Simulation of short-range navigation system based pseudolites and investigation of its accuracy characteristics

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Abstract. This paper considers a laboratory complex for studying the characteristics of short-range navigation system based pseudolites. The complex was built on the National Instruments hardware platform in the LabView programming environment. The complex is a real prototype of a navigation system based on pseudosatellites. It provides simulation of the navigation field, analysis of received signals, determination of signal characteristics and navigation parameters. The article presents the results of experimental studies of the complex with the aim of determining the error in pseudo-range measurements from the signals of navigational spacecraft and pseudosatellites.

1. Introduction
The use of pseudolites to improve navigation support aircraft and marine vessels is a promising direction of development of short-range navigation systems. Such systems are particularly effective in providing aircraft landing modes. Greater value represents navigate pseudolites when sailing in harbor areas and performing special sea and river of [1].

- Navigation system based pseudolites allow:
  - Increase the accuracy of positioning to 5…10 cm due to the absence of ephemeris and ionospheric errors and geometrically optimal placement of pseudosatellites.
  - Increase the resistance to interference by increasing the power of the navigation signal.
  - Provide navigation indoors.
  - Provide the ability to work with different types and types of signals.

Pseudolite – a ground beacon that transmits navigation signals in a GNSS range. Pseudolites signals have a structure similar GLONASS / GPS signals. The use of such signals allows the consumer to use a standard GNSS receiver with a small software modification. This navigation system is a network of pseudolites, placed on the ground [2]. The coordinates of each pseudolite are measured in advance with high accuracy and transmitted to the user as part of the navigation message. The location of pseudolites in the terrain is selected in accordance with the necessary navigation support zone. When placing pseudolites on the terrain, take into account the required range of signal powers in the navigation zone (usually from minus 140 to minus 165 dBW). The geometry of the placement of pseudolites is chosen from the criterion of the best indicator of the geometric factor [3].

One of the typical structures of short-range navigation systems based pseudolites system is shown in figure 1.
However, the presence of significant advantages gives rise to several contradictions [4]. These contradictions are as follows:

- The increased power level of signals emitted by pseudolites improves noise immunity, but gives rise to the problem of "near-far".
- The location of pseudolites near the underlying surface leads to multipath propagation of the navigation signal, which significantly increases the errors in the code and phase measurements of navigation parameters.
- Powerful signals from pseudolites can interfere with GNSS navigation signals.

At the Siberian Federal University was designed by the laboratory for modelling short-range navigation system based pseudolites. [5] At present, it is being modernized. Positive results were obtained in the studies of pseudo-range measurement errors.

2. Requirements for laboratory complexes
Based on the nature of existing problems and contradictions, the following requirements were imposed on the laboratory complex:

- The power of the signals of each pseudolites should ensure the creation of a situation "near-far" in the area of research.
- Pseudolite must simulate the situation multipath signals.
- Pseudolites should be able to generate navigation signals with frequency and code division.
- Laboratory complex should provide the possibility of changing the geometric arrangement of pseudolites.

3. Structure of the laboratory complex
The mission of the laboratory complex is the formation of an artificial navigation field in a given area of space. This task is performed layouts pseudolites. Layouts emit navigation signals in the space of this structure. The transmitting antenna layouts are accurate geodetic reference to the terrain.

In the basic configuration in the complex there are four layout pseudolites. To solve navigation tasks pseudolites signals used GNSS receiver with modified software. GNSS receiver control and processing of measured navigation data is performed on a personal computer. The structural diagram of the laboratory complex is shown in figure 2.

During the development of the project to create analysis of options for building layouts pseudolites was conducted laboratory complex [6–9]. Analysis has shown that for the study of navigation systems based pseudolites as layouts simulators use satellite navigation signals from GLONASS / GPS.

The project as pseudolite layout has used the National Instruments virtual instrumentation company running the LabVIEW software.

Usually the vector generator NI PXIe-5673E [6] is used to create GNSS signal simulators. The formation of test navigation signals in this simulator takes place under the control of special GLONASS Toolkit and GPS Toolkit software tools developed in the LabVIEW programming system.
However, LabVIEW allows you to create your own "virtual instruments" (VI) that control the
generation of signals by the NI PXIe-5673E generator. Thus, there are opportunities to generate
signals with the structure and parameters necessary for carrying out the experiments. In particular, in
the informative part of the navigation signals ephemeris must instead transmit spacecraft navigation
coordinates pseudolites layouts. Data on the exact coordinates of the pseudolite antenna is used to
solve the navigational task in the receiver.

Layout pseudolite may consist of the following functional units (figure 3):
- Vector signal generator NI PXIe-5673E;
- RF attenuator NI PXI-5695;
- Computing controller NI PXIe-8880;
- NI PXIe-1085 chassis.

Navigation signals are generated by a vector signal generator NI PXIe-5673. The vector signal
generator NI PXIe-5673 uses direct signal transfer from the main band to the radio frequency range.

For the navigation support of consumers, the time scales of all pseudolites must be synchronized,
and the signals – coherent [10]. In addition to the internal synchronization of devices [11] in the
pseudolite layout, additional synchronization is necessary. To do this, on the chassis of pseudolites
layouts must submit a highly stable reference frequency of 10 MHz.

