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Comparative Survey of the Relative GPS Fix Accuracy

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Abstract: There have many different GPS solutions applied in agriculture. Some of them can achieve 1 cm accuracy, but they are very complicated and expansive. From the investigations, whose are made, it is determined that many of the low cost receivers are making systematical errors. Because the farmers know the exact geographic place of their fields, it is more important be determined the relative displacement to the field corners or other marks. Due to this relative accuracy becomes by our opinion most significant parameter for precision farming GPS development. The main purpose for our team is to survey the relative accuracy of GPS receivers, for witch operations they are suitable and finally find a possibility to increase the precision and applicability of the low cost solutions. For the aim we have planed a series of experiments with different configurations for static and dynamic observe.
Key words: GPS receivers, GPS accuracy, precision agriculture.

INTRODUCTION

GPS receivers are important component of the precise agriculture. Generally GPS are used for automatic steering or in common with other electronic systems and sensors for position dependent data acquisition. There have three different type satellite navigation systems, but some of them are not completed and most used appears the GPS system. Many research groups are trying to determine the GPS fix accuracy at the different locations in the world. For the aim they are using various methods and techniques. Some researchers are using GPS receivers, placed on a rail cars (Taylor, R.K., etc., 2004), or on different vehicles (Witte, T.H., A.M. Wilson, 2004) in exploitation conditions or simulated exploitation conditions. Other groups are making laboratory tests (Weltzien, C., A. Chappuis, 2003) or are using different simulation methods (Kopf, S., T. King, W. Effelsberg, 2007). In most surveys results compares with absolute coordinates, predicted analytical or measured with most accurate ways. But there stay still opened the question what is the accuracy of the GPS receivers relative themselves i.e. if we measure with one device only and collate statistically results wit other cumulated data. In relative measurements systematic error is ignored. So comparison between absolute and relative accuracy can gave systematic error estimation. In our study we are trying to compare absolute and relative GPS fix accuracy and to create methodology for GPS receivers fix accuracy determination tests.

Figure 1. Experiment installation view.

METHOD

Used method is similar to this in (Weltzien, C., A. Chappuis, 2003) and it is based on continuous closed circle movement. This method is very suitable as for absolute, as for relative accuracy determination, because movement trajectory is known and the mean coordinates must coincide with circle centre. The study was conducted at the test area of "Testing for

Agricultural and Forest Machinery and Spare Parts Centre" – Rousse, Bulgaria. Installation consists from concrete ring apron and rotable jib with 16m radius, as shown in Figure 1. The jib is operated by driving wheel and motor. The jib periphery velocity can be regulated gearless between 0 and 11 km/h. GPS receivers are placed at one arc on 16m radius exactly, as shown in Figure 2 and at the ring centre for the static observe. There have been used three types low cost GPS receivers from three different manufacturers respectively: Garmin-60, HP iPAQ rx5935/rx5720 and ELT-3 GPS locator produced from Bulgarian company ElectronInvest. All receivers are single frequency, none DGPS. The experiment was conducted during 12h with velocity 10km/h, witch corresponds with agriculture machines working speed. The data from the GPS receivers was sampled every 1S and saved on FLASH memory or have been translated via a built in radio transmitters. Because Latitude-Longitude-Altitude (LLA) geodetic coordinates are not appropriate for our analyses, all data records have been converted to Universal Transverse Mercator (UTM) coordinates. For more convenience UTM Longitude coordinates will be considered as X – axis and UTM Latitude coordinates as Y – axis.

Figure 2. GPS receivers placement on Experimental installation view.

