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GPS mass-market receivers for precise farming

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Abstract — The use of Global Navigation Satellite Systems (GNSS) can help farmers become more efficient, reduce their use of chemicals, and increase crop yields. By increasing the accuracy, availability, reliability and continuity of satellite signals, the use of some augmentations systems (such as WAAS or EGNOS or other private systems) will remove some of the barriers to the adoption of precision agriculture, also not only considering geodetic receivers and complex systems of navigation.

Precision farming may require accuracies starting from a few meters to a few centimeters. For example high accuracies are required for seeding or fertilization activities. These accuracies can be partially obtained with SBAS (EGNOS in Europe) corrections: today with these methods it is possible to arrive approximately at 1 m in plan at 95% of reliability with geodetic receivers. For accuracies between 1m and 20-40 cm in real time, some private systems can be considered, such as Trimble H-Star (R) but for better accuracies, typically needed for example for sowing, it is necessary to move to CORSs networks.

In Italy there are networks of permanent stations available in all regions.

The improved accuracy of GNSS can also be used by farmers for what is called Variable Rate Application (VRA), a practice used in precision farming. VRA requires the use of GNSS sensors, aerial images, and other information management tools for determining optimum herbicide doses, fertiliser requirements and other inputs to help farmers save money, reduce their impact on the environment and increase crop yields. With VRA farmers adjust their doses in field operations to the observed variability in the field. For example, only sections of a field with weeds are treated with a herbicide. So they need different levels of precision and accuracy, starting from few centimeters to few meters, depending on the application.

The goal of this work is to show how it is possible to consider both mass-market receivers and antennas to obtain centimetrical accuracies, useful for many precise farming applications. As it is possible to find in bibliography, the accuracy of real-time positioning depends mainly on the type of receiver (whether it is single frequency or low-cost) and antenna (whether it is patch, mass-market or geodetic) used. Some different receivers and antennas were tested and some results can be shown, not to analyze what receiver or antenna is the best but in order to analyze the state of the art of these type of instruments.

Nowadays many GNSS companies have developed an owner system for precise farming but the order of cost is very high: considering this, the Geomatics Research Group at the Politecnico di Torino has carried out several experiments in order to evaluate the achievable precision which are allowed using mass-market GNSS receivers and antennas for different purposes.

The tests have been conducted considering several positioning methods, such as NRTK (Network Real Time Kinematic) and stand-alone, always considering the real-time approach.

The NRTK experiences have been conducted using mass-market receivers (mainly u-blox) within the Regione Piemonte network of permanent stations. The area in which the tests has been performed is located near Vercelli that is a famous place in Italy for rice colture. Some network differential correction products has been used (VRS[®] and nearest correction), using the RTKLIB software. This software is composed by different parts, in particular for RTK application, the RTKNAVI unit is employed. This tool allows for providing as input both the raw data (pseudorange and carrier-phase measurements) of the u-blox receiver and the stream data of differential correction broadcasting from a RTK network by the NTRIP protocol.

Good results have been obtained: in fact, despite a single frequency instrument is used, the horizontal and vertical components have centimetrical level of accuracy. The maximum 2D error in the case of 'fix' positioning is always less than 5 cm, precision required in many applications of precise farming, such as to individuate livestock positioning and fencing or for crop cultivation (e.g. cereals) and other low-accuracy operations (fertilising and reaping).

Practical experiences have demonstrated the value of precise navigation and guidance technologies to increase yield and efficiency of agriculture operations and we want to show it in this paper.

Under this condition, mass market sensors could be a valid instruments for a large part of surveying applications related to precise farming.

Keywords — GPS positioning; mass-market receivers; quality control; kinematic positioning; precise farming.

I. INTRODUCTION

The combination of GNSS (Global Navigation Satellite System) and GIS (Geographic Information Systems) has made possible the development and the rapid growth of precision agriculture. GNSS-based applications in precision farming are being used for farm planning, field mapping, soil sampling, tractor guidance, crop scouting, variable rate applications, and yield mapping. The GNSS and GIS coupling allows farmers to work during low visibility field conditions and to increase receipts. This is possible today thanks to more precise application of pesticides, herbicides, and fertilizers, and better control of the dispersion of those chemicals, reducing the chemical pollution and saving also the environment.