**Figure 3.** Pseudolite layout structural diagram.

Pseudolites layouts synchronization in the laboratory can be implemented in the following ways:
- Synchronization of RF cable pseudolites layouts from one master layout.
- Synchronization of RF cable layouts from all pseudolites highly stable time and frequency
standard.
- Synchronization of RF cable pseudolites layouts from a single GNSS receiver.
- Synchronization of each layout on their own GNSS receiver (in the case of large distances between layouts pseudolites).

The permissible relative error of the reference signal should not exceed $\pm 3 \times 10^{-10}$.

To expand the range of output power variation, a two-channel programmable RF attenuator NI PXI-5695B is introduced into the pseudolite circuit. At a maximum output power of the vector generator of 10 mW, the RF attenuator allows you to change the signal power at the output of the pseudolite in the range from 1 mW to 10 mW. A large range of variation in the power of the pseudolite navigation signal will make it possible to investigate the influence of the power level of the signals on the reliability of navigational determinations under the influence of interference.

As initial conditions, the receive and transmit antenna gain factors can be assumed to be 3 dB, and the required signal level at the receiver input is minus 161 dB. In this case, it can be determined that the signal level with a power of 1 mW to 10 mW will provide the possibility of carrying out experimental researches on the distance from the pseudolite layout from 500 m to 50 km.

To create the information part of the navigation signal in simulators based on NI PXIe-5673, almanac and ephemeris files in RINEX format are used. A fragment of the description of the format of the ephemeris file for GLONASS is shown in Table 1. Thus, the pseudolite signal is simulated by replacing the ephemeris parameters of the orbits with the coordinates of the layout.

The mutual arrangement layouts pseudolites and their number depends on the terrain and the area to be carried out research work developed short-range navigation system. Thus, it is possible to obtain practical experimental data geometrical factor depending on the number of pseudolites and their mutual arrangement. This will enable us to calculate the potential accuracy of the coordinate measurement, the accuracy of determining the spatial position of the users of navigation information, as well as the noise immunity indices of the near navigation system being developed.

**Table 1.** GNSS navigation message file – GLONASS data record description.

| OBS. RECORD | DESCRIPTION | FORMAT |
|-------------|-------------|--------|
| ISV / EPOCH / SV CLK | - Satellite system (R), satellite number (slot number in satellite constellation) | A1, 2.2, |
| | - Epoch: Toe – Time of Clock (UTC) | 1X, I4, |
| | - year (4 digits) | 5(1X, I2.2), |
| | - month, day, hour, minute, second | 3D19.12 |
| | - SV clock bias (sec) (–TauN) | a) |
| | - SV relative frequency bias (+GammaN) | |
| | - Message frame time (tk+nd*86400) in seconds of the UTC week | |
| BROADCAST ORBIT – 1 | - Satellite position X (km) | 4X,4D19.12 |
| | - velocity X dot (km/sec) | |
| | - X acceleration(km/sec2) | |
| | - health (0=OK) (Bn) | |
| BROADCAST ORBIT – 2 | - Satellite position Y (km) | 4X,4D19.12 |
| | - velocity Y dot (km/sec) | |
| | - Y acceleration(km/sec2) | |
| | - frequency number(–7 ... + 12) | |
| BROADCAST ORBIT – 3 | - Satellite position Z (km) | 4X,4D19.12 |
| | - velocity Z dot (km/sec) | |
| | - Z acceleration(km/sec2) | |
| | - Age of oper. information (days) (E) | |
During the construction of a laboratory complex, we conducted studies of the measurement error of the pseudo signals in navigation satellites and the pseudolite layout. Navigation signals were received by the MRK-101 receiver. The determination of the pseudo-range measurement error was carried out by signals from the GLONASS navigation satellite with the G1 letter and the pseudolite layout. (vector generator PXIe-5673) at the equivalent frequency. The results of the measurements are shown in figures 4, 5.

![Figure 4](image1.png)

**Figure 4.** Error of pseudorange measurement from the signal of the navigation satellite GLONASS with the letter G1.

![Figure 5](image2.png)

**Figure 5.** Error of pseudorange measurement to a signal from the layout pseudolite.

After the mathematical processing of the measurement results, the following indicators were obtained:
- the pseudorange measurement error of GLONASS signals was 0.9 m.
- measuring pseudorange error signals by the pseudolite layout was 0.15 m.

To estimate the error in measurement object coordinates from the signals of pseudolites is necessary to consider the value of the geometrical factor.

4. Conclusion
The proposed laboratory complex will provide ample opportunities for modeling and research short-range navigation systems based pseudolites. The complex allows:
1. To study the effect of the parameters of the navigation signal of a pseudolite (signal type, power, frequency, modulation, etc.) on the accuracy of navigation measurements.
2. To evaluate the efficiency of algorithms for processing navigation signals of different structures in a receiver.
3. To study the influence of a geometric factor on the accuracy characteristics of a navigation system based on pseudolite.

4. To study the ways of synchronization of pseudolite and their influence on the accuracy of navigation definitions.

5. To carry out approbation of new algorithms for measuring navigation parameters for their introduction into prototypes of navigation receivers.

According to the results of experimental studies were obtained by measuring pseudorange error signals from the pseudolite layout. The pseudorange measurement error was 0.15 meters. To estimate the error in measurement object coordinates from the signals of pseudolites is necessary to consider the value of the geometrical factor.

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