How to prevent loss of satellite navigation continuity caused by nimbostratus? Concept for Polish ATM

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Agenda

- Background of the problem;
- Errors of satellite navigation systems;
- Satellite navigation signal – how can be defined?
- SBAS in Polish ATM;
- Research problem, data, method;
- Results;
- Conslusions

Background of problem

- in 2022 an increase in the volume of air traffic in Poland should be expected of 3.3% compared to 2015;
- demand for terminal and area navigation services provided will increase;
- flexible use of air space based on the 4D trajectory;
- it is necessary to look for different methods of navigation that will meet the challenges posed by air transport industry;
- satellite navigation seems to fit best in trends of flexible forms of aircraft movement;
- particular attention must be paid to requirements and limitations of satellite systems prior to their implementation in aviation

Errors of satellite navigation systems

In general, the errors of satellite systems can be divided into four groups:

- **signal propagation errors**, including:
  - ionospheric errors;
  - tropospheric errors;
  - multipath errors;
- **relativistic errors**;
- **system operation errors** (errors mainly occurring in the space segment of the satellite system), including:
  - ephemeris errors;
  - clock errors;
- **receiver errors** (this group of errors is generated in the user segment, i.e. receivers for commercial and non-commercial purposes), including DOP (Dilusion of Precision).

Satellite navigation signal – how can be defined?

Satellite navigation signal must meet the requirements set for it, which are determined by navigational parameters:

- **accuracy** – in GNSS it is the difference between a designated and a real position
- **integrity** – according to ICAO, it is defined as a measure of trust in the correctness of information provided by the system
- **continuity** – it is the system's ability to perform the assumed functions without unplanned interruptions during the flight operation
- **availability** – can be defined as the percentage of time that a satellite system can be used for navigation

Why continuity is so crucial?

- in case of route, approach and landing operations - the ***continuity of the service is related to the ability of the navigation system to provide output data with a certain integrity and accuracy during the operation***, assuming that this data was available at the beginning of the operation;
- due to the fact that the duration of individual operations is different, the ***continuity requirement is defined as the range of probability of a signal discontinuity per hour***;
- according to ICAO recommendations, ***flight planning cannot be validated*** if it is based solely on GNSS navigation, in which the ***signal is burdened with a high risk of loss of continuity at the time of planning the operation***

SBAS in Polish ATM

- agreement on cooperation between the Polish Air Navigation Services Agency (PANSA) and the European Satellite Service Provider (ESSP) was crucial in the use of GNSS navigation assisted by SBAS (Satellite Based Augmentation System);
- "EGNOS Working Agreement" pointed to implementation of an APV SBAS approach procedures at Polish airports and in the Polish airspace;
- thanks to the EGNOS satellite system operated by the PANSA (as part of cooperation with EUROCONTROL), it is possible to daily analyze this signal on the basis of its parameters;
- Septentrio PolaRx receiver decodes data for EGNOS using PEGASUS software;
- for each of EGNOS geostationary satellites, PEGASUS automatically generates once a day, in the form of report, a summary of the most important values characterizing operation of system

Research problem

ionospheric limitations

How to prevent loss of satellite navigation continuity?

tropospheric limitations

Research data

the reports generated from PEGASUS (EGNOS signal received by Septentrio) generated for Warsaw station for **PRN120, PRN124, PRN126 satellites** with data on, among others, **continuity** and other parameters in 2014

data on cloud cover and precipitation (Institute of Meteorology and Water Management) in Warsaw in 2014

data on solar activity (Space Research Center PAS) in Warsaw in 2014

Research method

- **Artificial Neural Networks (ANN)** are mathematical structures and their software or hardware models that perform calculations using artificial neurons;
- ANNs provide objective and verified results and can be **defined by an artificial neuron model, network topology, and network training rules;**
- the basic step in creating an artificial neural network is to **determine the model of a single neuron**;
- neurons are complex objects, but can be simplified to have two basic states - rest and excitation. At the same time, in order for the neuron to be in this second state - it must be triggered by the **input signals**

Research method - process

Phase I. Definition of input and output data

The following input data has been defined (x) as well as output data (y):

- x_1 - cloudiness;
- x_2 - preciptation;
- x_3 - solar activity;
- x_4 - accuracy;
- x_5 - availability;
- x_6 - integrity;
- y_1 - continuity (number of discontinuity events).