Precision agriculture management practices can significantly reduce the amount of nutrient and other crop inputs used while boosting yields. Farmers thus obtain a return on their investment by saving on phytosanitary and fertilizer costs. The second, larger-scale benefit of targeting inputs (in spatial, temporal and quantitative terms) concerns environmental impacts. Applying the right amount of inputs in the right place and at the right time benefits crops, soils and groundwater, and thus the entire crop cycle. Consequently, precision agriculture has become a cornerstone of sustainable agriculture, since it respects crops, soils and farmers.

With increasing the equipment size, power, multiple equipment functions, and speed (as well as monitors reporting on performances) also the requirements in terms of production for the operators has changed considerably. These increasing demands could be increase the operator's errors increasing also costs, environmental problems, and operator efforts. Many of the new innovations rely on the integration of on-board computers, data collection sensors (primarily due to INS and GNSS instruments), and a well-defined time and position reference systems.

Several tools (UAVs, ground navigation tools, etc.) to help farmers based on GPS equipment were developed in order to make more productive and efficient their activities: in this paper we want to focus the attention on the GPS positioning accuracy obtainable in real-time with mass-market receivers, useful to the guidance of agricultural vehicles.

The required accuracies depending on the activities made: for some applications a meter level of accuracy is enough while for other activities a centimetric level of precision is necessary. So in the first case a SBAS corrections can be considered sufficient while in the other cases it is possible to use private systems (ie. Trimble H-Star[®] - <http://investor.trimble.com/releasedetail.cfm?ReleaseID=372358>) or CORSs (Continuous Operating Reference Stations) networks that allows the user to obtain centimetrical accuracies in real-time.

As it is known, the use of low-cost GPS instruments introduces a number of problems, easily find in bibliography [8][9]. Also the Geomatics Research Group at the Politecnico di Torino has carried out some experiments in order to evaluate the achievable precision which are allowed using mass-market GNSS receivers in real-time for different applications [3].

The use of mass-market receivers is widespread, primarily thanks to their low cost. The GPS chip is produced in millions of copies and costs only a few euros. Very often these receivers are assembled in 'evaluation kits' (composed by receiver and patch antenna) with a cost of about € 200-300. All these instruments are able to track the GPS signals but few of this are also able to track the GLONASS constellation. Some of them are also able to manage differential corrections broadcasted by a software that manage a CORSs network while other are only able to make a stand-alone positioning. In the first case, with this type of receivers, it is possible to do an NRTK (Network Real-Time Kinematic) positioning whose basically informations can be found on section III.

In this paper we consider a mass-market receiver able to acquire both the pseudorange and carrier phase measurements on L1 GPS frequency that manage differential corrections. In the following sections (section II) a brief description of this type of instruments is performed as a briefly description of the NRTK positioning and differential corrections. Particular attention will be focus also on the role of mass-market antennas in this type of positioning.

A practical experiment (section IV) of precise farming with the use of mass-market GPS receiver in NRTK modality want to show the accuracy obtainable today with this type of instruments, in order to verify if they are useful for precise farming. The conclusions and bibliography close this work.

II. RECEIVERS AND ANTENNAS USED

Nowadays more and more mass-market receivers and antennas are available. Considering this category of instruments, we have focused our attention on a common mass-market receiver of u-blox company: the LEA 5T in the evaluation kit mode (LEA EVK-5T). In order to evaluate the performances of this type of instruments, we have decided to compare the positioning performed with the u-blox with those ones obtained with a double frequency instruments, that in our case is represented by the Leica 1230+GNSS of Leica Geosystems[®]. To do this, a splitter was used: this instrument allows splitting the GNSS signal which arrives at the antenna to more than one receiver (Fig. 1).

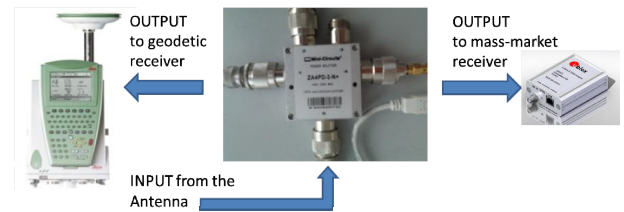


Fig. 1. The system configuration using the splitter

The characteristics of these receivers can be found in Table 1.

At the same time, considering previous tests that we have made, we have also decided to dedicate particular attention to the GNSS antennas. We have compared two different external antennas: a low-cost antenna (GA29F) provided by the Garmin company and a geodetic one (LEIAX1203+ GNSS) provided by the Leica Geosystems[®]. The last one is a triple frequency antenna generally used with the Leica receiver shown in TABLE I. Characteristics of these types of antenna are summarized in TABLE II.