Coordinates of the ring center X_C and Y_C are determined by more accurate geodetic instruments and so can be assumed that they are the true coordinates. As have been mentioned above, in ideal cease, both static and dynamic measured mean values for X and Y coordinates X_m and Y_m must coincide with the real geodetic coordinates of the ring centre. Due to the measurement errors, practically results do not coincide. The difference between mean coordinates and real ones gives the Mean Systematic Error for each axis. The full Mean Systematic Error can be calculated with next expression:

$$\varepsilon = \sqrt{\left(X_m - X_C\right)^2 + \left(Y_m - Y_C\right)^2} \qquad (1)$$

Standard deviation S for static observations can be calculated from standard deviations for both axes S_X and S_Y respectively:

$$S = \sqrt{S_X^2 + S_Y^2} \qquad (2)$$

Measured dynamical coordinates for dynamic tests, in ideal case must be situated at circumference with radius 16 meters and center coordinates at the ring center X_C and Y_C. The current point, received from the GPS will lie to circle with different radius. This current radius can be calculated with the next equation:

$$R_i = \sqrt{\left(x_i - X_C\right)^2 + \left(y_i - Y_C\right)^2}\ , \qquad (3)$$

where x_i, y_i are coordinates of current pointer and R_i is current radius.

But as be mentioned above, the measured (Relative) center does not coincide with the real. In order last calculation can be made similarly for this relative center with the next equation:

$$R_i = \sqrt{\left(x_i - X_m\right)^2 + \left(y_i - Y_m\right)^2} \qquad (4)$$

Others most important parameters for accuracy estimation are: standard deviation, range, coefficients of variance and absolute deviation. The last one can be calculated with the next expression:

$$D = \left|R_i - 16\right| \qquad (5)$$

RESULTS

All points layout from the survey are shown on Figure 3. From first look it can be seen that points from different receivers are dispersed considerably and the relative centers are displaced.

Calculated statistic parameters for static survey are sown in Table 1. For some devices as HP watches sizable standard deviation value and also difference between values by two axes. Mean coordinates are not coincide with coordinates of the center. The disparateness or mean systematic errors are biggest for HP and smallest for ELT-3. Completely the last one device haves little bit better static parameters in comparison with other two.

Dynamic test results are dissimilar with static test ones. Calculations are sown in Table 2. Coordinates of the relative centers are remote differently for the three devices. So the mean systematic errors for the center as can be seen from the table are bester for ELT-3 and worst for Garmin.

Mean radiuses, referenced to relative centers excluding HP are closer to the real value in comparison with referenced to the absolute center. For mean radiuses (absolute and relative) bester value haves ELT-3 again. Worst value for absolute center haves Garmin, when for relative referenced measurements gives HP.

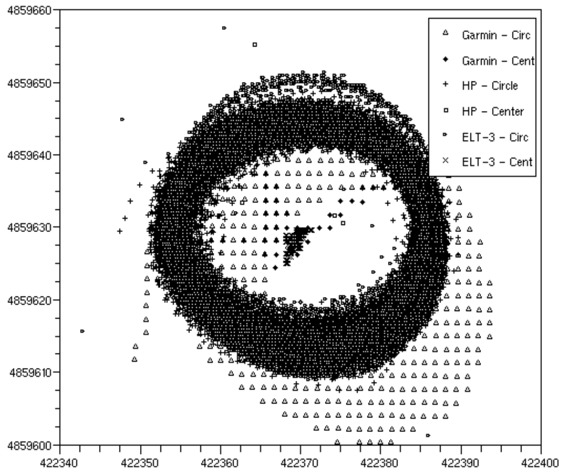

Figure 3. Received points layout.

Table 1. Calculation results for static observations.

	Garmin	**HP**	**ELT-3**
Center Longitude Coordinate X_C, m	422368.90		
Center Latitude Coordinate Y_C, m	4859627,86		
Mean longitude value X_m (Relative centre), m	422369.16	422373.70	422369.29
Mean latitude value Y_m (Relative centre), m	4859628.69	4859631	4859628.06
X – Axis Standard Deviation S_x, m	1.08	4.15	0.72
Y – Axis Standard Deviation S_Y, m	1.02	1.17	1.19
Standard Deviation S, m	1.49	4.31	1.39
Mean Systematic Error, m	0.87	5.74	0.44

Table 2. Calculation results for dynamic observations.

