Mirosław CZECHLOWSKI[1], Tomasz WOJCIECHOWSKI[1], Mariusz ADAMSKI[1], Gniewko NIEDBAŁA[1], Magdalena PIEKUTOWSKA[2]
[1] Poznań University of Live Science, Institute of Biosystems Engineering
ul. Wojska Polskiego 28, 60-637 Poznań, Poland
e-mail: tomasz.wojciechowski@up.poznan.pl
[2] Koszalin University of Technology, Department of Agrobiotechnology
ul. Racławicka 15-17, 75-620 Koszalin, Poland

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APPLICATION OF ASG-EUPOS HIGH PRECISION POSITIONING SYSTEM FOR CEREAL HARVESTER MONITORING

Summary

The paper presents the application of a high precision positioning system ASG-EUPOS and its service NAWGEO for agricultural machines positioning. A measurement set was mounted on a cereal combine harvester and consisted of a GNSS antenna and receiver with a GSM modem for RTK corrections transfer. The positioning system was validated in a field during the 2011 harvest period in selected farms in southern and western Wielkopolska region in Poland. The total area of the field under study was 75 hectares. The quality of determining the machine's position was monitored. It was understood as standard deviation values for longitude, latitude and altitude above the mean sea level. The hypothesis about the importance of impact of the adopted criteria on the level of changes in the recorded deviation errors was tested. Field tests show usefulness of the ASG-EUPOS network and its VRS NAWGEO service for precise positioning of agricultural machinery in dynamic conditions. The obtained data can be used to create numerical models of fields on-line, for example, in selective cereals harvesting technology, but they require filtration to remove the points affected by positioning error exceeding the acceptable value.
***Key words**: GNSS, ASG-EUPOS, RTK, precision agriculture, agricultural machines positioning, combine harvester*

ZASTOSOWANIE SYSTEMU PRECYZYJNEGO POZYCJONOWANIA ASG-EUPOS DO MONITOROWANIA PRACY KOMBAJNU ZBOŻOWEGO

Streszczenie

W pracy przedstawiono zastosowanie systemu precyzyjnego pozycjonowania ASG- EUPOS i jego serwisu NAWGEO do pozycjonowania maszyn rolniczych. Zestaw pomiarowy został zamontowany na kombajnie zbożowym i składał się z anteny i odbiornika GNSS z modemem GSM do przesyłania sygnału korekcyjnego RTK w czasie rzeczywistym. Walidacja systemu pozycjonowania wykonana została w warunkach polowych w okresie zbiorów w 2011 roku na wybranych komercyjnych polach gospodarstw południowej i zachodniej Wielkopolski regionu Polski. Całkowita powierzchnia pola objęta badaniami to 75 hektarów. Jakość pozycjonowania urządzeniu była monitorowana, jako odchylenie standardowe błędu pomiaru długości, szerokości geograficznej oraz wysokości nad poziomem morza. Analizowano cztery kryteria jakości sygnału korekcji w funkcji czasu. Kryteriami tymi były: dokładność pozycjonowania w czasie zimnego i ciepłego startu oraz dynamika dokładności pozycjonowania w czasie ruchu i w spoczynku. Testowano hipotezę o znaczeniu wpływu przyjętych kryteriów na poziom zmian odchylenia standardowego rejestrowanych błędów. Przedstawiono przydatność sieci ASG-EUPOS i jej serwisu NAWGEO do precyzyjnego pozycjonowania maszyn rolniczych w warunkach dynamicznych oraz wykorzystania pozyskanych danych przestrzennych oraz ich filtracji przy tworzeniu modeli numerycznych np. w warunkach zbioru selektywnego.
***Słowa kluczowe**: GNSS, ASG-EUPOS, RTK , rolnictwo precyzyjne, pozycjonowanie maszyn rolniczych, kombajn zbożowy*

1. Introduction

For centuries successful management in agricultural production has been based on spatial and temporal variability in soil or plants in the field. With the development of precision land management systems, named precision agriculture, 30 years ago it became more precise and successful. The growth of precision land management is inextricably linked with the development of positioning systems such as Global Navigation Satellites Systems (GNSS). Nowadays the increasing application of GNSS receivers is connected with the development of positioning systems giving subdecimetre and subcentimetre precision. It gives an opportunity to increase the application of GNSS in agricultural production. GNSS correction signals used by farmers depend on specific operations. A typical yield or soil monitoring and mapping process can be done with subdecimeter accuracy, whereas such processes as site-specific transplanting, drilling or automated in row seed control can only be done with accuracy better than 0.04 m [1][2]. High positioning and navigation accuracy is indicated by the use of GNSS receivers for navigating agricultural vehicles, machinery and tools, as in agricultural autonomous ground vehicles [3]. However, in the case of soil and yield mapping submeter accuracy can only provide an acceptable position measurement but it is not possible to determine the field hypsometry. Hypsometry and further digital terrain models (DTM) could be used to estimate the variables of agricultural soil parameters, as indicated Florinsky with co-authors in their study [4]. The information about spatial soil variability in infield landforms may be useful data in the selective cereal harvest technology, as presented in earlier studies [5][6], but it needs decimetre or subcentimeter vertical accuracy.

