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PRECISION GNSS LANDING SYSTEM WITHOUT THE USAGE OF AUGMENTATION SYSTEMS

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Abstract. *The article is devoted to the elaboration of a new ideological concept of the landing system which leads an aircraft during the approach and landing phases of a flight. The peculiarity of the system lies in the absence of an augmentation system which usually is used by all satellite landing systems known and operated today. The main benefits of the proposed GNSS landing system are its efficiency, integrity, low cost, sufficiently high reliability and safety.*

Keywords: Global Navigation Satellite System; Ground-based Augmentation System; navigational errors.

1. Introduction

The landing systems which use the Global Navigation Satellite Systems (GNSS) like "Smartpath landing system" designed by Honeywell are obliged to insert the external information into the calculations in order to improve the navigation systems' attributes, such as accuracy.

Though, there are three kinds of augmentation systems (ground-based, satellite-based and aircraft-based), the most common and widely used during the landing phase is the first one, namely Ground-Based Augmentation Systems (GBAS) because the small the coverage area ensures much more precise error corrections since the external conditions both for an aircraft and a GBAS station is more or less the same.

These errors mainly constitute clock drift, ephemeris, ionospheric delay, signal deviation, etc.

The process of the error detection and evaluation is very sophisticated and requires a huge amount of calculations.

The reason for this is that it does not involve any augmentation systems into the process of improvement of navigation systems' attributes.

The kernel of the concept lies in the acceptance and neglect of the errors caused by the factors mentioned above upon the simple reason that they will just delete each other.

The comprehension of the proposition requires further acquaintance with the concept elaboration.

2. Analysis of last researches

Recently, we very often face with the investigations of the application of various navigation systems which enhance the characteristics of the GNSS.

Hence, the performance of the augmentation systems allow us to use those navaids for the instrument landing phase of flight.

These augmentation systems compute the errors of the coordinates determination and transmit them to the aircraft systems as the difference between the true value and the determined one [1,3].

3. Concept of operation

As mentioned above, the system will not use any of the augmentations to correct the location of an aircraft but rather will take the advantage from the error cancellation technique described further.

The system is divided into 3 main components:

– ground segment;
– space segment;
– user segment.

Ground segment consists of the GNSS tracker, antenna and computer.

GNSS tracker receives and calculates its position disregarding all the errors considered.

Afterwards, the computer, knowing the exact distance from both thresholds of the runways in (x;y;z) coordinates to it, calculates the location of those runways ends and broadcast this information.

So, the data package transmitted to the users will look like the following: $X_{rwy\ thrs1}$, $Y_{rwy\ thrs1}$, $Z_{rwy\ thrs1}$; $X_{rwy\ thrs2}$, $Y_{rwy\ thrs\ 2}$, $Z_{rwy\ thrs\ 2}$ (Fig. 1):

$X_{rwy\ thrs1} = X_{tranc\ GNSS} +/- \Delta X_1$;
$Y_{rwy\ thrs1} = Y_{tranc\ GNSS} +/- \Delta Y_1$;
$Z_{rwy\ thrs\ 1} = Z_{tranc\ GNSS} +/- \Delta Z_1$;
$X_{rwy\ thrs\ 2} = X_{tranc\ GNSS} +/- \Delta X_2$;
$Y_{rwy\ thrs\ 2} = Y_{tranc\ GNSS} +/- \Delta Y_2$;
$Z_{rwy\ thrs\ 2} = Z_{tranc.\ GNSS} +/- \Delta Z_2$,

where $X_{tranc\ GNSS}$ – value of the coordinate X of the transceiver location evaluated with the help of GNSS;

$Y_{tranc\ GNSS}$ – value of the coordinate Y of the transceiver location evaluated with the help of GNSS;

$Z_{tranc\ GNSS}$ – value of the coordinate Z of the transceiver location evaluated with the help of GNSS;

$\Delta X_{1,2}$ – the exact distance from the transceiver to the runway thresholds on the X-axis;

$\Delta Y_{1,2}$ – the exact distance from the transceiver to the runway thresholds on the Y-axis;

$\Delta Z_{1,2}$ – the exact distance from the transceiver to the runway thresholds on the Z-axis.

