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ACCURACY ANALYSIS OF GPS SPORT RECEIVERS IN DYNAMIC MEASUREMENTS

ABSTRACT

Producers of GPS receivers nowadays offer many easy-to-use, mobile units for amateur and professional athletes. Similar functionality parameters and a relatively low price make it difficult for the average user to make a choice. This article compares technical aspects of different GPS devices and presents results of their dynamic accuracy evaluation. Selected GNSS units were divided into two groups: specialized dedicated to sports and GPS data loggers. The tests were carried out on the sports stadium of the Gdansk University of Physical Education and Sport, where the lanes were measured with the use of the GPS Total Station phase receivers Leica GS-15 VIVA, supported by Polish Active Geodetic Network ASG-EUPOS. The ellipsoidal coordinates logged in the GNSS sports receivers were transformed in Gauss-Kruger projection to conformal *x*, *y* coordinates and statistical distributions of the predictable accuracy were calculated. The article also discusses other (important from a functional point of view) characteristics of GPS receivers used by athletes.

Keywords:
GPS, sport measurements, accuracy.

INTRODUCTION

Progress in global satellite navigation systems, NAVSTAR GPS in particular, made them easily accessible in many areas of life. Ever-higher accuracy of positioning, as well as progress in practical use of electronics (manifested in miniaturization, for example), brought a complicated technology to the level of operation acceptable for everyone.

An average user finds it very difficult to choose from a wide variety of mobile, easy-to-use and relatively cheap receivers for athletes and tourists — some are designed for runners and joggers, others for cyclists, still others for sailors — and they all have similar parameters. Moreover, some producers do not even provide navigation specifications of their devices. So how to assess and adjust their potential to users' expectations? The receivers are specific 'measuring devices', requiring (by definition) access to satellites. In this article, they are divided into groups according to the purpose for which they are intended, and then compared to the model, i.e. the geodetic model of the stadium, determined with the use of precision equipment.

OUTLINING GEODETIC MODEL OF A STADIUM

Tachymetric measurement

In order to carry out kinematic tests of GPS sports receivers it was necessary to take precise total station measurements of the track and field stadium of Gdansk University of Physical Education and Sport. Within the research, a position of two lanes was outlined with the use of the Leica TPS 1103 total station. It is an automated station with internal measurement storage, with precise 10 ^{cc} angle measurement, at a range of 3,000 m, with outlining precision (± 2 mm). The first lane was outlined at a distance of 30 cm from the track's kerb, the other one was marked out according to the line separating the first and the second lanes. Measurement was made with a reflector technology, using a 1,8 m long pole (fig. 1).


Fig. 1. Measuring instrument — an electronic total station TPS 1103
and reflector technology for measuring a sports stadium track [own photo]

As a result of measurements, 259 topographical points were obtained, as coordinate points for each lane. On straights, the points were positioned every 10 metres, and on curves — every 1 m. The total station was placed on the field, which ensured good aiming direction (visibility) of the measuring reflector. Each surveyed point was assigned with three ortho-Cartesian coordinates in relation to the adopted coordinate system — the position of the total station. The figure below shows the stadium layout with point numbers and height values.