The tractors and combine harvesters produced nowadays are equipped with GNSS receivers with the technical possibility to receive high precision correction signal. The agricultural machines produced about 15-20 years ago were not fitted with high precision GNSS receivers as standard, and those receivers do not support the latest protocol used by commercial satellite-based augmentation systems (SBAS) services such as Omnistar or StarFire. Such harvesters are still used. A potential solution to the problem could be the correction information from ground-based augmentation systems (GBAS) such as active geodetic networks. GBAS networks may be paid or used free of charge, and on the other hand, they can have a global, continental, regional or national range, e.g. IGS (worldwide), AUSPOS (Australia), CORS (USA) FarmRTK (Central Europe), SAPOS (Germany), SWEPOS (Sweden) or ASG-EUPOS (Poland) [7]–[10].

In Poland in practical agricultural applications there are such active, paid geodetic networks in use: ASG-EUPOS (Active Geodetic Network of EUropean Positioning System), Leica Smart Net, Nadowski Net, Topcon TPI-NETpro, or Trimble VRSNet. ASG-EUPOS is a nationwide network of reference stations, which officially started in 2005 but in practice they were launched in 2008 and originally free of charge but changed the status from free to paid in 2014 (2 years after the research). AGS-EUPOS makes continuous observations of GNSS satellites mainly from GPS Navstar but also from Beidu, Glonass and Galileo in accordance with EUREF standards. The standard service of ASG-EUPOS is NAWGEO service, which provides updates to RTK measurements. NAWGEO guarantees the highest accuracy both in kinematic measurements and in determining the location of static objects.

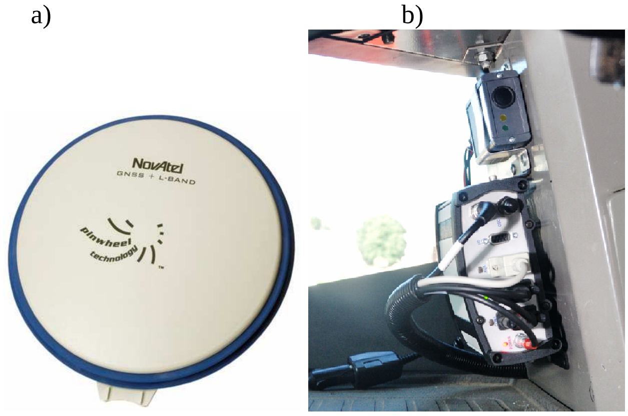
There is some information about use of ASG-EUPOS services in agricultural machines in static conditions but due to the lack of sufficient information about dynamic test research have been undertaken. GNSS accuracy in dynamic conditions can be different than in static conditions [11]. The aim of the study was to assess the possibilities to use the active geodetic network, such as the ASG-Eupos service, in agricultural machines in motion using the NAWGEO service provided by the GSM network and the quality assessment of these data for their use in controlling and modeling selective cereal harvesting process.

2. Methods

The study was conducted in 2011, on a Claas Lexion 480 combine harvester equipped with a Novatel RT2 PROPAK V3 GNSS receiver cooperating with a GPS-702-GG: a dual frequency (L1/L2) antenna and a SmallTRIP 3.2 GPRS/NTRIP modem (Smalltouch ApS) with automatic connection to the NAWGEO service. The RTK correction signal RT-2 was received via internet through the GPSR infrastructure belonging to the Plus GSM network. Fig. 1 presents the elements of the positioning system.

Due to the fact that the implementation of the MAC (Master and Auxiliary Concept) stream of NAWGEO in tests was not successful the studies were conducted with the VRS (Virtual Reference Station) stream. At the time of the operation, the combine measurement system recorded GPGGA, GPGST of NMEA sentences. During the study the following recorded data were evaluated: the time that elapsed since the last patch obtained from the NAWGEO system and standard deviation of positioning errors for longitude, latitude and altitude.

a) b)



Source: own work / Źródło: opracowanie własne

Fig. 1. The elements of the positioning system used in the research: a) Novatel GPS-702-GG: L1/L2 antenna, b) Novatel RT2 PROPAK V3 GNSS with SmallTRIP 3.2 GPRS/NTRIP modem

Rys. 1. Elementy systemu pozycjonowania użytego w badaniach: a) Novatel GPS-702-GG: L1/L2 antena, b) Novatel RT2 PROPAK V3 GNSS z modemem SmallTRIP 3.2 GPRS/NTRIP

The performance of the corrections system was tested in four fields of three experimental farms of Poznań University of Life Sciences: RGD Brody (one field), RGD Przybroda (two fields) and RGD Swadzim (one field) (RGD – from polish: Rolnicze Gospodarstwo Doświadczalne - agricultural experimental farm). The fields with winter wheat production in the total area of 75.24 ha were located in the western Wielkopolska region, Poland. Fig. 2 shows the recorded raw signal path for each field.

