ASSESSING THE PERFORMANCE OF DIFFERENT DIRECT-GEOREFERENCING STRATEGIES

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ABSTRACT

The use of direct georeferencing by GPS/IMU can be distinguished in two different concepts:

1. Direct georeferencing to measure the exterior orientation parameters for photogrammetric data processing without using the aerial triangulation.
2. Direct georeferencing using the aerial triangulation and the automatically measured minor control points (tie and pass points).

Each approach is suitable for a specific task taking into consideration many factors, e.g. the required accuracy and the image scale. In general, direct georeferencing without aerial triangulation is used for medium to small scale projects, while direct georeferencing with aerial triangulation is applied to large and medium scales.

This paper aims to investigate some of areas that might affect the quality, performance and reliability of the direct georeferencing by pre-processing GPS/IMU including:

- Using one reference station with varying baselines lengths (10 km – 230 km) for direct georeferencing.
- Using a network of reference stations rather than a single station only.
- Using a combined GPS and GALILEO solution.

The results of direct georeferencing from real trials using a traditional Zeiss RMK TOP 15 frame camera and a Vexcel UltraCam D digital camera will be presented. Both cameras are fitted with an Applanix POS AV 510, GPS, IMU integrated system. An important question that needs to be considered is how the distance of the reference station from the rover affects the direct georeferencing and the subsequent photogrammetric processes. Also results will be introduced showing the performance of multiple reference stations based on GPS network.

INTRODUCTION

Before the use of GPS and IMU measurements in photogrammetry, aerial triangulation is used to orient the images and to create the stereo models. The use of direct georeferencing radically changes things. If direct georeferencing is performed, each image is oriented independently (Casella et al., 2003).

The use of in-flight control systems for controlling blocks of aerial photography is now an established procedure. The technology of GPS and an inertial measurement unit (IMU) integrated with an aerial camera, either analogue or digital, is regularly being used for production purposes. The importance of GPS and IMU measurements is increasing as there is greater and greater interest to work without ground control and strive towards direct

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georeferencing of imagery. Arguably, direct georeferencing can be considered with and without aerial triangulation as the use of automatically measured minor control points (tie and pass points) can be easily and efficiently undertaken by modern aerial triangulation software.

The use of automatically measured tie points is a cost effective way of generating ground control points. To measure ground control points in the field is time consuming, labor intensive and therefore expensive. So it is most efficient to minimize the measured ground control points and maximize the use of aerial triangulation generated tie points (Casella et al., 2003).

In such cases the use of integrated GPS/IMU and digital aerial triangulation offers a possibility to achieve the required accuracy for object point determination. Therefore using GPS/IMU data should improve the quality of tie points matching and increase the overall stability and reliability of the block. Cramer (2003) identifies some of the advantages of using direct georeferencing:

- Direct georeferencing based on GPS/IMU provides high flexibility because it can be used with any type of sensor (frame/line, analogue/digital).
- There are no restrictions on flying regular block structures.
- The direct georeferncing is an ideal method for tie point matching even in applications, where generating tie points are difficult like coastlines and dense forest regions.
- If the correct GPS/IMU data processing and an appropriate overall system calibration are used, then direct determination of exterior orientation parameters using high-quality integrated GPS/IMU systems can reach high accuracy fairly close to the traditional aerial triangulation.
- Direct georeferencing without any ground control is possible, but the use of a certain number of check points in the test area itself is recommended to provide redundant data for quality assessment and quality control. If errors are present, then these check points may serve as control data to compensate the error effects.

The baseline length is the major interest for photogrametric application, where the distance between the GPS master and rover station might be very long especially in remote areas. This was the motivation for performing a more investigations on the accuracy that can be obtained from different GPS baselines. The processing of direct georeferencing with ZEISS RMK TOP 15 frame camera and Vexcel UltraCam D digital camera was repeated using the exterior orientation data from single reference stations with varying baselines lengths (10 km – 230 km).

Also, direct georeferencing is presented with GPS multiple reference stations solution for photogrammetric point determination. The multiple baselines network solution is used in this paper to create a larger redundancy of the adjustment system, to lead to an increased possibility for detecting gross errors, and to have more reliable solution for the parameters of exterior orientation (Wegmann et al,. 2004).