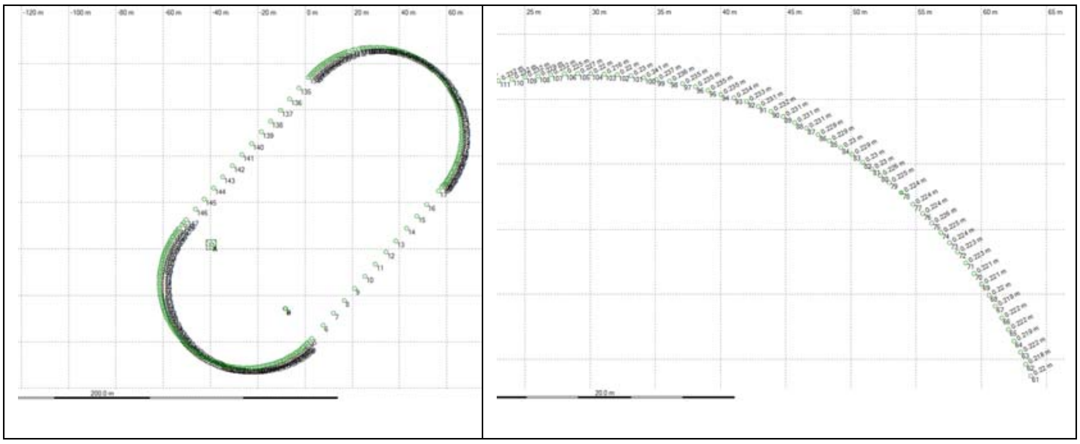

Fig. 2. The layout of the stadium measured with the total station (left), height above ground level measured on the curve (right) — a single lane [own study]

According to the rules [IAAF, 2008], the track measurement should be carried out at a distance of 30 cm from the kerb (for the first lane), and for the other lanes the measuring distance is 20 cm (fig. 3).

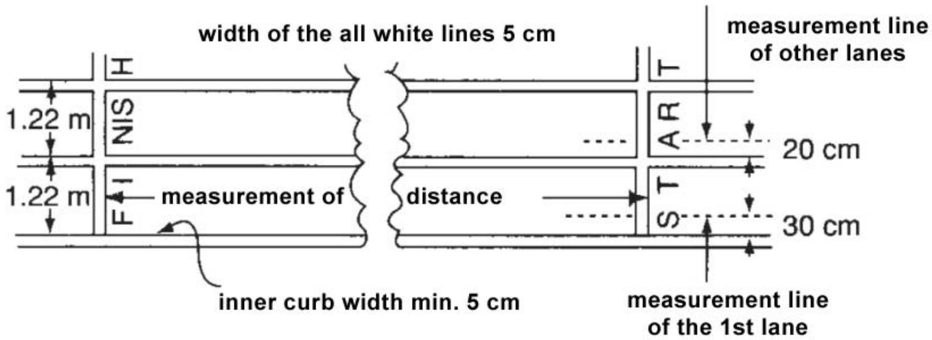

Fig. 3. The rules for marking out lines for the stadium measurement [2]

Moreover, the IAAF standards say that cross fall of the track should be 1%, and longitudinal fall (in the direction of running) 0,1%. According to these directives, the longitudinal fall is measured along the direction of running every 50 metres starting from the finishing line. The fall of each section (i.e. 50 metres) should not exceed 0,1%. The total longitudinal fall should be 0% (this means that the sum of all the falls measured every 50 metres, taking into account the differences in relation to the level at the finishing line, should equal 0). Fig. 4 below shows the changes in the stadium level measured on the first — inner — measuring lane.