	Garmin	**HP**	**ELT-3**
Center Longitude Coordinate X_C, m	422368.90		
Center Latitude Coordinate Y_C, m	4859627,86		
Mean Longitude value X_m (Relative centre), m	422373.52	422369.27	422369.72
Mean Latitude value Y_m (Relative centre), m	4859625.18	4859629.69	4859629.18
Mean Absolute Radius R_A, m	16.58	15.78	16.07
Mean Relative Radius R_R, m	16.19	15.73	16.05
Standard Deviation for Absolute Center S_A, m	4.49	1.96	2.02
Standard Deviation for Relative Center S_R, m	2.08	1.42	1.48
Range for Absolute Center Δ_A, m	28.79	13.82	30.57
Range for Relative Center Δ_R, m	20.49	15.01	29.75
Mean Absolute Deviation for Absolute Center D_A, m	0.58	0.22	0.07
Mean Absolute Deviation for Relative Center D_R, m	0.19	0.27	0.05
Coefficient of Variance for Absolute Center V_A	0.127837	0.088938	0.088446
Coefficient of Variance for Absolute Center V_R	0.089010	0.075834	0.075741
Mean Systematic Error, m	5.34	1.87	1.55

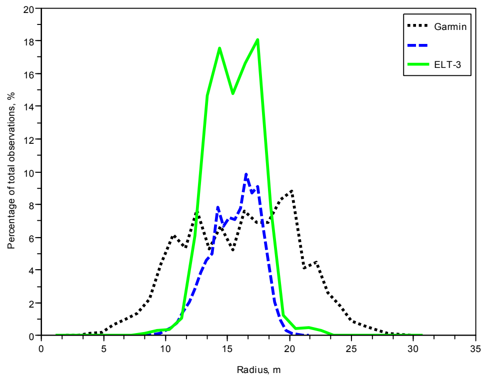

Figure 4. Observed radius distribution diagram, referenced to absolute center.

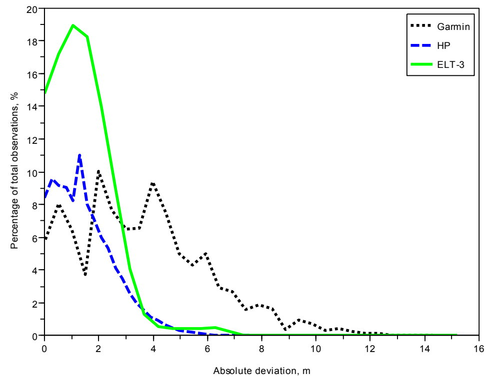

Figure 6. Observed absolute deviation distribution diagram, referenced to absolute center.

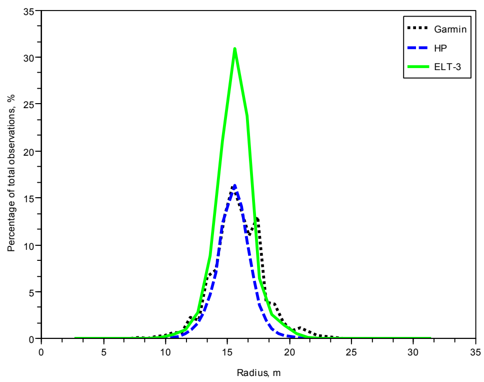

Figure 5. Observed radius distribution diagram, referenced to relative center.

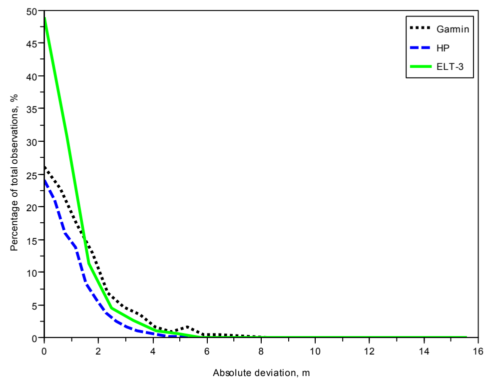

Figure 7. Observed absolute deviation distribution diagram, referenced to relative center.