3. Results

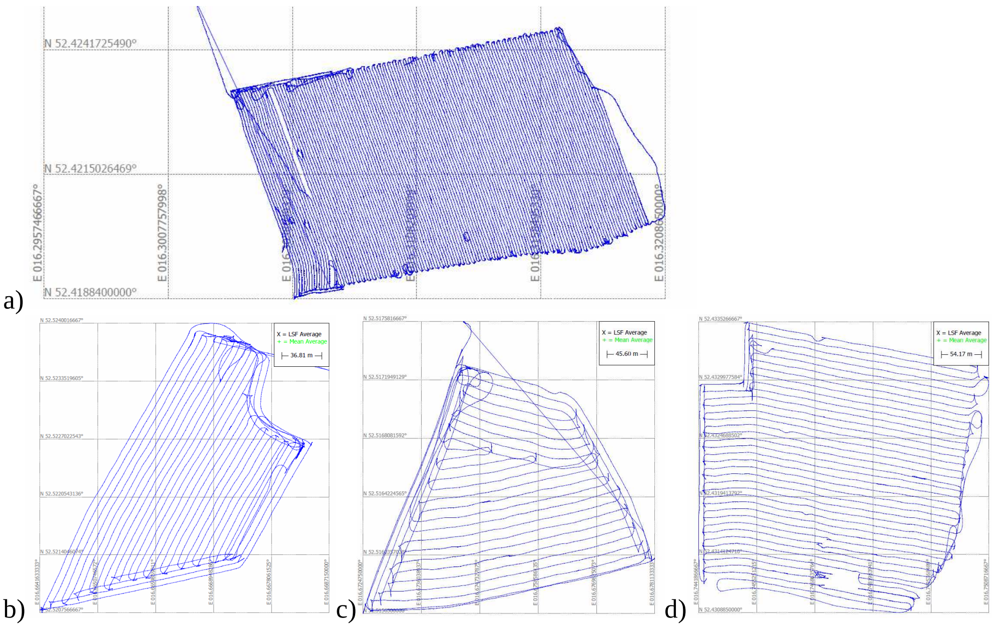
128876 records were logged in all of the experimental fields (Fig. 2). The logged data show the total working time of the harvester from 3 to 16 August. Table 1 shows a comparison of the recorded data and obtained accuracy, presented as HDOP coefficients. Not more than 2.6% and on average 1.2% of position data were recorded with poor accuracy HDOP >2.0. On average 76.2% of the records had accuracy with HDOP below 1.0.

Table 3 shows the analysis of the delay time of corrections from NAWGEO. The results computed for each field look similar in the comparison. In general, during the operation of the combine in individual fields the delay of corrections was 2 seconds. The corrections received with this delay made from 86.9 to 89.0% of all the corrections received from the base station. In 95% of the fixes interruptions in data transfer did not exceed 8 seconds but only for 2% of the corrections the delay times were calculated in tens of seconds. There were much better results for field S.69. This situation could be explained with the fact that in that field harvest continued without interruption, so the percentage of data related to the system start-up was reduced.

Table 1. The distance between fields and the ASG-Eupos reference station and between fields and Plus GSM network nearest BTS station
Tab. 1. Odległość pól uprawnych od stacji referencyjnych ASG-Eupos oraz od najbliższych stacji BTS sieci Plus GSM

Farm	Field number	Average distance from ASG-EUPOS reference station [km]	Average distance from nearest BTS (GPRS) station [km]
RGD Brody	B.21	17.5	2.7
RGD Przybroda	P.2	43.7	2.0
RGD Przybroda	P.50	44.3	1.3
RGD Swadzim	S.69	44.7	1.0

Source: own work / Źródło: opracowanie własne



Source: own work / Źródło: opracowanie własne

Fig. 2. Visualization of the raw signal path recorded in experimental fields: a) B.21, b) P.2, c) P.50 and d) S.69 (not in scale)
Rys. 2. Wizualizacja ścieżek surowego sygnału zarejestrowanych na polach doświadczenia a) B.21, b) P.2, c) P.50, d) S.69 (nieskalowane)

Table 2. A comparison of field areas and positioning accuracy in the fields
Tab. 2. Porównanie wielkości pól oraz uzyskanej dokładności pozycjonowania

Farm	Field number	Field area [ha]	Number of records	HDOP		
				≤1.0 [%]	1.0-2.0[%]	≥2.0[%]
RGD Brody	B.21	53.69	81131	72.9	26.8	0.3
RGD Przybroda	P.2	4.44	14228	68.1	29.2	2.6
RGD Przybroda	P.50	4.98	14415	81.2	17.3	1.5
RGD Swadzim	S.69	12.13	19102	82.5	17.2	0.4

Source: own work / Źródło: opracowanie własne

Table 3. An analysis of the time that has elapsed since the last update of the NAWGEO service
Tab. 3. Analiza czasu, jaki upłynął od aktualizacji serwisu NAWGEO

Field number	Time			Accumulated relative frequency of mode value [%]	Time since last % records update		
	Min. [s]	Max [s]	Mode [s]		95% [s]	98% [s]	99% [s]
B.21	1	99	2	86.9	6	22	46
P.2	1	99	2	87.9	8	31	71
P.50	1	99	2	88.4	7	44	99
S.69	1	49	2	89.0	5	9	15

Source: own work / Źródło: opracowanie własne

Table 4. Analysis of the standard deviations of latitude
Tab. 4. Analiza odchyleń standardowych oznaczenia szerokości geograficznej