Results from integrated GPS and GALILEO with aerial triangulation are described, and it shows that there is a marginally improvements on the quality of sensor positioning when the simulated GPS and GALILEO data is used with aerial triangulation.

There are two basic ways to quantify the quality of direct georeferencing: firstly, through the measurement of check points in the stereo model secondly, by the magnitude of residual ‘y parallax’ and ‘x-parallax’ in the stereo model, the traditional quality measure of relative orientation. Both are important from a mapping point of view, the second being particularly important for a manual measurement of the stereo model.

The software used in the trials includes Leica LPS, ORIMA and the in-house bundle adjustment IESSG software 3DB. ORIMA was used for all aerial triangulation computations and 3DB was used to calibrate the misalignment between the IMU and camera.

THE TEST SITE

In order to assess the various parameters, a series of test flights are undertaken by Simmons Aerofilms Ltd over their Milton Keynes test site. It contains 12 ground control points with object space coordinates known to sub-centimeter accuracy. The following data sets were utilized within the test process:

Figure 1 shows the 18 UltraCam images block, taken at a nominal flying height of 1500m and imagery scale of 1:15000. A traditional flight plan was used with a nominal forward overlap of 60% and nominal side overlap of 20% for all flight.

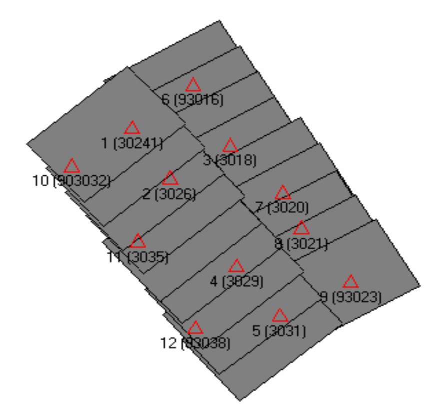

Figure 1. Block of 18 images taken at 1500m flying height – using the UltraCam D.

To enable some comparison to take place with a frame camera, results from a 24 photograph metric ZEISS RMK TOP 15 block are assessed. The images are taken at 880m flying height and an imagery scale of 1:6000 over the same test area, see Figure 2. The data from the frame camera taken at scale 1:6000 was specially chosen as it has the same swath width as the UltraCam D digital camera.

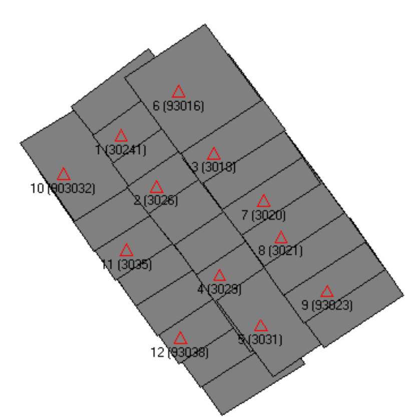

Figure 2. Block of 24 photographs taken at 880m flying height – using the metric ZEISS RMK TOP 15.

The direct measurement of position and attitude is produced by an Applanix POS 510 GPS/IMU system using the post processing software, POSPac (4.02). The specification provided by the manufacturer for the GPS/IMU system is given in Table 1:

Table 1. Specification of the Applanix system for direct measurement of position and attitude

Position (m)	0.05 - 0.30
Velocity (m/s)	0.005
Roll and pitch (deg)	0.005 (1/200th)
True heading (deg)	0.008 (1/125th)

This system provides the potential for in-flight control for aerial triangulation, enabling a reduced amount of ground control to be used, or direct geo-referencing of individual images.

In summery three tests were undertaken to asses some of the various effects on direct georeferencing measurements:

1. A comparison of direct georeferencing using single reference station with different baselines lengths.
2. Direct georeferencing based on GPS network solutions.
3. Using combined GPS and GALILEO data with aerial triangulation.

TEST 1 - A COMPARISON OF DIRECT GEOREFERENCING USING SINGLE REFERENCE STATION WITH DIFFERENT BASELINES LENGTHS

The accuracy of GPS positioning is the limiting factor for the overall accuracy of direct georeferencing (Wegman et al,. 2004). An important parameter in the accuracy of GPS is the distance between the rover (aircraft) and the ground reference base station.