Radius distribution diagrams, referenced to absolute and relative centers are shown on Figure 4 and Figure 5. Likewise these diagrams give notion about standard deviation. For absolute center, distribution is not by normal law. Due to the different axis errors, there have by two expressed peaks. For relative center, distributions are close to normal law.

Standard deviation estimates are given in Table 2. Because the mean values minimizing the standard deviation, estimations referenced to relative center are less than to absolute. Comparison between standard deviations referenced to absolute and relative centers by Fisher criterion shows, that they are not statistically equivalent. By standard deviation bester value haves the HP receiver. ELT-3 gives close values, but worse by this parameter, when the worst appears the Garmin receiver again. These results are confirmed additionally from diagrams on Figure 4 and Figure 5.

Absolute deviation distributions referenced to absolute and relative centers are shown on Figure 6 and Figure 7. This parameter graphically characterizes the probability the absolute deviation have particular value. For relative center absolute deviation becomes less than for absolute. For both centers the biggest dispersion haves the Garmin receiver. Bester in mean absolute deviation appears ELT-3, but HP receivers haves better distribution characteristics.

Most complex numerical parameter is coefficient of variance. It matches mean value and standard deviation estimations. Less value in this case means better accuracy. Coefficients of variance for relative referenced results are less than for absolute ones. By this parameter HP and ELT-3 GPS receivers are identical.

Range parameter characterizes maximal measurement deviation achieved from GPS receivers. By this parameter bester are the results from HP.

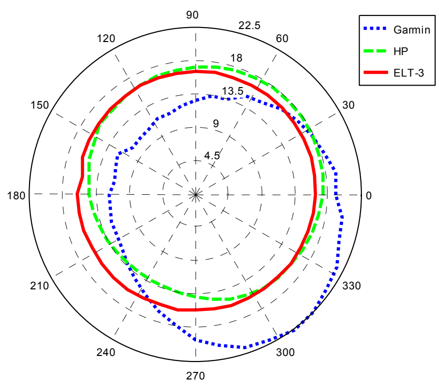

Figure 8. Mean radius value in dependence from rotation (speed vector direction) angle, referenced to absolute center.

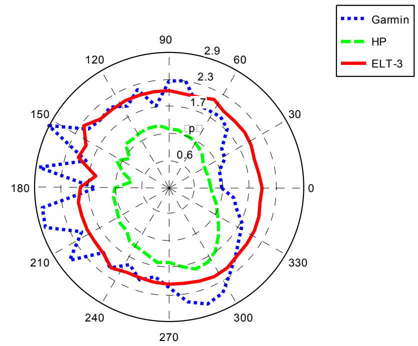

Figure 10. Standard deviation in dependence from rotation (speed vector direction) angle, referenced to absolute center.

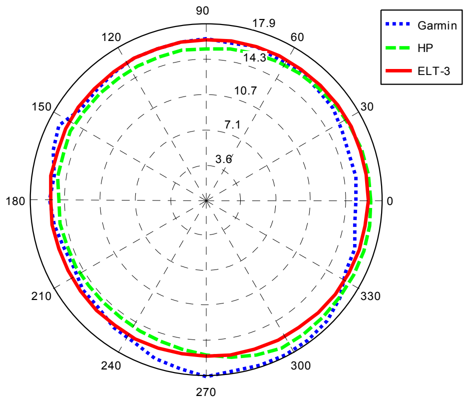

Figure 9. Mean radius value in dependence from rotation (speed vector direction) angle, referenced to relative center.

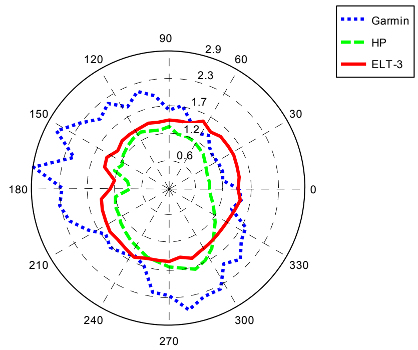

Figure 11. Standard deviation in dependence from rotation (speed vector direction) angle, referenced to relative center.