Field number	Min [m]	Max [m]	Mode [m]	Accumulated relative frequency of		σ for 95% of records [m]	σ for 99% of records [m]
				mode value [%]	records with σ≤0.05 [%]		
B.21	0.01	6.59	0.02	84.9	96.7	0.04	1.32
P.2	0.02	2.00	0.02	43.1	91.7	0.38	1.03
P.50	0.02	2.54	0.02	58.6	95.5	0.05	1.61
S.69	0.02	1.01	0.02	62.8	98.7	0.04	0.06

Source: own work / Źródło: opracowanie własne

The analysis of the estimated positioning error standard deviations is shown in Tables 4, 5 and 6. On this basis, it is possible to conclude that the standard deviation from the obtained latitude and longitude values usually amounts to 0.02 m. By averaging the results for each field we can say that this situation occurred for 62.4% and 91.3% of the fixed latitude and longitude values, respectively. The higher accuracy of the recorded longitude results is also confirmed by the median value of the standard deviation, which was 0.01 m for field B.21. On average in 95.7% of the cases the latitude measurement error did not exceed the value of 0.05 m and in 96.2% of the cases it did not exceed that value for longitude. However, these values looked less favourable in field P.2 because 95% of the records had the maximum positioning error of nearly 0.4 m for the latitude and slightly above 0.3 m for the longitude. This may have been caused by the fact that in this relatively small field the harvest process was interrupted by rain three times, and that resulted in the subsequent cold start-ups of the GNSS receiver.

The measuring system determined the altitude above the mean sea level with slightly lesser accuracy. In this case the most frequently logged standard deviation value was 0.03 m, and after averaging the results from all the fields we can conclude that this value was obtained in 68.4% of the records. On the other hand, in field B.21 71.1% of the records contained the altitude information with 0.02 m error. The mean values obtained for all of the fields lead to the conclusion that in 93.3% of the cases the error in determination of the altitude did not exceed 0.05 m. In 95% of the records the accuracy in determination of the altitude oscillated around this value. Only in field P.2 there were significantly worse results, because the error in determination of the altitude exceeded 0.5 m in 95% of the records and, as was mentioned above, it may have been the result of several "cold start-ups" of the measuring system.

The following Figs 3, 4 and 5 show the graphs summarizing information about the time that elapsed since the last correction received from NAWGEO. They also include information about the type of correction applied for final positioning and the instantaneous values of standard positioning errors. It should be clarified that the GGA frame contains information about the type of correction used, which is encoded in the "Fix quality" with the values from 0 to 9, where 1 means - no corrections, 2 - corresponds to DGPS-SBAS corrections. When using NAWGEO the expected value of this cell is 3, which corresponds to the RTK correction. Unfortunately, in order to achieve proper cooperation between the GNSS receiver and combine on-board computer it was necessary to modify these values. Thus, the value of 2 was assigned to the RTK signal, forcing the allocation of the value of 9 to the DGPS-SBAS correction. The values of 0 and 10 the GNSS receiver shown in the graphs were caused by the GNSS receiver switching between different correcting methods.

The analysis of the obtained collation shows that the assumed 60-second correction age corrects the receiver set of items on the basis of the update of the NAWGEO system, and after this time the receiver enters the correct positioning on the basis of the DGPS-SBAS correction. However, even with delay corrections received at approximately 10 seconds the positioning error begins to increase considerably and when the delay time reaches approximately 20 seconds, the standard deviation obtained for the latitude and altitude may exceed 0.05 m. A break in the use of the NAWGEO system, which can be seen at about 14 kiloseconds (Fig. 3) was caused by the system start-up and problems with receiving corrections from the EUPOS server with the NTRIP modem.

A sharp decrease of about 3 ks (kiloseconds) in the positioning accuracy, which is visible in Fig. 4, was caused by unknown reasons. At that time, the position was determined on the basis of: signal from 9 satellites, the NAWGEO system delay correction was 2 seconds, PDOP (Positional Dilution of Precision) was 0.9, whereas the positioning error was 1.5 m. It is noticeable in this field (P.2) that the correction delay of around 10 seconds is the reason for an increase of more than 0.05 m in the positioning error value. The remaining jumps worsening the positioning accuracy, which were observed around the time of 5 ks, 10.5 ks and 13 ks, were caused by exceeding the maximum acceptable 60 s correction age. This could have been caused by problems with connectivity to the GPRS network.

Table 5. Analysis of the standard deviation for longitude
Tab. 5. Analiza odchyleń standardowych oznaczenia długości geograficznej