The baseline length is the major interest for photogrametric application, where it is desirable to have the distance between the master and rover receiver as short as possible especially in remote areas. The direct georeferencing with UltraCam D digital camera and ZEISS RMK TOP 15 was repeated using the orientation data from the following three reference stations:

- Cranfield (baseline = 10km)
- Northampton (baseline = 30km)
- Taunton (baseline = 230 km)

As a first step the different solutions of the GPS trajectories for the available baselines were computed using the GrafNav Software. In the second step the GPS/IMU data were integrated by the PosProc software of Applanix Corporation. The software combines the pre-computed results of the GPS processing (position and velocities) and the IMU data within a Kalman Filter. In the final step, the accuracy of check points in the manual stereo models, which are created by the direct georeferencing data for the three baselines, is determined. The stereo analyst tool within the Leica Photogrammetry software is used to perform this step.

The demands on the accuracy from the GPS using these different baselines lengths for the positions of the perspective centers camera at the moment of exposure are very high. In general, for analogue and digital cameras, we need an accuracy of height of the projection centers, as measured by GPS of (Krause, 1997):

$$\varsigma_{Po-GPS} = \pm m_B * \varsigma_B$$

Where:

ς_{Po-GPS} is the accuracy of projection centers derived from the GPS observations.

m_B is the photo-scale.

ς_B is the accuracy of coordinate measurements in the photograph.

For a coordinate measuring accuracy of ± 5 µm and photo-scale of 1:10000 with ZEISS RMK TOP 15 frame camera, the GPS accuracy in the aircraft should then not be significantly poorer than ± 5 cm. In the case of UltraCam D for the same photo scale, the measuring accuracy of the image coordinates will be ± 2 µm, and therefore the GPS accuracy in the aircraft for the same photo-scale should then not be significantly poorer than ± 2 cm. which means that GPS data used for direct georeferencing with UltraCam D should be more accurate than the GPS data needed for the frame camera.

Table 2 shows the plan and height residuals of the check points after performing the direct georeferencing for the three different baselines lengths with ZEISS RMK TOP 15 frame camera. The RMSE of the 12 Check points are computed by applying the forward intersection after using all the exterior orientations obtained from GPS and IMU as constant values. Although the baseline length differs from 10-230 km, the results are quite consistent for all the baseline solutions and there is no significant dependency on base station distance visible. The horizontal accuracy of the check points is within 15-25 cm, and the height accuracy is within 33-42 cm for all the references stations. These values are larger by a factor 2-3 when compared to standard aerial triangulation with ground control points because the parameters of exterior orientations, obtained from the GPS and IMU were not accurate enough. Therefore improvements on the accuracy of check points can be expected by refining the exterior orientations resulted from GPS/IMU (Heipke et al., 2002).

Table 2. RMSE residuals of Check Points on the manual stereo models for different baselines length for ZEISS RMK TOP 15

Baseline length (km)	RMSE of 12Check Points in the manual stereo model (m)		
	East	North	Height
Cranfield (10 km)	0.210	0.143	0.330
Northampton (30 km)	0.320	0.152	0.420
Taunton (230 km)	0.251	0.188	0.315

In the case of UltraCam D digital camera, Table 3 shows that the RMSE of the check points are significantly effected by the selection of the baseline length. The results show the importance and the influence of GPS that needed for the direct georeferencing with UltraCam D digital camera, and how this camera is sensitive to baseline length. The accuracy of the check points are decreased by the factor 2 in the height and by the factor 10 in the plan position when the Northampton (30 km) and Taunton (230 km) references stations are used. These results show that the GPS accuracy produced from using the Northampton and Taunton references stations needs to be more accurate.

Table 3. RMSE residuals of Check Points on the manual stereo models for different baselines length for UltraCam D digital camera

Baseline length (km)	RMSE of 12 Check Points in the manual stereo model (m)		
	East	North	Height
Cranfield (10 km)	0.082	0.079	0.390
Northampton (30 km)	0.977	0.730	0.856
Taunton (230 km)	0.960	0.760	0.770

TEST 2 - DIRECT GEOREFERENCING BASED ON GPS NETWORK SOLUTIONS

There are many strategies and solutions used for improving the differential GPS results for direct georeferencing especially when the long baseline reference station is used. One of these solutions is using a network of reference stations rather than a single station only. Multiple baselines lead to a larger redundancy of the adjustment system, and thus to an increased possibility for detecting gross errors, and to a more reliable solution for the parameters of exterior orientation.

