WHITE PAPER

GPS CONTAINER POSITIONING FOR STRADDLE CARRIERS

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Straddle Carrier application

A Straddle Carrier (SC) is one of the most difficult container handling vehicles to be positioned using GPS. A Rubber Tired Gantry crane (RTG), for instance, is clearly more simple, since RTG is a tall vehicle and will stay always under the clear sky, without GPS-signal breaks.

The fundamental difficulty of Straddle Carrier is that during each work cycle, the carrier will pass under the crane, and the GPS-receiver will lose the satellite signals. Several GPS-algorithms offered by general-purpose GPS-vendors require a long time after the signal break until they reach again their nominal specified accuracy. In Straddle Carrier operation, positioning methods requiring long initialisation times (e.g. RTK) can not be used.

Several proposals have been made to cover the long initialisation times with e.g. dead-reckoning and gyroscopes, but these attempts have failed, since a Straddle Carrier can move more than 1 kilometer during the initialisation time, and no reasonably priced gyroscope can maintain 1…2 meters accuracy over this distance.

GPS accuracy measures

Analysing the GPS performance on paper is often difficult, because the accuracies presented by GPS-vendors are only statistical mean values (CEP, σ or RMS). No GPS-vendor specifies a maximum error for their receivers. Different vendors use different statistical measures, making the comparison difficult.

And even though the vendors use statistical parameters, they do not guarantee that the position errors follow a certain distribution (e.g. normal distribution) when extending to high confidence levels. And finally, many vendors do not specify the satellite geometry required to reach the specified accuracy.

The accuracy required for SC operation

In Straddle Carrier operation, the container rows are normally spaced roughly at 4 meter distance. The GPS antenna is typically mounted in the upper frame of the Straddle Carrier, horizontally in the middle of the spreader. When SC places a container down, the GPS antenna, due to spreader side-shift and container placement inaccuracy, may be 10…30 cm offset from the centre line of the container row. The critical GPS position error is thus 1.7…2 meters in the direction perpendicular to the container row. If the position error is greater than this, the container slot in the next row seems to be closer than the true slot and the container target slot is identified wrong.

Positioning error is naturally made also in the direction of container row, but since the containers are at least 6 meters (20 ft) long, we do have 1 meter more error margin in this direction, and thus this direction is not significant when analysing GPS statistics.

In technical terms, because we are sensitive to errors mainly in one direction, rather than studying the CEP-value of a given GPS-receiver:

CEP (Circular Error Propable) = a circle containing 50% of the GPS-measurements, (1)

we are more interested in the LEP-figure (Linear Error Propable), which is normally specified as σ (sigma):

σ = standard deviation of the error of a specified coordinate (e.g. x-coordinate) (2)

Even though CEP and σ are related, transforming one value to another requires complex mathematical calculation, since CEP-values are two-dimensional (Raleigh-distributed), while one-dimensional σ -values follow normal distribution.

Let us illustrate this by an example. Statistically, 68% of the x-coordinates have error less than or equal to σ. It follows then mathematically that a circle of radius σ contains (only) 39.4% of GPS-observations [1], which is less than CEP-circle.

Sub-meter DGPS performance

Let us analyse the performance of a modern “sub-meter” DGPS-receiver by an experiment. In this test, base station and rover GPS antennas have been placed in known locations. The test situation is quite idealistic, since there are no obstacles reducing line-of-sight to satellites and the distance between the antennas is short (15 meters).

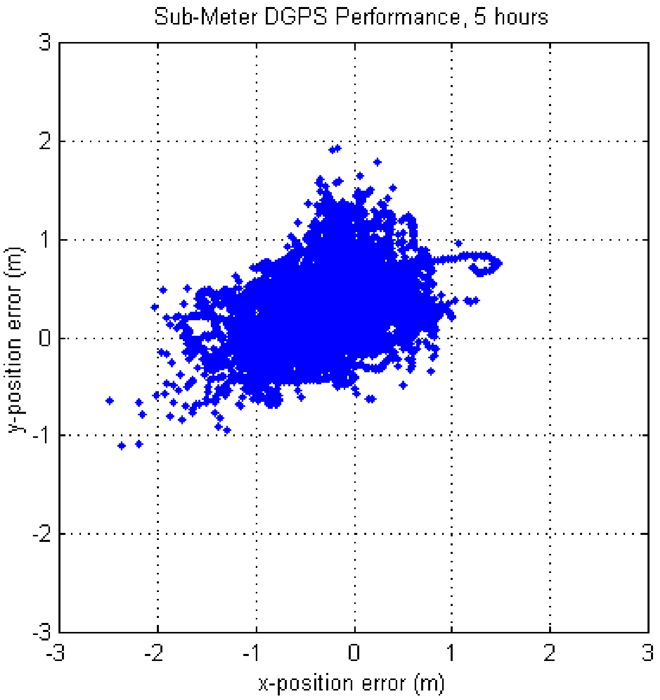

Figure.1.

