna receiver, which increases the number of available satellites by approximately one. For critical cases with a low number of available satellites, a receiver with combined GPS and GLONASS capabilities (red) will receive almost the double amount of satellite signals. As said before, to obtain a good precision in positioning, at least six satellite observations are needed. Six satellites are needed but not optimal 75% of the time, at least observations from six satellites are collected at the filed field study in Östergötland. Since it is situated in the south of Sweden, this precision is likely better than in a comparable stand in the north of Sweden.

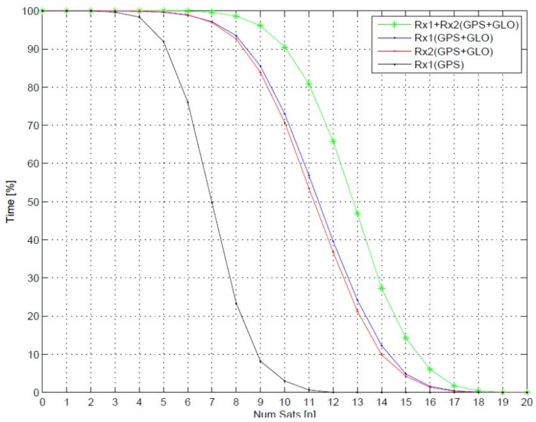

Figure 9: Number of satellites observed over time, different cases

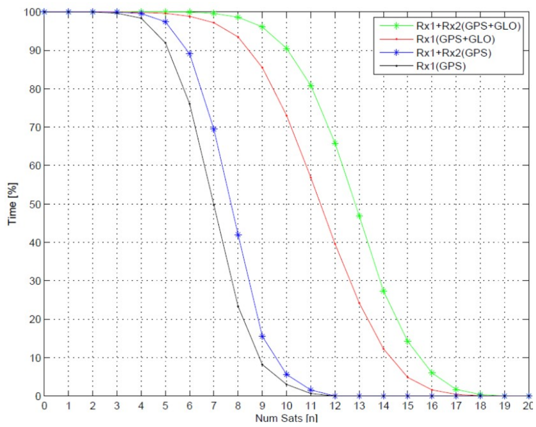

Figure 10: Number of satellites observed over time, different cases

4 Discussion

The tests must be done through field study to be able to analyze the impact of real environment and conditions at harvesting sites, which makes the analyses more difficult to perform an succeed in practice. One good example of this is the antenna that was swept off from the cabin roof by a branch, but was not damaged, during the measurements. The rough environment the equipment should be adjusted for should be kept in mind and taken in consideration when developing new and better products adjusted for positioning of forest machines. The results above show that it is beneficial to use two navigation systems to be able to determine a position with an acceptable precision. In Sweden today, the GPS system using one antenna is prevailing. The antennas used in production most likely have less precision than the ones used in the field study. This study will be followed by further studies to deeper analyze the improvements of a better positioning using two systems and/or two antennas.

The tests will continue during the summer and autumn 2012 and includes field tests in the northern part of Sweden as well as a field studies in final felling, both in south and north part of Sweden. Since the GPS satellite orbit has a less good coverage in the northern part, the use of a combination of GPS and GLONASS will be especially evaluated in these regions.

In order to analyze the accuracy and the need of precision, of positioning the project requires to identify the decision support systems which currently use the coordinates as an information basis. In the first stage, the project will scrutinize what resolution is relevant for today's existing decision support systems, etc. Furthermore, if possible, an analysis of the expected accuracy that can be seen in the near future, such as at the boom tip positioning utilized in road construction work. The aims are to investigate the accuracy of coordinates that are needed in the current situation and evaluate the existing system of signal engineering perspective and find the development potential of current and future use in the forest industry.

Acknowledgements

The authors would like to thank Holmen skog for access to machinery and personnel during the field study. We would also like to thank Leica Geosystems for providing the GNSS equipment.

5 References

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