In order to analyze the difference between using one reference station and multiple base stations network, the following characteristics of the multiple references stations are considered (Wegmann et al,. 2004). A network of baselines with different lengths (short and long) is not selected, because the network of these baselines produced average results, which is not accurate as the solution for the shortest baseline only, as it shown from the results of test 1. Two long baselines (Newcastle (330 km) and Carlisle (350 km)) of similar lengths are selected to be compared with a single long baseline ((Newcastle (330 km)). The distance between Newcastle and Carlisle is about 80 km. If there are short term errors in any of these two baselines, the network of these two references stations is able to reduce or eliminate the effect of these errors.

Table 4 shows the plan and height residuals of the check points produced from the aerial triangulation, for the two solutions (single baseline and network solution) with ZEISS RMK TOP 15 frame camera. The accuracy of the check points is significantly improved by approximately the factor 1.5 in the height and the factor 3 in the plan position, when the network from two base stations is used. This indicates that the systematic errors concerning the GPS data in the single baseline ((Newcastle (330 km)) can of course be detected and eliminated by using multiple base stations (Newcastle (330 km) and Carlisle (350 km)). A comparison with table 2 in test 1, table 4 show that using the network of two long baselines give approximately the same results as using the short single base line.

Table 4. RMSE residuals of the check points in the manual stereo model with a single reference station and GPS network reference stations for a ZEISS RMK TOP 15

	Newcastle reference station			Newcastle and Carlisle reference stations		
	East (m)	North (m)	Height (m)	East (m)	North (m)	Height (m)
RMSE	0.709	0.943	0.600	0.342	0.331	0.416
Standard deviation	0.468	0.450	0.341	0.145	0.122	0.086

Table 5 shows the obtained results from the direct georeferencing with UltraCam D digital camera (single baseline and network solution). Neither of the solutions (single and network GPS) achieved a good results when compared to the standard photogrammetric solution, although, the height and the plan accuracies of the check points are marginally improved when the network of references stations is used. This can be explained by the sensitivity of UltraCam D digital camera to the long baseline, as it shown in test 1.

Table 5. RMSE residuals of the check points in the manual stereo model with a single reference station and GPS network reference stations for UltraCam D digital camera

	Newcastle reference station			Newcastle and Carlisle reference stations		
	East (m)	North (m)	Height (m)	East (m)	North (m)	Height (m)
RMSE	0.839	0.743	1.210	0.940	0.620	1.191
Standard deviation	0.550	0.360	0.651	0.530	0.241	0.550

In order to analyze the difference between using one reference station and multiple reference stations network, a traditional aerial triangulation is used with ground control points to determine the parameters of exterior orientation for the ZEISS RMK TOP 15 images and simultaneously the object coordinates of the check points. The results of UltraCam D digital camera are not analyzed because there are not enough improvements, when the GPS network is used. The results from the traditional aerial triangulation are considered as a reference to calculate the difference in the plan and height residuals of the check points for the two solutions of direct georeferencing (single baseline and network solution). Figure 3 shows the plan and height RMSE of the check points.