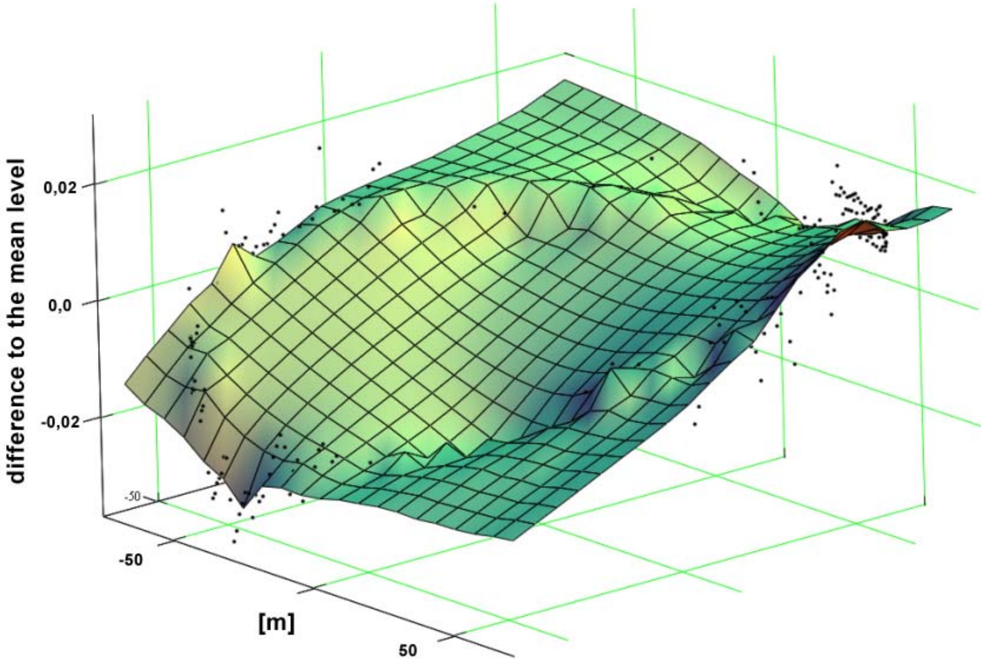

Fig. 4. Changes in the stadium level measured with the total station on the first — inner — measuring lane [own study]

The tachymetric survey showed that maximum change in height was 65 mm for the first lane and 48 mm for the line separating the first and second lanes. Standard deviation set for lane 1 is 14,23 mm, and for the borderline between lanes 1 and 2–12,61 mm. The histogram of the height differences between the mean value for lane 1 and the borderline between lanes 1 and 2 is presented below.

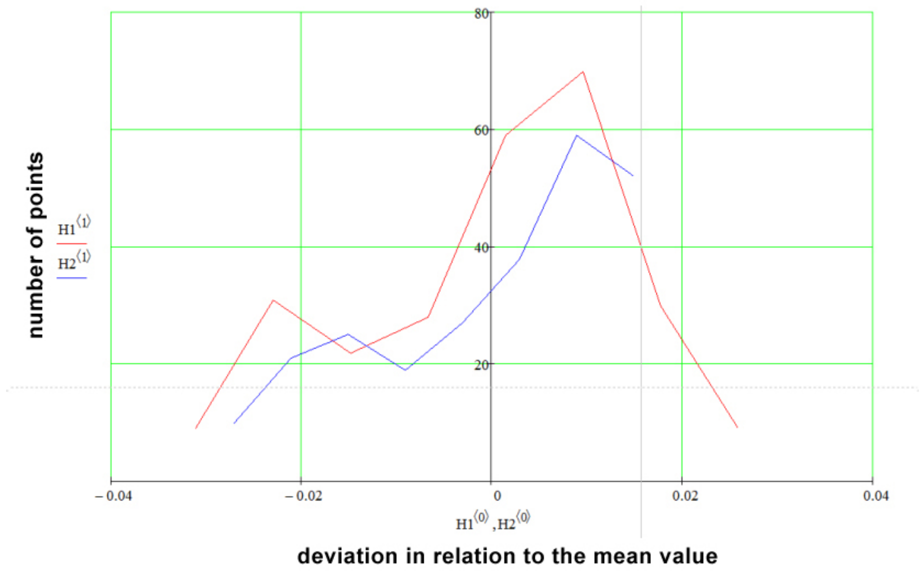

Fig. 5. Histogram of height deviation of points in relation to the mean value of the stadium level [own study]

Technique of the GNSS survey

Inventory satellite survey was conducted with the use of the Active Geodetic Network ASG-EUPOS. At present, ASG-EUPOS measuring architecture consists of the following groups of reference stations: 84 stations with the GPS module and 14 stations with the GPS/GLONASS module. Additionally, the system co-works with almost 30 stations abroad. Another segment of the ASG-EUPOS system is National Management Centres (KCZ). The main Management Centre is located in Warsaw, with a reserve centre in Katowice. The scope of their tasks include control and management of the station network, generating adjustments to observations, and making satellite observations accessible. The Computing Centre deals with the maintenance of the frame of reference. Computing Centres are designed to handle concurrently a maximum of 1,200 users.