TABLE I. RECEIVERS CONSIDERED



Receivers		
	LEA EVK-5T (u-blox)	Leica 1230GX+ GNSS (Leica Geosystems®)
Image		
Default Antenna	patch	Geodetic
Constellations	GPS	GPS + GLONASS + Galileo
Type of observations	GPS: C/A, L1, Doppler, S/N	GPS: C/A, L1, L2, L5 Doppler, S/N GLONASS: L1/L2, Galileo: E1, E5a, E5b, Alt-BOC
Position update rate	0.25 ÷ 1000 Hz	0.2 ÷ 100 Hz
Corrections type	RTCM 2.x, RTCM 3.0, SBAS (WAAS/EGNOS/MSAS/GAGAN) Owners corrections (AssistNow Online & Offline)	RTCM 2.x RTCM 3.0 CMR / CMR+

TABLE II. ANTENNAS CONSIDERED

Antenna type	Garmin GA29F	LEIAX1203+ GNSS
Image		
Gain	27 dB on the average	≈17 dB
Cost	about 40 €	about 1000 €

III. NETWORK REAL-TIME KINEMATIC POSITIONING

As described in [2], a network of permanent stations for real-time positioning is an infrastructure consisting of three parts: the first one is composed by all the permanent stations in a certain area (more or less extended), which position is well-known, that transmit their raw data to a control center in real-time. The second part consists of a control centre which receives and processes the data coming from all stations in real-time: this control centre must also fix the ambiguity phase for all satellites of each permanent station and calculate all dispersive biases (ionospheric and tropospheric delays etc.). The third part is the set of network products that can be broadcasted from the control center to the user. The less elaborate product is the raw measurement file of each permanent station that the user may require for post processing purposes.

The most required products are the stream data called ‘differential corrections’ which are provided in real-time from the control centre to each user who needs to perform a real-time positioning. These differential corrections are usually broadcast through the web, according to the RTCM standard encoded by the Homonymous Commission [6], with a specific protocol both for decoding and a user authentication called NTRIP. Only the correct fixing of the network carrier phase ambiguities allows the correct estimation of these biases. The biases calculated from the control centre can easily be interpolated in the position of the various rover receivers [7]. The rover receiver can also fix the ambiguity phase using the data broadcasted by the network software: in this way the user can obtain a high positioning accuracy in real-time.

Different interpolator modalities [1] [11], which are more or less complex, are available: some of them are possible only with double frequency instruments (the first two described in the following list) while other can be applied also by a L1 receiver.

The only two specific alternatives for L1 receivers are outlined here:

- NRT (nearest correction): in this modality the network software broadcast the data of the nearest station to the rover. The receiver must transmit to the control centre its approximate position (for example through the NMEA – National Marine Electronics Association - message)
- VRS® (*Virtual Reference Station*): in this modality, the task of the network software is not only to model, but also to interpolate these biases in the position of the rover receiver, which uses these corrections as if they came from a master station that really exists [10]. The task of the network software increases, while it decreases that of the receiver [2]. The rover receiver also must not have special computing power, but it must be able to use the differential corrections and to fix the ambiguity phase [5][7]. Also in this case the receiver must transmit to the control centre its approximate position.

This last modality, which requires the broadcasting of ‘correct’ pseudorange and carrier-phase measurements, is also ideal for the use of single-frequency or mass market receivers.

This positioning method, despite it being more complex for the network software, also allows direct generation from the control center, while some of the ‘synthetic’ data files required are ideally equivalent to ones that could be generated by a permanent station located near the rover site. These files are produced in standard RINEX format, are also called ‘Virtual Rinex’ and allow for high accuracy of the positioning in a differential post-processing approach. These aspects are not considered in this paper because are not useful for precise farming applications, which needs the real-time.

IV. REAL-TIME PERFORMANCES

In order to verify the accuracy achievable with the u-blox EVK-5T receiver with the network corrections, it was decided to analyze both the EGNOS and the u-blox corrections for the test-site area under analysis.

The receiver was settled on a stable and undisturbed site and a measurement sessions of 24 hours length (in order to make results independent from the GNSS satellite constellation) with an acquisition rate equal to 1 s was made. The point reference coordinates were determined with high accuracy through a post-processing adjustment; this has allowed the evaluation of the positioning errors during the acquisition sessions.