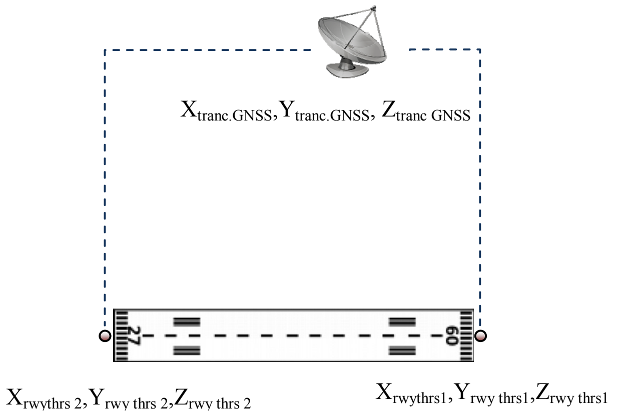

Fig. 1. Runway's coordinates

Space segment consists of the orbiting satellites of any GNSS system.

The most probable satellite system that will be in use within this concept is Galileo as till the time this idea is starting to be being realized and GPS.

Galileo is supposed to be fully operational and preferably used in aviation as well as GPS.

User segment is a group of airspace users intended to land on the aerodrome where the system operates.

In other words, this is Flight Management System (FMS) with the special function integrated in it to perform actions described further.

As soon as onboard GNSS receiver has obtained the signal from the satellites, it sends it to the FMS where it calculates the location of an aircraft not taking into account possible errors identified by other onboard systems (like Inertial Navigation System (INS), dead-reckoning, etc.) after correlation.

Upon the obtainment of the data from ground segment, FMS builds the approaching and landing flight path for an aircraft and safely guides it along the trajectory.

All possible errors which might have occurred due to ionospheric drift, ephemeris, signal deviation, etc., automatically cancel each other as the conditions for both transceiver and for the approaching aircraft within 25 km (the radius of GBAS acceptance accuracy coverage) are homogeneous, and consequently, the errors value are the same.

Moreover, constant exchange of the data (every second or even more frequent) will ensure the accuracy of the flight path adherence.

The Fig. 2 represents the general system use case.

4. Errors analysis

Although almost all the errors in the localization of both transceiver and a user are supposed to cancel each other, it is still necessary to scrutinize each of them and perform the studies proving with the experimental tests.

Since the idea is not yet as far elaborated as needed to execute some trials, the operationality of the system will be based exclusively on the theoretical assumption and deduction described below.

This following list encompasses practically all possible errors which are taken into account by an augmentation system [2]:

1) Signal arrival time measurement error:

The measurement of a satellite signal delay by receiver is performed through the comparison of the bit sequence with an internally generated version.

By comparing the rising and trailing edges of the bit transition, the best result of accuracy for today is equal to the signal offset value of 1 % of the bit pulse width; that is approximately 3 m.

However, the usage of the higher-chip rate P(Y) signal is widely used today as it decreases the error down to 30 centimeter [3].

Consequently, it is obligatory to use simultaneously either P(Y) signal or just normal signal.

2) Atmospheric effect:

Heterogeneous atmospheric conditions significantly influence on the satellite signals speed but in our case, these signals delays are the same for both the transceiver and the user because the radius from the transceiver to the IAF (Initial Approach Fix) is relatively small for the atmospheric conditions to vary.

Hence, the errors cancel each other.

3) Multipath effect:

The essence of this effect lies in the radio signal reflection off the surrounding terrain.

The effect has mainly the influence on the transceiver, as it is located on the ground, whereas the aircraft almost does not suffer from it.