Users of real time services receive adjustments by means of the Internet and GSM mainly. Adjusting data are sent to users through the network by means of the specifically designed NTRIP protocol. In GSM, a packet data service — GPRS — is used. The inventory survey of the stadium was carried out by means of NAWGEO service of the ASG-EUPOS network which enables the positioning of the receiver in real time with the accuracy of 2–3 cm (horizontally) and 3–5 cm (vertically). Of all available methods of making adjustments to GPS surveys, a ‘virtual station’ technique was used; the technique makes it possible to receive GPS adjustments dedicated to the receiver coordinates (fig. 7).

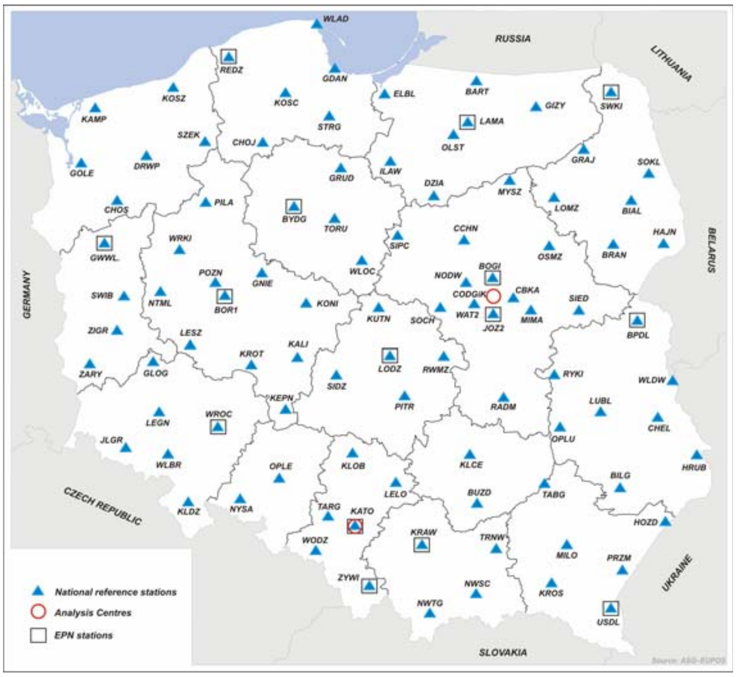

Fig. 6. ASG-EUPOS network architecture [3]

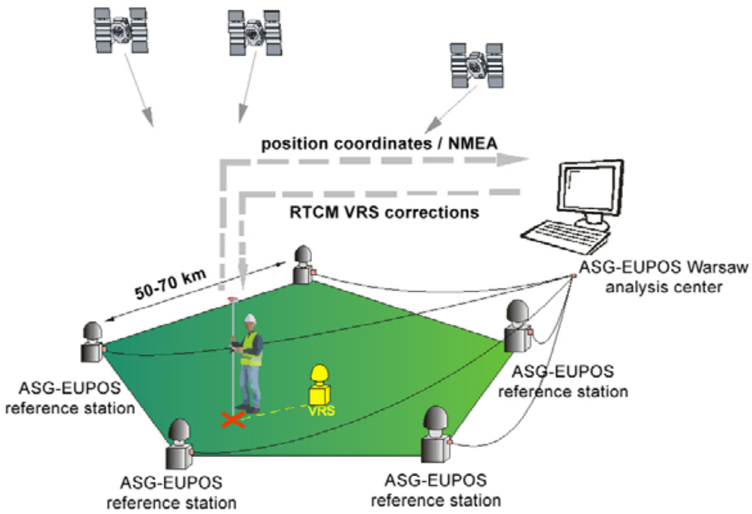

Fig. 7. Concept of VRS solution in GNSS systems [own study]

The measuring set included Leica VIVA GS-15 receiver with CS-15 controller, whose accuracy in kinematical mode (phase measurement) can be estimated as 10 mm

+ 1 ppm (rms) horizontally and 20 mm + 1 ppm (rms) vertically. It was placed on a range pole measuring points that were laid out earlier for the tachymetric survey. This geodetic set was used for taking measurements of the first measuring line and the borderline between lanes 1 and 2. The marked out point coordinates were recorded by the inner memory of the receiver. Both measuring series (the first measuring line of the stadium) included 259 measurements.