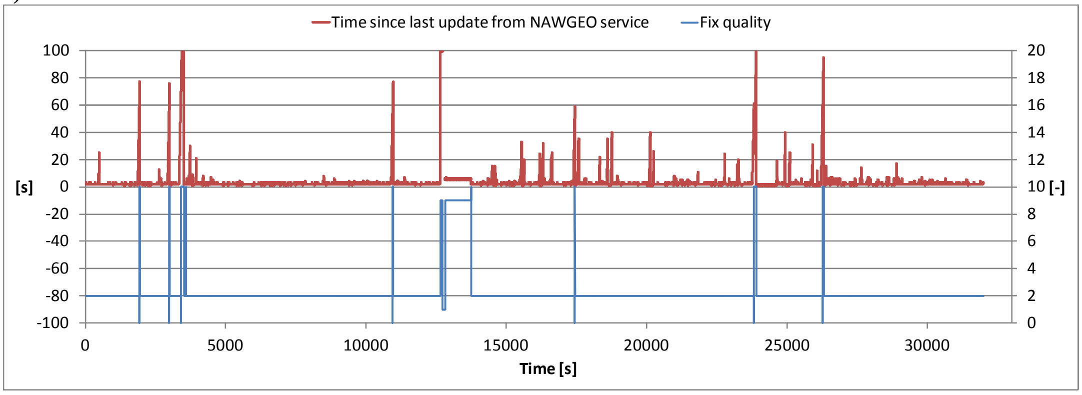
Field number	Min. [m]	Max. [m]	Mode [m]	Accumulated relative frequency of		σ for 95% of records [m]	σ for 99% of records [m]
				mode value [%]	records with σ≤0.05 [%]		
B.21	0.01	5.94	0.01	85.9	97.1	0.02	1.07
P.2	0.02	2.00	0.02	88.8	92.3	0.33	0.93
P.50	0.01	2.42	0.02	93.4	96.1	0.03	1.48
S.69	0.01	0.91	0.02	97.2	99.3	0.02	0.04

Source: own work / Źródło: opracowanie własne

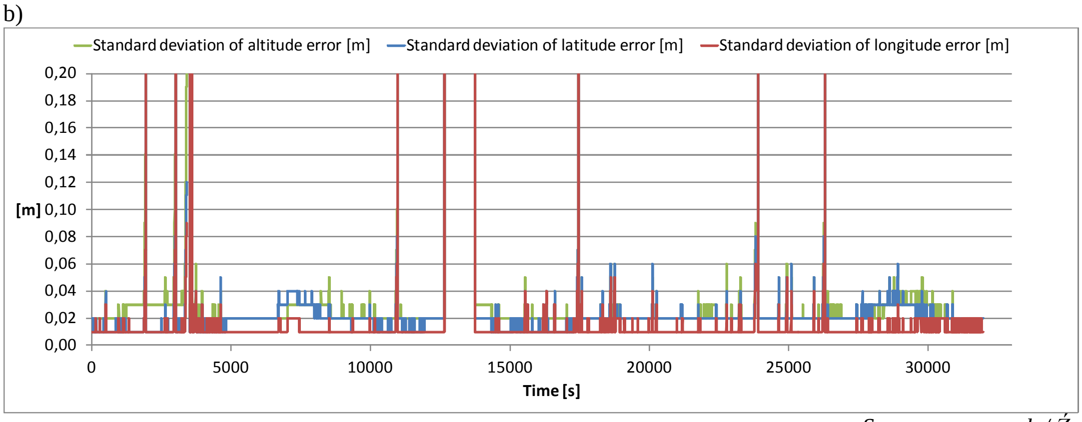
Table 6. Analysis of the standard deviation of the altitude a.s.l.
Tab. 6. Analiza odchyleń standardowych oznaczenia wysokości n.p.m.

Field number	standard deviation			Accumulated relative frequency of		σ for 95% of records [m]	σ for 99% of records [m]
	Min. [m]	Max. [m]	Mode [m]	mode value [%]	records with σ≤0.05 [%]		
B.21	0.02	9.67	0.02	71.1	96.3	0.04	1.84
P.2	0.02	2.00	0.03	49.6	87.6	0.54	1.34
P.50	0.02	3.46	0.03	73.1	92.6	0.06	2.28
S.69	0.02	1.36	0.03	79.6	96.7	0.05	0.07

Source: own work / Źródło: opracowanie własne a)



b)

