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To cite this article: I N Kartsan *et al* 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **255** 012011

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Pseudolite systems for close-range navigation: the problem of synchronization*

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Abstract. This paper discusses the implementation of an electronic pseudolite close-range navigation system provided that one of the pseudolites is located at a certain altitude. The authors have developed principles for building a timescale for this system to solve the problem of mutual synchronization of the pseudolites. The principle of retransmitting the signals from all the pseudolites to one reference station is considered as the basis for this system.

1. Introduction

Global navigation satellite systems (GNSS) have become the most widespread navigation systems enabling to accurately determine an object's position, its speed, and local time. On the basis of the main functions and concepts of GNSS, a multitude of secondary services and systems has been designed, including local and regional differential subsystems, systems for monitoring and controlling various types of vehicles, systems for monitoring and tracking cargos and objects, universal time-management subsystems, etc. For some applications, GNSS signals may be used as reference signals.

Despite their enormous popularity, GNSS are seldom applied for autonomous navigation of aircraft in the airspace (traffic zones) of aerodromes; unmanned flight control; navigation of vessels in harbors, narrow water strips, and rivers; providing information support for geodic and cartographic works. One reason for the limited application of GNSS in the mentioned fields is their low immunity to interference. This factor makes it difficult to cope with the requirements of continuity and accuracy for navigation systems.

A possible solution to this problem is the addition of a close-range ground radio-navigation system to the GNSS. Using ground-based pseudolites, the ground system will form a navigation field in a given area [1]. A high level of accuracy in such navigation systems is provided by accurate geodic ties and a mutual synchronization of the pseudolites, which are

* The work was supported by the Russian Science Foundation (Grant No. 16-19-10089).



stationary navigation signal transceivers. These signals are identical to the ones emitted by GLONASS satellites. The aspects of using pseudolites for GPS had been previously intensely discussed in [2].

The main problem in building a navigation system is synchronizing the pseudolites and the navigation devices of the user. As discussed in [3; 4], it is necessary to position the pseudolite at a specific altitude (elevation) to reduce the value of the geometric factor in terms of height. With this done, the measurement accuracy for the altitude of a moving object is improved. However, this results in problems with synchronizing and affects the measurement accuracy for the coordinates of the pseudolite, which is situated on a balloon-based system. A possible solution lies in the retransmission (re-radiating) of navigation signals from all the pseudolites to one reference station (Fig. 1).

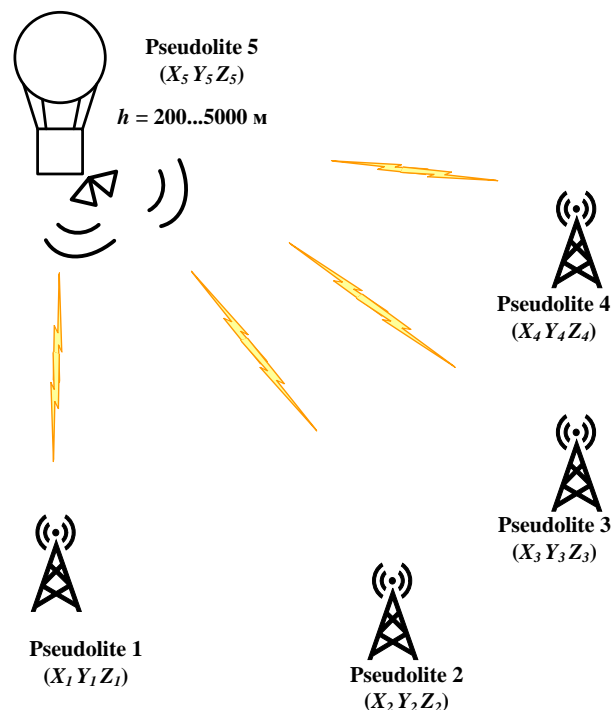


Figure 1. demonstrates the remote determination of the coordinates and speed of a mobile balloon-based pseudolite

2. A discussion on the approaches to solving the problem of mutual synchronization

Retransmitting signals via the suspended pseudolite may be used for the following:

1. Remote determination of the coordinates and speed of a mobile balloon-based pseudolite.

2. The determination of the coordinates of a pseudolite, which fails to receive signals from satellites (or is receiving them on a small scale, failing to fulfill its navigation and time tasks) by means of retransmitted pseudolite signals, emitted by a ground-based pseudolite.

Determining an object's navigational parameters (coordinates, speed and direction of movement, time and frequency scale, spatial orientation) remotely is possible after solving the navigation and timing problem, utilizing the measurement results for the radio-navigation

parameters (delays, Doppler shift, etc.) of the pseudolite retransmission systems in receivers and processing units of retransmitted pseudolite signals as follows:

$$\begin{cases} R_1^2 = (x'_5 - x_1)^2 + (y'_5 - y_1)^2 + (z'_5 - z_1)^2 = C^2(\tau'_5 + t_1)^2 \\ R_2^2 = (x'_5 - x_2)^2 + (y'_5 - y_2)^2 + (z'_5 - z_2)^2 = C^2(\tau'_5 + t_2)^2 \\ R_3^2 = (x'_5 - x_3)^2 + (y'_5 - y_3)^2 + (z'_5 - z_3)^2 = C^2(\tau'_5 + t_3)^2 \\ R_4^2 = (x'_5 - x_4)^2 + (y'_5 - y_4)^2 + (z'_5 - z_4)^2 = C^2(\tau'_5 + t_4)^2 \end{cases}$$

This approach may be used as an alternative to the traditional system of determining an object's navigational parameters remotely, built on the basis of a set of standard radio-navigation hardware, which provides navigation and timing services, and signal transmitting hardware. In a situation when retransmission is utilized, the information transmitting devices are replaced by retransmitting devices; in this case, the radio-navigation equipment becomes lighter, less bulky, more energy-efficient, and, as a result, less expensive. This is achieved by eliminating such nodes as the digital signal processing unit and the computing unit.