Fig. 8. Taking inventory measurements of the stadium and GNSS receiver with a controller [own study]

The coordinates of the receiver's position (curvilinear — angular) were projected to horizontal coordinates (rectilinear) of the national horizontal coordinate system 2000 (ellipsoid GRS-80, in Gauss-Kruger projection, central meridian 18°, scale factor $k = 0{,}999923$, according to the relationships:

$$x = k \cdot R \cdot \left[\frac{S(B)}{R} + \frac{(\Delta L)^2}{2} \cdot \sin(B) \cdot \cos(B) + \frac{(\Delta L)^4}{24} \cdot \sin(B) \cdot \cos^3(B) \cdot (5 - t^2 + 9 \cdot \eta^2 + 4 \cdot \eta^4) + \right.$$
$$\left. + \frac{(\Delta L)^6}{720} \cdot \sin(B) \cdot \cos^5(B) \cdot (61 - 58 \cdot t^2 + t^4 + 270 \cdot \eta^2 - 330 \cdot \eta^2 \cdot t^2 + 445 \cdot \eta^4 \right], \quad (1)$$

$$y = R \cdot \left[\Delta L \cdot \cos(B) + \frac{(\Delta L)^3}{6} \cdot \cos^3(B) \cdot (1 - t^2 + \eta^2) + \frac{(\Delta L)^5}{120} \cdot \cos^5(B) \cdot \right.$$
$$\left. \cdot (5 - 18 \cdot t^2 + t^4 + 14 \cdot \eta^2 - 58 \cdot \eta^2 \cdot t^2 + 13 \cdot \eta) \right], \quad (2)$$

where:

B, L — measured ellipsoidal coordinates;
R — radius of curvature of ellipsoid cross-section;
$S(B)$ — distance from the equator to a point of specific coordinates [m];
ΔL — distance of a point from the axial meridian [m];
$k = 0{,}999923$ — scale factor.

The other parameters of projection to planar coordinates in 2000 frame were:

$$t = \tan(B)\,; \tag{3}$$

$$\eta = \frac{e^2 \cdot \cos^2(B)}{1 - e^2} \tag{4}$$

where:

e — the first ellipsoid eccentric;
η — orientation angle of ellipse distortion.

As a result, the coordinates of the first measuring line and the borderline between lanes 1 and 2 were obtained in a form of planar coordinates.

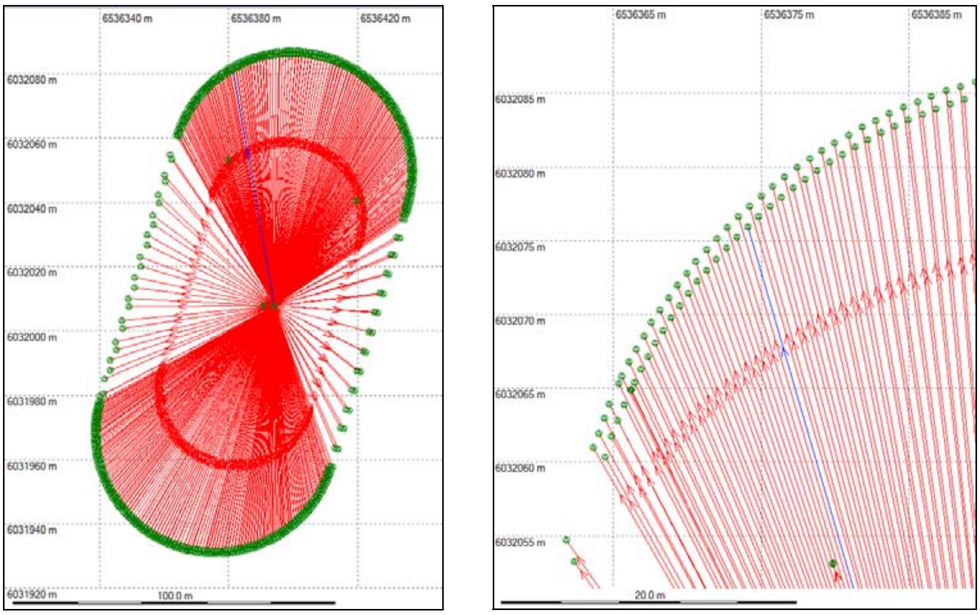

Fig. 9. Results of the inventory survey of the stadium carried out with a GNSS receiver [own study]