In Fig. 2 it is possible to see the graph, which shows the cumulative distribution frequency (CDF) of the planimetric error within 24 hours of measurement using different types of corrections. The blue curve represents the cumulative error with EGNOS correction [4], while the green curve represents the cumulative error correction using the Free service u-blox ‘AssistNow Online’ (<http://www.u-blox.com/en/assisted-gps.html>) one. As it is possible to note, 95% of the planimetric errors are less than 1.9 m with the first correction and less than 2 m with the second one. However with this receiver, in both cases, it is not possible to go down below the accuracy of a meter in planimetry: this level of accuracy may be sufficient for some purposes of precise farming, but not for those that we have cited.

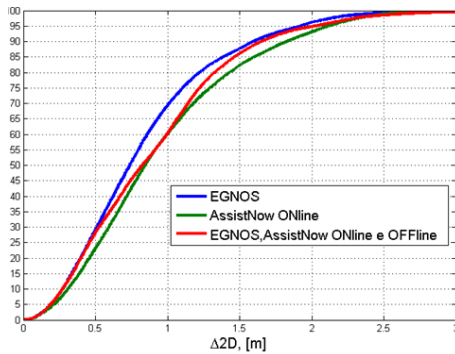


Fig. 2. CDF of the planimetric error with EGNOS and u-blox corrections

Starting from this results, some experiments using mass-market receivers for NRTK positioning were performed within the Regione Piemonte CORSs (Continuous Operating Reference Stations) network (<http://gnss.regione.piemonte.it/firmIndex.aspx>).

As rover site, an area near Vercelli (very famous city in Italy for rice culture) was chosen because this place is located at the centre of five permanent stations of the Regione Piemonte network (Fig. 3). The network products used are the VRS[®] and NRT streams broadcasted by the network software Spidernet of the Leica Geosystems[®] company. The route was deliberately chosen to represent an open space area in order to simulate the agricultural environment.

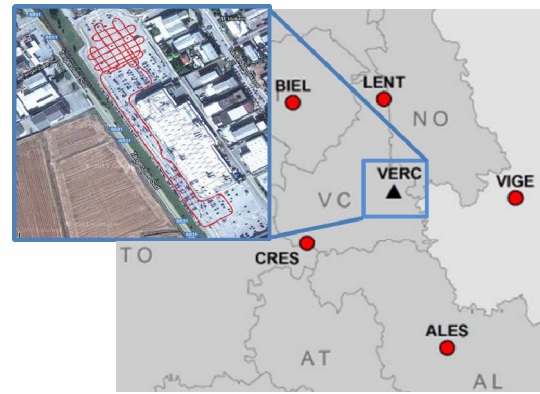


Fig. 3. The rover site (black triangle with a zoom of the area in the blue box) and CORSs (red point)

To perform the NRTK positioning the routines RTKLIB V. 2.4.2 were used (<http://www.rtklib.com/>). In particular for these experiments the RTKNAVI tool was used. This tool allows for providing as input both the raw data (pseudorange and carrier-phase measurements) of the u-blox receiver and the stream data coming from a network with NTRIP authentication. For this reason the receiver was connected to a laptop where was possible to have the Internet connection.

This software is also able to fix the ambiguity phase through different algorithms and it is also possible to set a threshold ratio to fix ambiguities. The ambiguity phase of a certain epoch is fixed if the ratio is greater than a threshold; the ratio is defined as a division of the variance (σ_0^2) of the best estimation respect to the variance of the second best estimation values while the threshold is a choice of the user. In this paper we have performed some tests with a ratio threshold equal to 3 (that is a reasonable value) and equal to 10^9 (that means ratio equal to plus infinity, so that all the positions calculated by the software were defined as ‘float’). We know that this last kind of positioning have generally less accuracy however, it exclude the possibility of gross errors caused by false fix.

TABLE III. RESULTS OBTAINED WITH DIFFERENT CORRECTIONS AND RATIO

	Ratio 3		Ratio ∞	
	VRS	NRT	VRS	NRT
% Fix	72 %	-	-	-
% False Fix	0 %	-	-	-
% Float	27 %	100 %	98 %	100 %
% Float < 20cm	100 %	0 %	51 %	68 %
Max HDOP	1.3	-	1.3	1.3
Max SNR	47	-	47	45
Residual errors	0%	-	0 %	5 %

The results obtained with the geodetic antenna are shown in TABLE III. Considering ratio equal to 3, a good result is related to the percentage of points with fixed ambiguities. With VRS[®] corrections the ambiguity phase is fixed in 72% of

cases, without any "false fix". If we consider the NRT correction, it is possible to note that there are no points with fixed ambiguity phase.