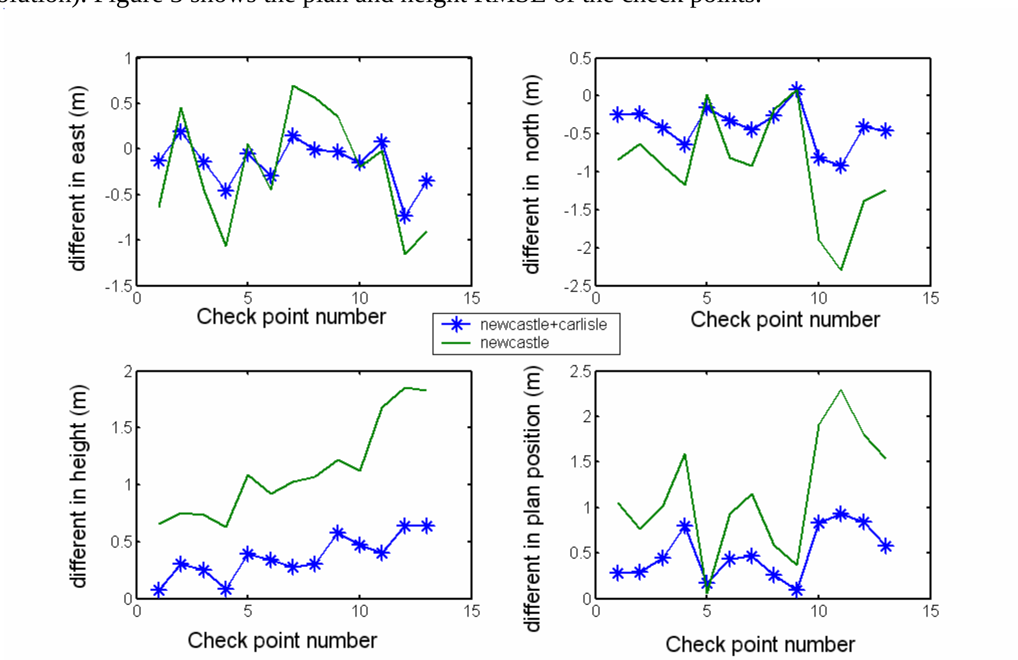

Figure 3. Plan and height residuals of the check point on manual stereo models created by single reference station and multiple reference stations with ZEISS RMK TOP 15.

Figure 3 shows that the residuals of the check control points are significantly decreased when Newcastle and Carlisle multi reference stations are used with the direct georeferencing, especially in the height.

On the other hand, to understand the properties of the aerial triangulation bundle adjustment for the single baseline and multi baselines with ZEISS RMK TOP 15, and to diagnose any problems or systematic errors, the qualitative evaluation is done by plotting the image residuals from the aerial triangulation.

The size of the residuals is usually exaggerated to emphasise the trends. Figure 4 shows the image residuals for two configurations. It would appear that the image residuals for multi baselines solution (lower figure) has more comparable sizes and more random distribution than the image residuals for the one baseline solution (upper figure). It means that the systematic errors are less for the network GPS references approach. In this case the photos will be fixed more. More stability to the photos means that the errors that pushed from the photos to the ground control points will be increased.

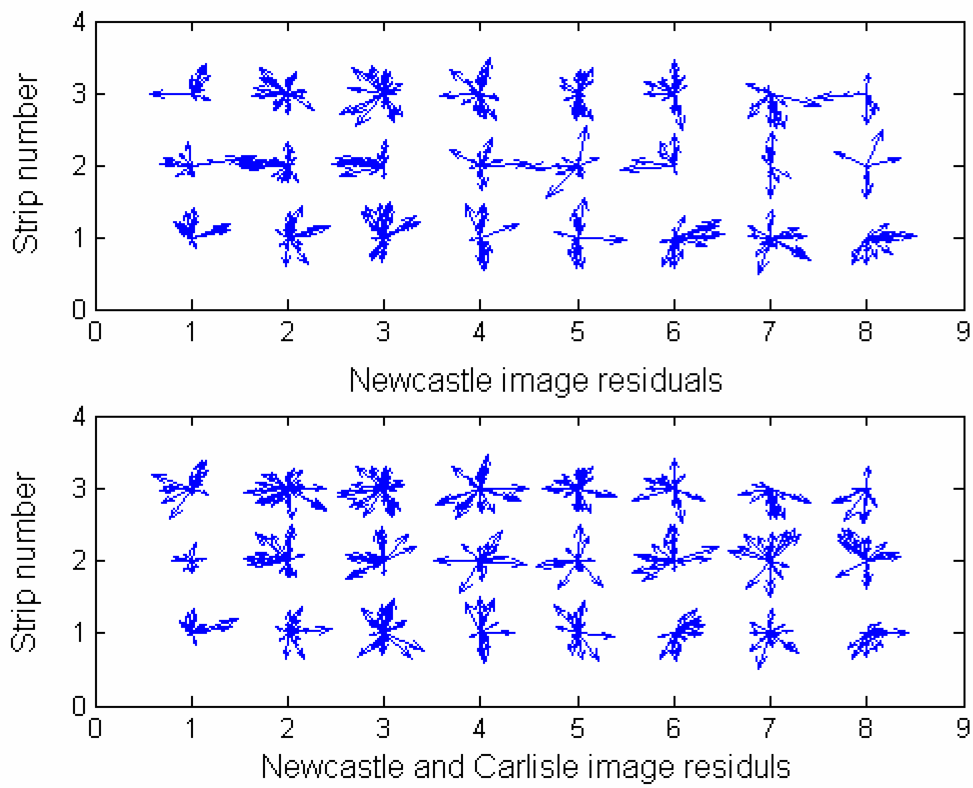

Figure 4. Image residuals (position) for single and network solution.