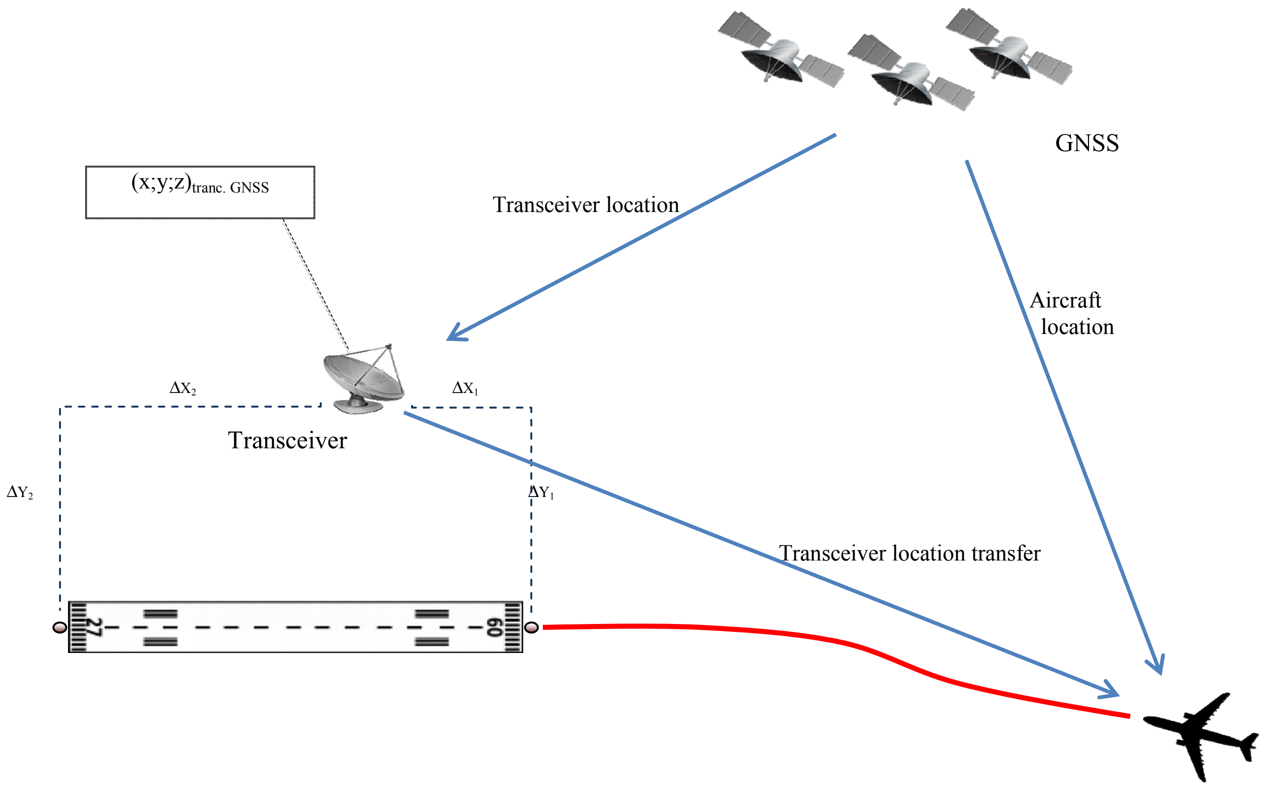

Fig. 2. The system operation principle

This case requires the elimination of such an error on the ground segment.

The solution lies in the usage of a chock ring antenna's principle to reduce the signal power as received by the antenna.

4) Ephemeris error:

Ephemeris (almanac) is the data on the satellite's position which is sent to a receiver to calculate its own location.

Due to the variability in solar radiation pressure, the actual position of a satellite does not coincide with the one sent to a user.

Since this error is present in both receiver and user's calculations, we may disregard it.

5) Clock drift:

This error also refers to the space segment of the system that means it is of the same value for the ground and user segment.

The essence of the error lies in the satellite atomic clock drift – the time of the signal transmission indicated in the message does not match with the actual one.

6) Geometric dilution of precision computation:

Sometimes, the visible satellites happen to fly closely to each other making the dilution of precision computation rise (angular separation decreases).

It leads to the deteriorated localization process of a receiver.