CONDUCT OF MEASUREMENTS AND RESULT ANALYSIS

Procedure of measurements and analysis of the results were carried out on the track-and-field stadium of the Gdańsk University of Physical Education and Sport. The receivers (14 different models) were placed one after another on a purpose-built trolley (fig. 10); the trolley was run with a constant speed of 5,5–6 km/h along the right edge of the borderline between lanes 1 and 2. Each lap ended with ca. 10-metre overlapping of measurements (removed during Leica Geo Office post-processing), performed because of the fact that it was impossible to switch off the ‘auto-pause’ function in one of the receivers, then the devices were switched off and moved on the trolley to the spot the measurement started, where they were switched on again. This way 7 traces of the stadium oval were logged (loggers — NMEA format, others — GPX universal exchange format, then both were converted to CSV format for further processing). The time of measurement was planned with the use of Trimble Planning 2.8 software, choosing the time of minimum values of geometry factors DOP.

For the purpose of this article, analyses were confined to those of two laps covered by six devices, divided into groups: handheld receivers dedicated to runners (Garmin Forerunner 310XT and 405), bicycle receivers (Garmin Edge 205 and 800), and universal loggers (Pentagram P3106, Qstarz BT-Q1000).

Fig. 10. Arrangement of devices on the measuring trolley [own study]

Handheld receivers Forerunner 405 and 310XT are dedicated to runners mainly, although the latter one is also convenient for triathletes, as it can be quickly mounted on a bicycle handle bar due to a special mechanism. Both receivers are waterproof (IPX7 standard). Bicycle receivers Edge 205 and 800 have easy-to-use touch screens, and data can be saved in their internal memory or microSD card (the Smart Recording mode suggested for Garmin units consists in logging key points only, where direction and velocity change). Universal loggers have the largest number of possible settings, and their producers give their exact navigation specification (contrary to the units of the first two groups). The units were set to the maximum frequency of logging (1/sec. — Garmin Forerunner 310XT, Pentagram P3106, Qstarz BT-Q1000), or used the mode suggested by the manufacturer (Garmin Edge 205 and 800, Forerunner 405).

The results of the measurements were analysed with the use of Mathcad 14 and Leica Geo Office Package. It must be pointed out that in navigation (geodesy) there are no strictly defined measures of accuracy of setting a position that could be applied to kinematic measurements. The lack of measures results from: diversified conditions of individual settings, loading consecutive positions with navigation data filtering, change in geometric conditions of GNSS constellations, etc. Therefore, implementing dynamic measurements makes it impossible to make basic assumptions for statistical studies:

— the occurrence of errors of δ value and $-\delta$ value is equally probable;
— the probability of the occurrence of error of δ value is a decreasing function of its absolute value $|\delta|$;
— the greatest probability of the occurrence of error δ is zero.

Therefore, it was reasonable to arbitrarily establish measures for the assessment of the accuracy of dynamic measurements by adopting selected statistics used in stationary measurements referred to 2D settings. The most frequently used statistical assessment measure of position error of a navigation system is Distance Root Mean Square:

$$DRMS = \sqrt{(\sigma_x)^2 + (\sigma_y)^2}, \tag{5}$$

where:

σ_x — is RMS uncertainty of determining longitude (geodetic);

σ_y — is RMS uncertainty of determining latitude (geodetic).

The probability of DRMS uncertainty stays within the range of 63,2–68,3% and depends on the relations between standard deviations. For $\sigma_x = \sigma_y$ p = 63%, while for $\sigma_x = 10 \cdot \sigma_y$ p = 68%.