Phase II. Determination of the network structure

- one hidden layer;

- eight hidden neurons;

- samples were divided into three subsets - training, validation, test;

- division was either in 80%/10%/10% configuration or in 70%/15%/15%

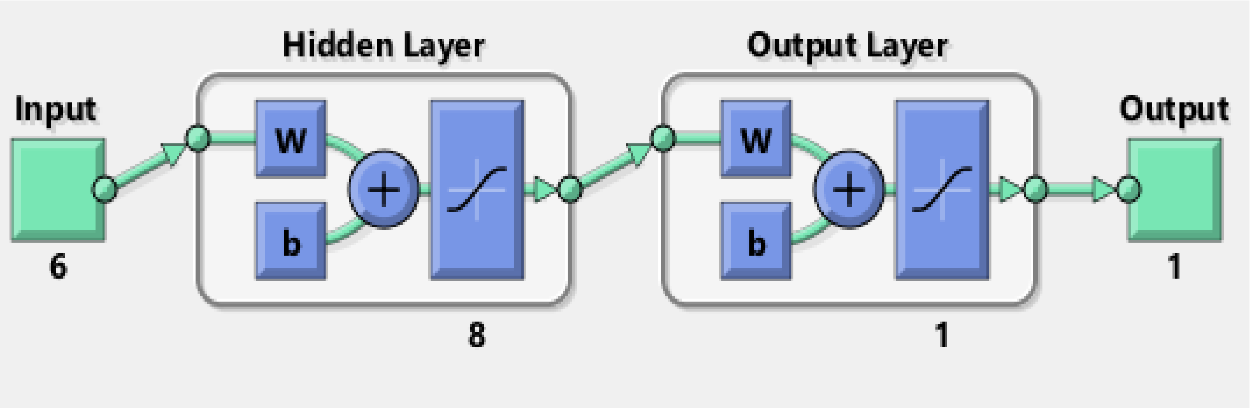
Phase III. Training of the network

In the training process, the Levenberg-Marquardt algorithm **(TRAINLM)**, Bayesian regularization **(TRAINBR)** and the smallest pitch-drop algorithm **(TRAINGDM)** were taken into account.

Phase IV. Validation of the network

The model uses a simple validation **(dividerand)** - a randomly divided data set into three subsets: training, validation and test.

ANN structure



$X_{i1} = [x_{i1}, x_{i2}, x_{i3}, x_{i4}, x_{i5}, x_{i6}]^T$
$Y_{i1} = [y_{i1}]^T$
$D_{i1} = [d_{i1}]^T$

Results - criteria

- the network chosen for optimal results was guided by the **basic criterion - the smallest MSE** (Mean Squared Error);
- the **additional criterion** was **the highest value of the R** index (Regression);
- R represents the relationship between the values of the current Y and the reference D;
- when **R = 1**, the relationship between Y and D is **linear**;
- when **R moves to 0**, it means a **nonlinear relationship**;
- the higher the R value, the smaller the difference between D and Y.

Results

The results of the research were presented in the following sequence:

- MSE and R values for a **given number of neurons in the hidden network layer;**
- MSE and R values with **different training algorithms** for the number of neurons in the hidden network layer for which the best result was previously obtained;
- MSE and R values **considering different divisions of the training set into subsets** with the selected learning algorithm and the number of neurons in the hidden network layer.

Results

Table 1. MSE and R values depending on the number of neurons in the hidden network layer

Number of neurons in the hidden network layer	MSE value	R value
1	$1{,}727 \ x \ 10^{-3}$	0,792
2	$2{,}750 \ x \ 10^{-3}$	0,833
5	$2{,}602 \ x \ 10^{-2}$	0,114
8	$1{,}390 \ x \ 10^{-3}$	0,831
10	$2{,}760 \ x \ 10^{-3}$	0,787

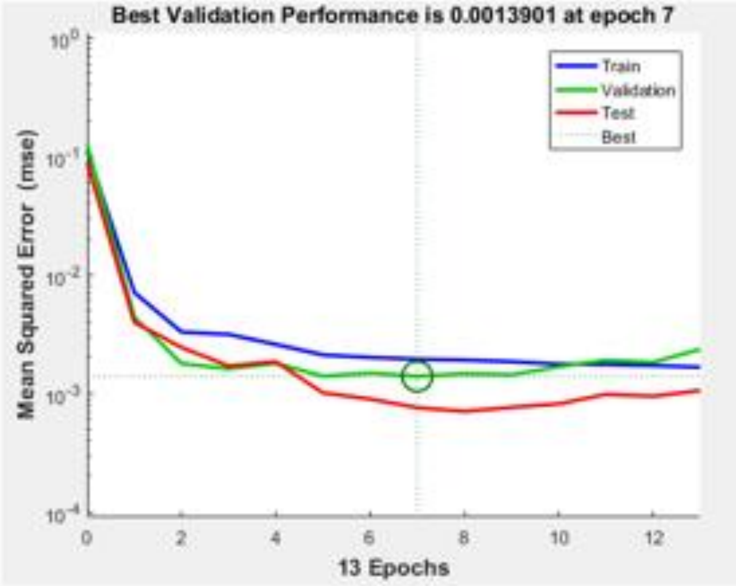
Table 2. MSE and R values depending on training algorithms (for eight neurons in the hidden network layer)