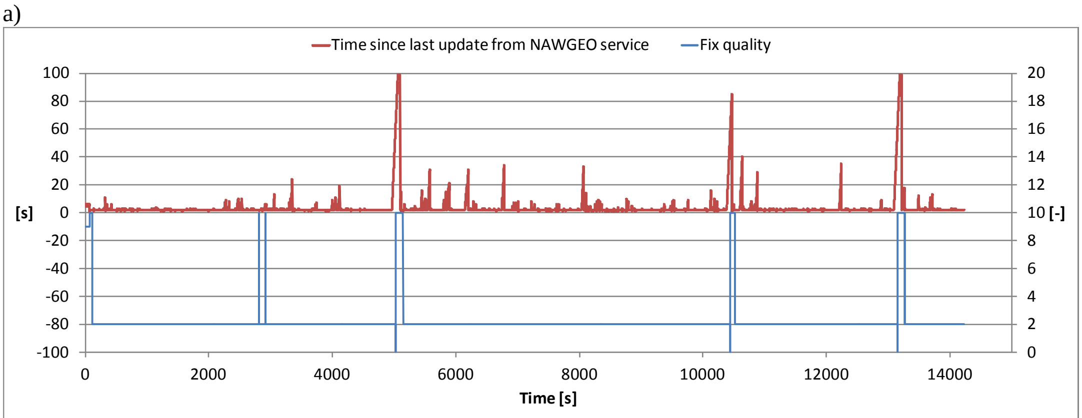


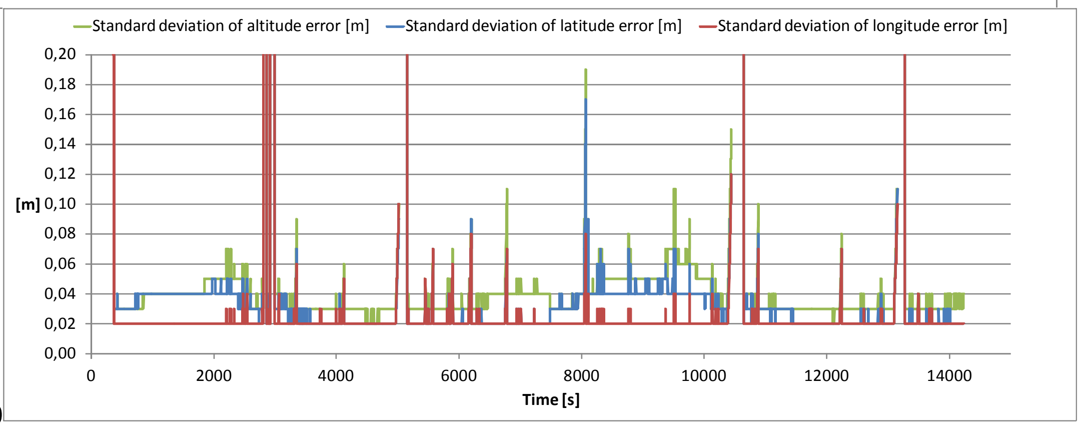
Source: own work / Źródło: opracowanie własne

Fig. 3. The age of corrections received from the NAWGEO service: fix quality a) and standard deviation of positioning errors b) in time in field B.21 – RGD Brody

Rys. 3. Wiek sygnału korekcyjnego otrzymanego z serwisu NAWGEO: jakość poprawki a) oraz odchylenie standardowe błędu pozycjonowania b) w czasie na polu B.21 – RGD Brody

a)



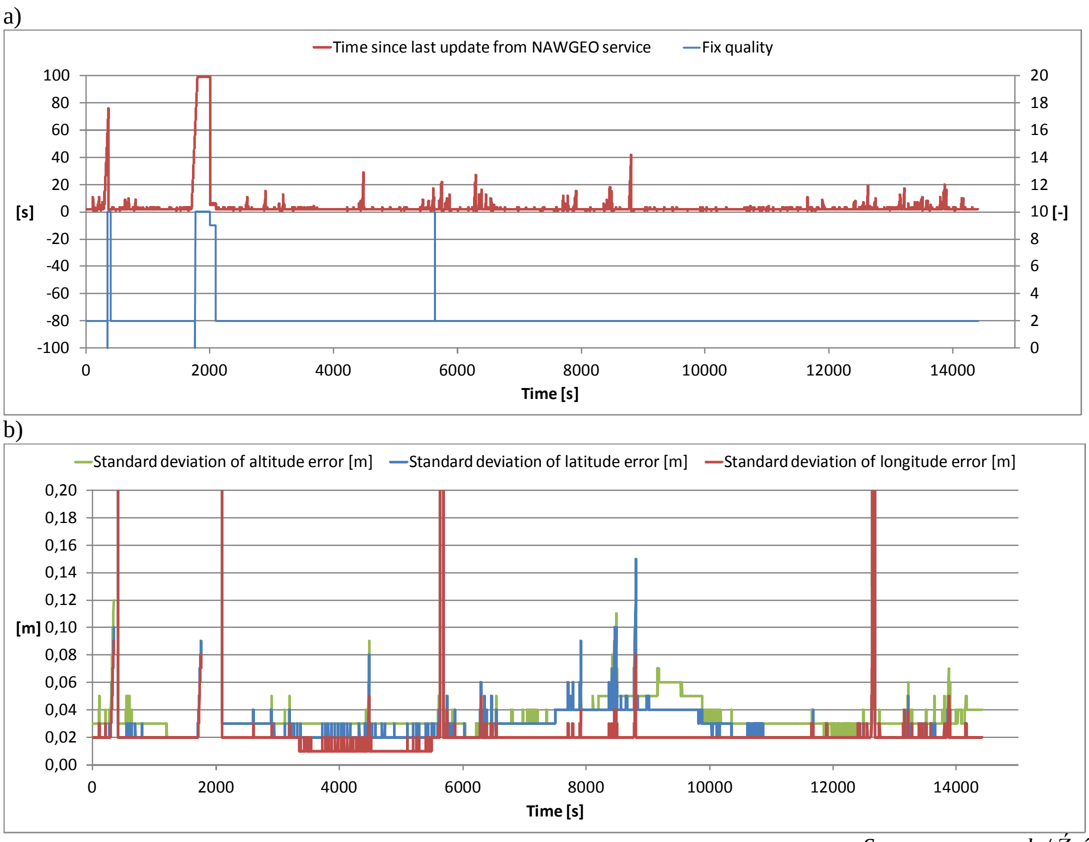


b)

Source: own work / Źródło: opracowanie własne

Fig. 4. The age of corrections received from the NAWGEO service, fix quality a) and standard deviation of positioning errors b) in time in field P.2 – RGD Przybroda