TEST 3 - USING COMBINED GPS AND GALILEO DATA WITH AERIAL TRIANGULATION.

Some improvements on the quality of sensor positioning are expected from the future availability of more satellites using the Galileo project and the use of tightly coupled GPS and GALILIEO data processing. The results expected to be more reliable because the increasing of the number of satellites. This test will explore this assumption.

IESSG has developed the Navigation Sensor Simulation (NSS) software (Farah et al., 2004). The software consists of two parts, a GNSS data simulator and an inertial measurement data simulator. The GNSS data simulation tool was originally designed to simulate the types of measurements that can be made using a GPS receiver. Specifically the simulator has the capability of producing code, carrier and Doppler measurements on both the L1 and L2 frequencies. The simulation is achieved by using the true locations of both the receiver and the satellites to calculate the true error-free measurements. Error models are then applied to account for the various inaccuracies seen in real-world measurements. The simulation results are returned to the user in a file in the standard RINEX (Receiver Independent Exchange) observations format.

Although the data simulator was originally designed for the simulation of GPS measurements, the software has recently been upgraded to allow for the simulation of both the proposed European satellite navigation system Galileo and modernized GPS.

Firstly, both GPS and GALILEO data are simulated from a real trajectory of GPS by GNSS simulation program. After simulation, a separate Rinex files for the rover and reference receivers were created for the GPS and GALILEO data. Secondly the simulated GPS data by GNSS was created from the real trajectory of GPS. Finally the solutions for GPS and GALILEO data, and GPS trajectories were computed using KinPos Software which developed in the IESSG (IESSG, 2003).

To evaluate the accuracy of using the combined data from GPS and GALILEO with ZEISS RMK TOP 15 in the photogrammetry and to see if the results relate to the real world, the accuracy must be determined using the residuals of the check points. The root mean square of the difference between the computed coordinates from the aerial triangulation with GPS/GALILEO data (without ground control points) and the known values provides a measure of the solution accuracy. This test shows the attainable accuracy for the GPS and GALILEO especially in the height.

Table 6 shows the height accuracy of the check points is improved by 3 cm and the plan accuracy is marginally improved, when the combined GPS and GALILEO is used with aerial triangulation. Also the results show that the position of perspective centers of the photos is marginally improved, when the combined GPS/GALILEO is used.

Table 6. RMSE of the check points and the image coordinates from using the GPS data and the combined GPS and GALILEO data with aerial triangulation

	RMSE of perspective centre (m)			RMSE of attitude angles (arc-min)			RMSE of check points residuals (m)			RMSE of image coordinates (micron)	
	X_o	Y_o	Zo	Omega	Phi	Kappa	X	Y	Z	x	y
GPS	0.02	0.02	0.09	0.550	0.378	0.516	0.058	0.089	0.144	5.28	5.49
GPS and GALILEO	0.01	0.01	0.08	0.453	0.378	0.516	0.055	0.062	0.110	5.56	5.200

The marginal improvements in the height accuracy when the combined GPS and GALILEO data are used can be explained by the presence of more satellites on the sky from both GPS and GALILEO, and further analysis are required to investigate the reliability and the important of these results and whether other benefits will be presented.

CONCLUSIONS

The results of the check points accuracy obtained from the ZEISS RMK TOP 15 frame camera show that there is no significant dependency on base station distance visible. In the case of UltraCam D digital camera, the situation is different because the GPS data should be more accurate when the baseline reference station is used and the influence of GPS accuracy that needed for the direct georeferencing must be respected.

Multiple baselines lead to a larger redundancy of the adjustment system, especially when the frame camera is used, and thus to an increased possibility for detecting gross errors, and to a more reliable solution for the parameters of exterior orientation. In the case of UltraCam D, the GPS accuracy is very important, because this camera is very sensitive, and need a very accurate GPS results.

Some improvements on the quality of sensor positioning are expected from the future availability of more satellites using the Galileo project and the use of tightly coupled GPS and GALILIEO data processing. The results expected to be more reliable because the increasing of the number of satellites.

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