Figure 1. shows the calculated positioning errors during 5 hours of test. From the results we can see immediately, that the critical error limit of 1.7…2 meters is often violated. The results in port environment would be even worse, since the Key Cranes block some of the satellites, and metal surfaces cause multi-path effects. We can not thus consider the general accuracy of the receiver good enough for container positioning.

How does the result agree with the specification of the receiver ?. The calculated σ -values from the measured data are: $\sigma_x = 0.46$ m and $\sigma_y = 0.35$ m, i.e. they are clearly sub-meter and within the specifications of the receiver.

Looking at the results, it is obvious, that the errors do not follow exactly the statistical distribution at high confidence levels, at least during one-day period. This can be seen by bare eye: the scatter diagram is far from symmetric and zero-mean. Multiplying σ_x by four ($4\sigma < 2$ meters) should give us a confidence level of 99.99 %, but from the test data we can see that this kind of reliability is not reached, at least in short-term. This is a major shortcoming of statistical specification: significant differences to statistical behaviour can happen during short time periods.

RTK dual-frequency GPS performance

Some years ago, a revolutionary new GPS positioning technology was introduced, called RTK (Real Time Kinematic) GPS-positioning, giving measurement σ accuracies around 2 centimetres. This technology is using GPS carrier waves (L1/L2) phase measurements and solves the integer number of full carrier wave cycles between the GPS antennas and satellites.

The accuracy provided by this technology would be ideal for container positioning, but the drawback is that the initialisation time needed to solve the unknown integer parameters is long, 2…5 minutes. Each time the Straddle Carrier passes under the Key Crane (or even goes close to Key Crane), the GPS position is lost/ disturbed and a new initialisation sequence is started. The GPS position is thus not recovered, when a container is placed down.

Other variants of carrier phase positioning

There are also some other GPS-receivers commercially available, which are based on carrier phase positioning and give a GPS-accuracy around 20 centimetres in steady state. These devices can operate on single GPS frequency (L1) and do have lower price than dual-frequency RTK device. The same initialisation problem, however, applies to these devices also. It may take 5…10 minutes, before the nominal 20 cm accuracy is obtained. During initialisation, the performance of these devices may be even worse than with a standard DGPS-receiver.

SUMMARY: The status of the commercially available GPS products

Let us conclude our previous analysis. When studying the performance of the commercially available GPS-receivers, it is important to consider two aspects at the same time: the accuracy of the computed position and the time needed to compute that position (i.e. recovery time). There are receivers that do have very good accuracy (e.g. RTK) , but they are too slow to recover. There are also very fast receivers (DGPS based on single epoch $\approx$ 1 second), but they seem to lack the needed accuracy/ reliability.