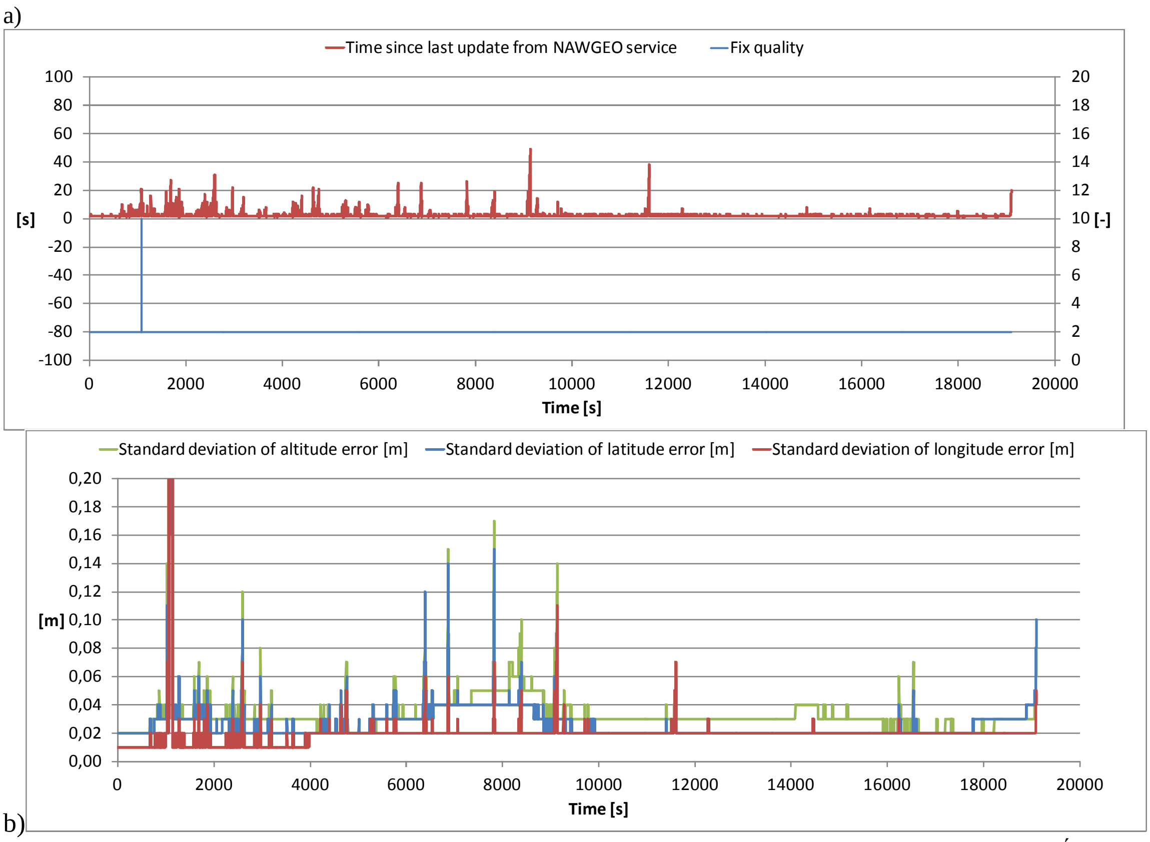
Rys. 4. Wiek sygnału korekcyjnego otrzymanego z serwisu NAWGEO: jakość poprawki a) oraz odchylenie standardowe błędu pozycjonowania b) w czasie na polu P.2 – RGD Przybroda



Source: own work / Źródło: opracowanie własne

Fig. 5. The age of corrections received from the NAWGEO service, fix quality a) and standard deviation of positioning errors b) in time in field P.50 – RGD Przybroda

Rys. 5. Wiek sygnału korekcyjnego otrzymanego z serwisu NAWGEO: jakość poprawki a) oraz odchylenie standardowe błędu pozycjonowania b) w czasie na polu P.50 – RGD Przybroda



Source: own work / Źródło: opracowanie własne

Fig. 6. The age of corrections received from the NAWGEO service, fix quality a) and standard deviation of positioning errors b) in time in field S.69 – RGD Swadzim

Rys. 6. Wiek sygnału korekcyjnego otrzymanego z serwisu NAWGEO: jakość poprawki a) oraz odchylenie standardowe błędu pozycjonowania b) w czasie na polu S.69 – RGD Swadzim

The sudden jumping decrease in accuracy at about 2 ks, shown in Fig. 6, in this case was caused by the night break of the harvester and starting work on the next day (so-called cold start-up). On the other hand, a sharp decrease in the positioning accuracy after about 5.5 ks was not caused by any of the recorded data and most likely it was the result of some external disturbance. A similar effect was observed around 12.5 ks and it was caused by a temporary decrease to 5 satellites observed. As in the case of field B.21, the standard deviation exceeding 0.05 m is related to the time of about 20 s since the last NAWGEO correction. A short decrease to 4 visible satellites should be considered as the cause of problems with accuracy, which can be seen in Fig. 6 at about 1000 s.

4. Summary and conclusions

Field tests led to the conclusion that under favourable conditions it is possible to use VRS services provided by the NAWGEO system for precise geographical positioning of agricultural machinery. This study also revealed that for the three fields (B.50, P.21, S.69) the positioning error was below 0.06 m (for 95% of the records). In one of the fields researched (P.2) this error reached the value of 0.4 m for the longitude and latitude, and a little over 0.5 m for the altitude. However, the worse results in that field were caused by problems in obtaining updates from AGS-EUPOS. It was most likely caused by temporary delays in communication via GPRS network.