In order to obtain a higher level of reliability of position measurements in geodesy and navigation, a measure of double DRMS is commonly used:

$$2DRMS = 2 \cdot \sqrt{(\sigma_x)^2 + (\sigma_y)^2}. \tag{6}$$

In navigation literature, the 2DRMS measure corresponds to the probability of the range of 95,4–98%, being in relation to mean square uncertainties determined by the values of two coordinates. It must be pointed out that in the NATO standardization terminology there is a similar term spelled: 2-D RMS, which is identical with DRMS (63–68%).

Another measure of accuracy assessment is a Circular Error Probability (CEP), referring to the length of the radius of a circle, where there will be 50% of measurements, determined according to real or approximate coordinates. Fig. 11 below shows the distribution functions of positions of individual receivers determined for two full laps.

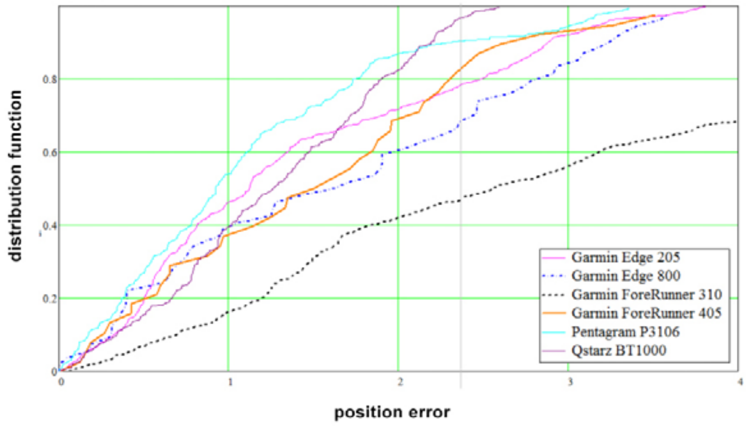

Fig. 11. Value of the error distribution function of positions of tested GPS receivers [own study]

In order to compare individual receivers, for which a diversified number of GPS position coordinates were logged, a probability density function was used, as shown in fig. 12.

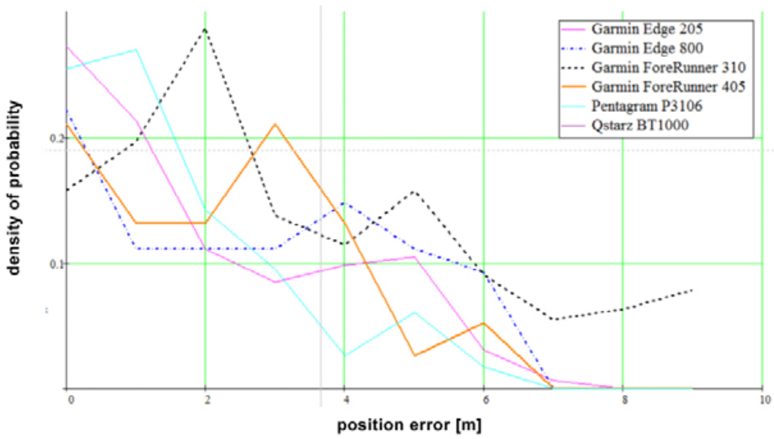

Fig. 12. Probability density function [own study]

The results of the assessment of the accuracy of individual receivers are presented in table 1.

Table 1. Accuracy of tested GPS receivers calculated on the basis of population

Type	drms	CEP	2drms
Garmin Edge 205	1,776	1,123	3,206
Garmin Edge 800	2,367	1,720	3,551
Garmin ForeRunner 310	3,955	2,567	7,099
Garmin ForeRunner 405	1,963	1,600	3,513
Pentagram P3106	1,323	0,924	3,045
Qstarz BT 1000	1,684	1,267	2,323

CONCLUSIONS

1. The measurements taken showed significant differences in the accuracy of coordinate determination between individual groups of receivers.
2. Logging receivers demonstrate the highest accuracy in determining positions.
3. A method of selecting points of position logging by means of Smart Recording, used by part of the tested receivers, does not show significant differences in relation to the other devices.

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