All the points have real ambiguity values, so they are less precise and they can be classified as "float". It is important to underline that all float position have an error position greater than 20 cm while in the case of VRS[®] all the points enter into this threshold. In any case, the best result is obtained with this last correction.

Considering the case with ratio equal to plus infinite, all points have real ambiguity: with VRS[®] corrections 51% of points have a planimetric error of less than 20 cm while with the NRT the percentage rises to 68%. In this case, it is better to apply corrections nearest.

The same experiment with the Garmin antenna was made: in TABLE IV. a comparison of results obtained with two antennas were made, considering ratio equal to 3 and VRS[®] correction.

TABLE IV. COMPARISON OF OBTAINED RESULTS WITH RATIO = 3

	VRS correction – Ratio = 3	
	Garmin	Leica
% Fix	60 %	65 %
% False Fix	0 %	0 %
% Float	40 %	35 %
% Float < 20cm	61 %	47 %
Max HDOP	1.3	1.3
Max SNR	47	47
Residual errors	0%	0%

As it is possible to notice, there are no relevant improvements considering a low-cost antenna despite the geodetic one. The number of fixed positioning obtained with the Garmin antenna is little less that those obtained with the Leica ones. Despite that, the float solution obtained with the Garmin antenna are more accurate respect to the other obtained with the Leica one: 61% of float positioning obtained with the first antenna has an accuracy less than 20 cm against 47% obtained with the second one.

The last brief analysis involve different types of antenna. We have considered one antenna at time splitted into two receivers thanks to the splitter in order to verify also the positioning accuracy obtainable with the u-blox.

In order to do this, we have acquired also the Leica raw data that we have post-processed to obtain the "true" positioning. After that, we have compared the coordinate obtained with two receivers in NRTK positioning with those obtained in post-processing (with fixed ambiguities thanks to Leica Geo Office 8.0 software). The results of these comparisons are shown in TABLE V. and TABLE VI.

TABLE V. POSITIONING ACCURACIES WITH GEODETIC ANTENNA

	LEIAX1203+ GNSS antenna	
	mean [m]	σ [m]
LEA EVK-5T (u-blox)	0.09	0.18
Leica 1230GX+ GNSS (Leica Geosystems [®])	0.03	0.04

TABLE VI. POSITIONING ACCURACIES WITH LOW-COST ANTENNA

	Garmin GA29F	
	mean [m]	σ [m]
LEA EVK-5T (u-blox)	0.14	0.20
Leica 1230GX+ GNSS (Leica Geosystems [®])	0.08	0.12

Despite the trajectories are not exactly the same in this two cases, it is possible to do some considerations.

The performances of the mass-market receiver are worse than those obtained with the geodetic one if the geodetic antenna is considered: in this case, the σ is 4 times more than those obtained with the Leica; in addition to this also the accuracy is worse.

Considering the Garmin antenna, the quality of the positioning change: the accuracy decrease and the noise of the solutions increase. Both the gap of noise and accuracy between Leica and u-blox positioning decrease drastically: these two solutions became more similar and the obtained results are useful for most precise farming applications anyway.

V. CONCLUSIONS

As previously said, some mass-market receivers are able to provide the pseudorange and carrier-phase measurements on the GPS L1 and, in the future, also on the Galileo E1 frequencies. By making full use of these characteristics, it is possible to obtain an average level of positioning accuracy which is much better than that obtainable today with EGNOS corrections, if the corrections which are broadcast by a network of permanent stations for real-time applications are considered.

The choice of different NRTK corrections bring the user to obtain different results in terms of accuracy and ambiguity fixing percentage. Also the ratio of the ambiguity fixing play a fundamental role in the positioning: the user ought to choose a good compromise to the ratio value and the positioning accuracies. In this paper it has shown that ratio equal to 3 is a good compromise between these two parameters: considering the VRS[®] correction, all the float solutions have a discrepancies less than 20 cm respect to the "true" position, obtained by a post-processing approach. With the NRT correction no fixed position are available and all the float position have an error greater than 20 cm; this is probably done due to the fact that the nearest station was about 20 km far from the rover site. So it is possible to affirm that, in every case, the

CORSs network allow to obtain, for a real-time approach, the best possible solution even if a mass-market receiver is considered.

Precision and noise of results in using these receivers depends very much also on the antenna used. However, it is possible to find a good compromise and a favourable price/performance ratio with the use of low-cost antennas.

So we can affirm that this type of low cost antenna combined with the u-blox receiver can be a good solution for some application of precise farming, if these instruments are used for a kinematic positioning into CORSs network.

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