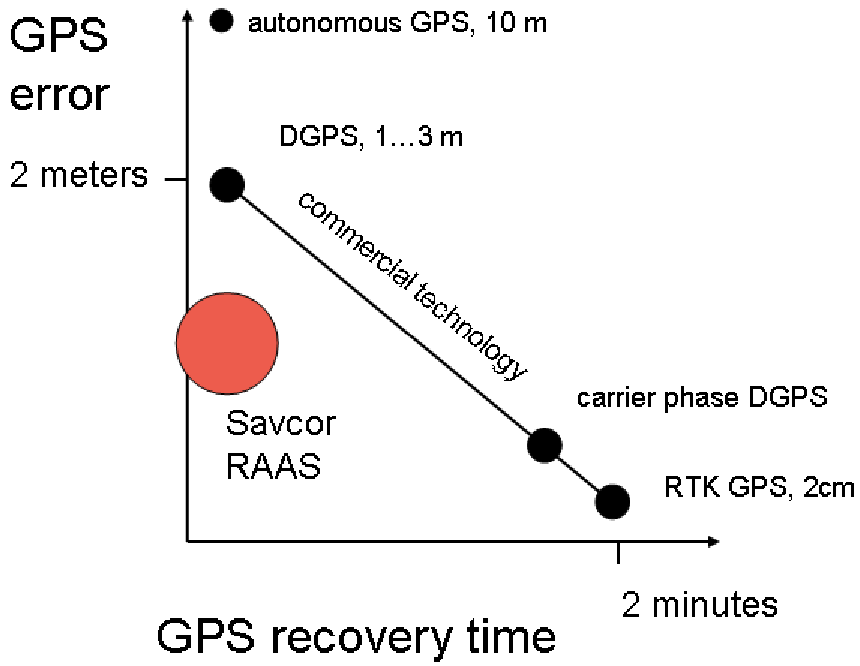

Figure 2.

This problem was the starting point for Savcor to develop their own in-house GPS-algorithms (Fig. 2.)

Savcor RAAS solution

The basic shortcoming of the commercial GPS-receivers is that they have been developed for general purposes (basically same receiver for surveyor, car or aeroplane) and they do not use the special knowledge of the container port application, layout or moving patterns of SC. The Savcor RAAS is using actively e.g. the port lay-out and understands that the main purpose is to deliver correct container slot positions (and not e.g. to compute the height of the GPS-antenna !)

The other shortcoming of the commercial GPS-algorithms is that despite the fact that the receiver collects a massive amount of data from satellites and base station, all that data is reduced into a few parameters (Latitude, Longitude, height, variances) and given to end-user in the form of e.g. a GGA-message. The end-user then tries to match this simplified data to the containers. The Savcor RAAS is using all satellites signals to identify each container slot, combining in total 100…2000 pieces of data from GPS satellites. The reliability of each satellite signal is carefully analysed based on the knowledge of the satellite positions, conflicts between the satellites, and possible multi-path situations.

Savcor RAAS performance

Based on extensive laboratory testing and experiences from installed, operational Straddle Carrier terminals, the performance of the RAAS-algorithm is found to be superior when compared to solutions offered by general-purpose GPS-vendors.

A typical 24 hour laboratory test in normal satellite environment contains 100 000 position fix samples. There are typically no errors (wrong container identifications) during such test. Thus the confidence level of container identification in these tests has been better than 99.999 %.

What is equally important (see Fig. 2.), there is no initialisation delay in RAAS-algorithm, and thus after passing under the Key Crane the position is available immediately (≈ 1 second) after the satellites are visible again.

Gyro support

It shall be noted, however, that under the cranes no GPS-algorithm can operate without proper satellite data. But if the position is still needed also under the cranes, RAAS-algorithm can use a fibre-optical gyroscope in order to navigate short distances in GPS-shadow. Special GPS-calculation has been developed for fast alignment of gyroscope during even short periods of GPS-visibility. The general-purpose GPS-receivers have not been optimised for this purpose and thus the direction determination based on standard GPS position-data is inaccurate.

CONCLUSIONS

The GPS-receivers offered by general-purpose GPS-vendors lack either the required accuracy or speed of GPS-positioning. It is possible to find accurate commercial GPS-receiver, but they do have even 5 minutes initialisation time after a GPS-signal break. In Straddle Carrier operation, a GPS-signal break is unavoidable during each work cycle, since the Straddle Carrier drives under the crane.

The performance of Savcor RAAS-algorithm is found to be superior when compared to solutions offered by general-purpose GPS-vendors.

There is no initialisation delay in RAAS-algorithm, and thus after passing under the Key Crane the position is available immediately (≈ 1 second) after the satellites are visible again.

Savcor RAAS is using all satellites signals to identify each container slot, combining in total of 100…2000 pieces of data from GPS satellites. RAAS is also actively using the lay-out data of the container terminal.

Standard GPS output-messages (e.g. GGA) only contain a reduced set of data, and the performance comparable to Savcor RAAS could thus not be obtained. Furthermore, general purpose GPS-receiver does not have any data concerning the Straddle Carrier application or lay-out. For this reason also the performance of Savcor RAAS could not be obtained.

Savcor RAAS has been implemented in several operational Straddle Carrier terminals, and the customers have given very positive feedback, especially when comparing the performance to their earlier experiences on standard GPS-receivers.

[1] Sam Wormley (http://www.edu-observatory.org/gps/gps.html)