However, for the ground segment and for a user the deterioration value is the same.

7) Relativistic effect:

The space segment (constellation of satellites) of the system is located at the Medium Earth orbits (22 000 km above the Earth).

According to the Einstein's special (satellite orbital speed causes the delay of the atomic clock of 45,9 µs/day) and general (the distance from satellite to the Earth causes the clock go faster than on the Earth's surface producing the delay of 7µs/day)theory of relativity, the time goes differently on the Earth's surface then it does on a satellite [1].

Since these delays are the same for the ground and a user segment, we may neglect this error.

The speed of an aircraft is relatively small to cause some relativistic effect relative to the stationary transceiver.

8) Natural and artificial sources of interference:

These kinds of errors occur at all three segments of the system.

Consequently, it is necessary to mitigate them as much as possible locally at each of the segments.

For example, the transceiver should be placed on the area where its receiver is not desensitized by the scattering of GNSS signal, man-made electromagnetic interference does not jam or disrupt the satellite signal, etc.

In general, it is possible to conclude that all the errors occurred at the space segment are the same for both the ground and the user segment allowing us to neglect them.

However, those errors listed to cause some effect at the ground or the user segment separately must be eliminated or reduced to the minimum safety margins.

5. Coverage area

The coverage area of the landing system should extend to at least 25 km from the runway threshold.

As GBAS covers the radius of 25-30 km, consequently, this distance does not deteriorate the quality of the signal.

The transmission of the data from the ground segment to the user will be executed through the very high frequency radio data link (VDL).

Since very high frequency signal can be transmitted only to a receiver which is on the Line of Sight (LOS) distance, it is necessary to estimate whether the signal is still valid at this point (25 km and more).

The LOS calculations are performed using the following formula:

$$\mathrm{LOS} = \sqrt{\left(2 * R_{\mathrm{earth}} * h_1 + h_1^2\right) + \left(2 * R_{\mathrm{earth}} * h_2 + h_2^2\right)},$$

where R_{earth} – radius of the Earth (6,371 km);

h_1 – elevation of transceiver (130 m)*;

h_2 – elevation of an aircraft (1500 m)*.

*The elevation of a transceiver and an aircraft were taken randomly.

The result is 179 km that means if there are no natural or artificial obstacles deflecting the signal, the approach and landing legs of flight will be entirely available for the landing system operations.

Moreover, the LOS value allows significant changes in the transceiver and aircraft elevations.

6. Conclusions

The idea on the landing system concept occurred due to the understanding of the GBAS complexity and the will of finding the possible way to simplify it.

The reason for the solution to develop the system precisely for approach and landing legs of a flight was based on the homogeneous weather conditions limitation.

If a ground segment and a user segment appear to be on the distance that is enough for the weather to change its state, the accuracy is possibly to deteriorate but since this is the first step of the system development process, the idea is yet to be so deeply elaborated as to describe the unusual circumstances.

The advantages of the landing system proposed are all based on the simplicity of it: no need of a powerful computer to perform various difficult calculations, the price of the installation I relatively low, easy to install etc.

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М.М. Богуненко[1], О.О. Пригара[2]. Супутникова навігаційна система посадки з застосуванням спрощеного наземного доповнення

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Розглянуто нову ідеологічну концепцію наземного доповнення, яка підвищує можливості супутникової навігаційної системи на етапі посадки. Показано, що особливість цієї системи полягає в заміні традиційних наземних доповнень спрощеною технологією наземного доповнення.

Ключові слова: навігаційні похибки; наземне доповнення; супутникова навігаційна система.

Н.Н. Богуненко[1], А.А. Пригара[2]. Спутниковая навигационная система посадки с использованием упрощенного наземного дополнения
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Рассмотрена новая идеологическая концепция наземного дополнения, повышающая возможности спутниковой навигационной системы на этапе посадки. Показано, что особенность этой системы выражается в замене традиционных наземных дополнений упрощенной технологией наземных дополнений.

Ключевые слова: навигационные ошибки; наземное дополнение; спутниковая навигационная система.

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