As can be seen from Figure 1, measured points are distributed unsteady by the different arcs from the circle. This involves consideration existing dependence from the rotation angle, witch means from speed vector direction. To be surveyed speed direction dependence measured coordinates are divided to 40 groups in dependence from position angle, referenced to absolute or relative center. With each group are calculated several parameters. Results are placed in polar coordinates in dependence from each mean group angle. Position zero point is in east direction, but it corresponds to north zero speed direction.

Mean radiuses from speed direction angle correlations referenced to absolute and relative centers are sown on Figures 8 and 9. As can be seen at figures ELT-3 the mean radius results practically are not correlated with speed direction angle. For other two receivers observes correlation in absolute center referenced measurements only. This means that absolute coordinates are displaced with the mean systematic errors.

Standard deviation – speed direction angle correlations, referenced to absolute and relative centers are shown on Figures 10 and 11 respectively. For ELT-3 device standard deviation practically do not correlates with speed direction angle again.

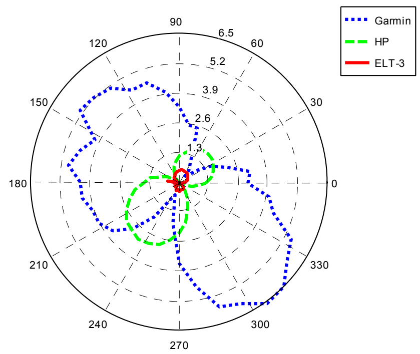

Figure 12. Absolute deviation in dependence from rotation (speed vector direction) angle, referenced to absolute center.

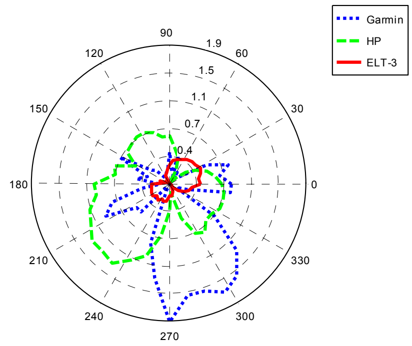

Figure 13. Absolute deviation in dependence from rotation (speed vector direction) angle, referenced to relative center.

For HP receiver small standard deviation – speed direction angle correlation can be observed. In Garmin this dependence is most brightly expressed. Only for ELT-3, relative center referenced standard deviation values are decreased comparative with absolute ref. ones. For other devices haves not significant change.

Other speed direction angle correlation will be considered is for absolute deviation. Results for absolute and relative centers are sown on Figures 12 and 13. How ca be seen from figures and Table 2, ELT-3 device gives very low mean absolute deviation and its results can be ignored. So can be mentioned this receiver absolute deviation is not dependent from the speed direction. Both other devices absolute deviations are strongly correlated from the speed direction. HP gives less absolute deviation and less expressed correlation from speed direction angle comparative with Garmin. In relative centre referenced investigation Garmin and HP haves less absolute deviation, but not less speed direction correlated, when for ELT-3 haves not significant difference.

CONCLUSIONS

Before any conclusions be made, there is very important to be specified that in difference to others ELT-3 devices haves not (or it was disabled) acceleration or other GPS assistance sensors.

Completely HP iPAQ rx5935/rx5720 and ElectronInvest ELT-3 GPS receivers have equivalent accuracy. ELT-3 gives better mean values, when HP haves better dispersion characteristics.

Garmin-60 haves worst parameters, comparative with other two tested devices.

Using of acceleration or other GPS assistance sensors usually involves speed direction dependence.

GPS assistance sensors in some cases can improve some low cost receiver’s parameters like standard deviation, but cannot improve considerably complete fix accuracy.

Low cost, single frequency, none DGPS receivers are suitable for some not required so high accuracy operations as grain crop or soil condition mapping, but for other operations like automatic steering they are not appropriate.

Dual frequency and/or DGPS receivers are required for automatic guidance or other high precision operations.

Relative measurement method can make GPS fix accuracy little bit better, but then needs statistical information to be accumulated. Therefore numerous measurements must be made.

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