The time that elapsed since the last update of the NAWGEO system had the biggest influence on the positioning accuracy. The acceptable delay time patch was 5 seconds. After exceeding the value of 5 seconds the positioning error may exceed the value of 0.1 m. The second most important factor affecting the accuracy of positioning concerned the number of observed satellites used for determining the position. In individual cases, when the number of such satellites dropped to 5, it resulted in a sharp increase in the positioning error, with the values of approximately 1 m. Therefore, the obtained data can be used to create numerical field models on-line, for example, in selective cereals harvesting technology, but they require filtration to remove the points affected by positioning errors exceeding acceptable values. If the NAWGEO system is to be used for agricultural machinery guidance and traffic control, the positioning system should be equipped with inertial sensors [12][13]. Reason: the existing delay in the reception of system updates may adversely affect the driving accuracy.

Despite these problems we think that the potential use of an active geodetic network in the agricultural sector could be better mobilized, especially when the communication between a GNSS receiver and SBAS satellites is limited by the field infrastructure, e.g. in orchard production, as was presented by Min et. all in their studies [11]. However, there must be continuous access to the GPRS network for successful communication.

The development of an active geodetic network, which can be seen in Poland and other EU countries [2] can contribute to the promotion of Precision Land Management technology and affect the economic increase with benefits from high precision positioning systems. The increase in signal distribution channels in standard RTCM correction can also contribute to this. An example of this is the introduction of CMR + protocol standard in the ASG-EUPOS services in 2012, but also the EU project, EDAS (Egnos Data Access Service) that assumed the transmission of high-precision correction data for mobile devices in the future. Another promising solution could be open-source concepts as RTKLIB [14].

Research will be continued to check the positioning accuracy on agricultural machines that can be achieved by using the MAC services (Net) provided by the NAWGEO service, but also with other SBAS services providing, for example, PPP (Precision Point Positioning) fixes.

5. References

[1] Pérez-Ruiz M., Carballido J., Agüera J., Gil J. A.: Assessing GNSS correction signals for assisted guidance systems in agricultural vehicles. Precis. Agric., 2011, 12**,** 639–652.

[2] Reckleben Y., Noack P. O.: RTK correction data networks for comprehensive, high-precision position determination in agriculture. Landtechnik, 2012, 67**,** 162–165.

[3] Rovira-Mas F., Chatterjee I., Saiz-Rubio V.: The role of GNSS in the navigation strategies of cost-effective agricultural robots. Comput. Electron. Agric., 2015, 112**,** 172–183.

[4] Florinsky I. V., Eilers R. G., Manning G. R., Fuller L. G.: Prediction of soil properties by digital terrain modelling. Environ. Model. Softw., 2002, 17**,** 295–311.

[5] Czechlowski M., Wojciechowski T.: The utilization of information about local variable environmental conditions to predict the quality of wheat grain during the harvest. J. Res. Appl. Agric. Eng., 2013, 58**,** 31–34.

[6] Niedbała G., Czechlowski M., Wojciechowski T.: The use of artificial neural networks to predict the spatial variability of grain quality during combine harvest of wheat. J. Res. Appl. Agric. Engng, 2013, 58**,** 126–129.

[7] Bosy J., Graszka W., Leończyk M.: Aktywna Sieć Geodezyjna EUPOS jako element składowy państwowego systemu odniesień przestrzennych. Przegląd Geod., 2008, R. 80**,** nr 12**,** 10–16.

[8] Specht C., Skóra M.: Analiza porównawcza wybranych aktywnych sieci geodezyjnych. Zesz. Nauk. Akad. Mar. WOJENNEJ, 2009, 3**,** 39–54.

[9] Specht C., Oszczak S., Nowicki K.: Testowanie serwisów i infrastruktury teleinformatycznej aktywnej sieci geodezyjnej ASG-EUPOS. Inżynieria Morska i Geotech., 2010, nr 2**,** 104–112.

[10] Specht M.: Ocena dokładności określenia pozycji systemów EGNOS i DGPS na podstawie wieloletnich pomiarów w latach 2006 – 2014. Pol. Przegląd Kartogr., 2015, 47**,** 127–136.

[11] Min M., Ehsani R. S. M.: Dynamic accuracy of GPS receivers in citrus orchards. Appl. Engienering Agric., 2008, 24**,** 861–868.

[12] Włodzimierz K., Ratajczak P.: Research of positioning precision by the selected GPS receiver in static and dynamic conditions. J. Res. Appl. Agric. Engng, 2005, 50**,** 10–15.

[13] Pawelski Z., Pałczyński T.: Badania drogowe pojazdów w inteligentnych systemach transportowych z użyciem technologii INS i GPS. Czas. Tech. M, 2008, 8**,** 3–17.

[14] Wiśniewski B., Bruniecki K., Moszyński M.: Evaluation of RTKLIB's Positioning Accuracy Using low-cost GNSS Receiver and ASG-EUPOS. TransNav - Int. J. Mar. Navig. Saf. Sea Transp., 2013, 7**,** 79–85.

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