An additional advantage to executing navigation and timing services on retransmitted signals is the relative mode of determining the real-time navigational parameters of an object using receiving and processing devices for retransmitted signals. For this mode to function, it is not necessary to transmit any supplementary data from the object. Thus, since the solution of the navigation and timing problem is found in the receiving and processing devices for retransmitted signals, the object itself does not contain data on its navigational parameters.

During the distribution of the pseudolite signal, an additional delay occurs along its retransmission path, which is determined by the distance between the GNSS repeater and the retransmitted signal receiver and processing unit. Another Doppler shift also occurs, as there is a mutual motion of the repeater and the retransmitted signal receiver and processing unit. These factors alter the results of measuring the radio-navigational parameters of the pseudolite, which are executed in the retransmitted signal receiver and processing unit, with the objective of providing navigation and timing services, as well as determining the navigational parameters of the balloon-based pseudolite. An additional factor that alters the results of the decisions made by the receiver and processing unit of the retransmitted signals for solving the navigation and timing problem for balloon-based pseudolites is the deviation of the frequency and time scale of the receiver and processing unit from the frequency and time scale of the balloon-based pseudolite.

In order to eliminate the influence of the distribution path on the solution of the navigation and timing problem for the receiver and processing unit of the retransmitted signal, as well as the parameters of the frequency and time scale of the receiver and processing unit of the retransmitted signal, a special pilot signal, generated in the repeater and transmitted from the object with the pseudolite retransmitted signal, can be implemented. Such parameters as delays and the Doppler shift of the pilot signal in reference to the frequency and time scale of the retransmitted signal receiver and processing unit are measured by the reference station. These results determine the additional pseudolite signal delay, which is dictated by the retransmitted signal path and deviations from the timescale of the receiver and processing unit, together with an additional Doppler shift of the pseudolite signals. The Doppler shift is caused by the mutual motion of the repeater and the receiver and processing unit of the retransmitted signal, along with the frequency deviation of the reference generator of the receiver and processing unit of the retransmitted signal from the reference signal generator of

the repeater.

There are a number of options on utilizing the pilot signal. The first option supposes that the reference signal generator of the receiver and the processing unit of the retransmitted signal can be synchronized by the pilot signal. In this variant, an automatic frequency tuning counter (analog or digital) of the reference signal generator of the receiver and processing unit of the retransmitted signal, adjusting to the frequency of the received pilot signal, is used. One advantage of this method is that there is no need for any additional complicated software for the receiver and processing unit of the retransmitted signal during the initial stage of processing and solving navigation and timing problems. A disadvantage to this method, which utilized a direct automatic frequency tuning of the reference signal generator of the receiver and processing unit of the retransmitted signal, adjusted to the frequency of the pilot signal, is a limit to the system's bandwidth capabilities. In this case, the receiver and processing unit can process only one signal from a repeater at a time.

Another option for utilizing the pilot signal is the measurement of its frequency regarding the reference signal generator of the receiver and the processing unit of the retransmitted signal. In this case, the synchronization of the processes in the receiver and the processing unit of the retransmitted signal is executed from a specific reference signal generator, the frequency of which is not tuned to the frequency of the received pilot signal. The receiver and processing unit of the retransmitted signal assesses the frequency deviation of the pilot signal from a nominal value. Using this data, an additional component, determined by the distribution path and the parameters of the frequency and time scale of the receiver and processing unit of the retransmitted signal, is excluded from the frequency assessment of the pseudolite retransmitted signal.

A third option is more complicated in terms of its implementation as it requires adjusting the initial data processing software for the receiver and processing unit of the retransmitted signal. A positive aspect is the absence of any principal limitations for the bandwidth capabilities of the receiver and processing unit of the retransmitted signal. One device can service a few repeaters.

The receiver and processing unit of the retransmitted signal can operate in such a mode in which the navigation and timing problem is solved as if it were taking place on a balloon-based pseudolite. The receiver and processing unit of the retransmitted signal is, in its way, a structural element of the navigation receiver of an object, e.g. the digital signal processing unit and the computing unit. The repeater, the retransmission path, the receivers and processing units of the retransmitted signal are included in the discontinuity between the reception antenna, the signal path (a section), and the remaining units of the traditional radio-navigation system. In this mode, the receiver and processing unit of the retransmitted signal, along with the reception of retransmitted signals from the repeater in a retransmission frequency range, executes the reception of pseudolite signals in a standard frequency range.

3. Conclusion

The mutual processing of the measurement results of the pseudolite signal, received by the navigation antenna receiver and processing unit of the retransmitted signal, and the pseudolite signal, received by the object and retransmitted by a repeater, allows one to implement a highly-accurate determination of the object's coordinates in respect of the receiver and processing unit of the retransmitted signal. In this mode it is possible to implement a code and phase mode for determining the relative coordinates [5]. The phase mode can be implemented due to the fact that the receiver and processing unit of the retransmitted signal, on account of the pilot signal, contains all the necessary data on the frequency and time scale of the object.

Thus, we have discussed on a number of approaches to solving the problem of synchronization in pseudolite navigation systems. Further inquiry into this problem will provide an answer to the topical GNSS issues, particularly in relation to GLONASS.

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