Training algotrithm	MSE value	R value
Levenberg-Marquardt (TRAINLM)	$1{,}390 \ x \ 10^{-3}$	0,831
Bayesian regularization (TRAINBR)	$1{,}476 \ x \ 10^{-3}$	0,281
smallest pitch-drop algorithm (TRAINGDM)	$1{,}731 \ x \ 10^{-3}$	0,838

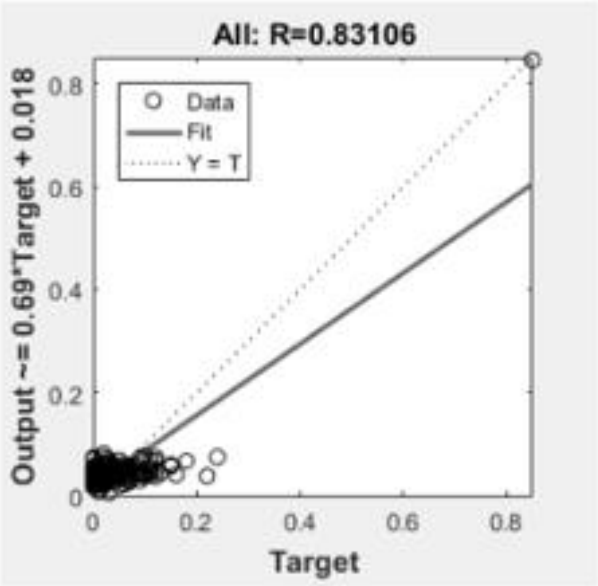
Table 3. MSE and R values depending on the division of the training set (for eight neurons in the hidden network layer and the TRAINLM training algorithm)

Division of training set	MSE value	R value
70%/15%/15%	$3{,}996 \ x \ 10^{-3}$	0,851
80%/10%/10%	$1{,}390 \ x \ 10^{-3}$	0,831

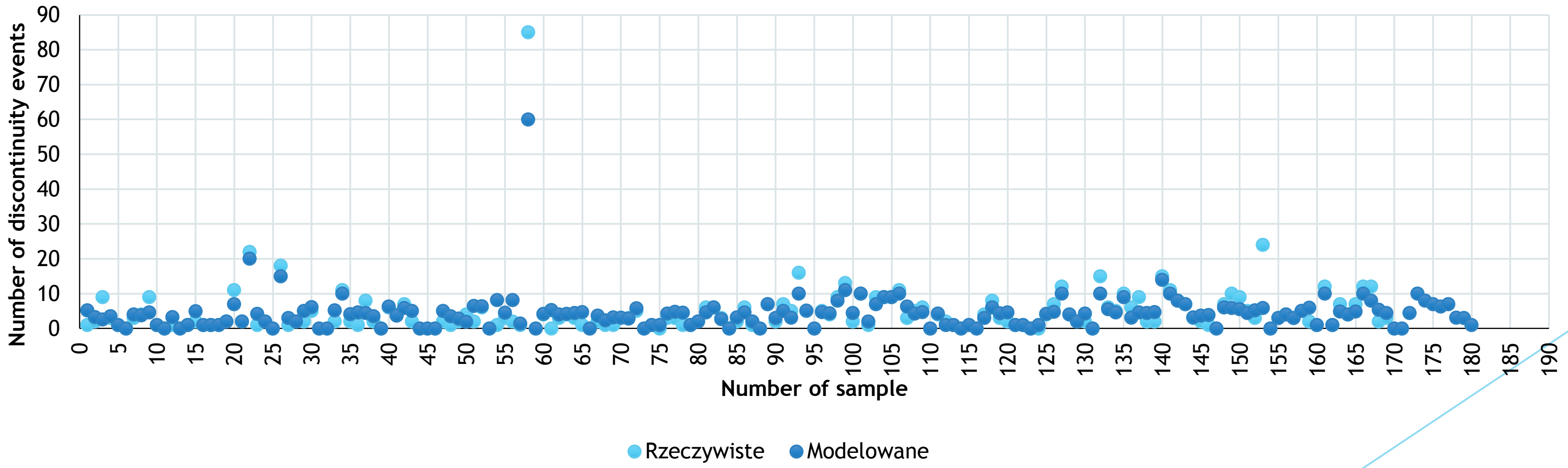
Results



Best Validation Performance is 0.0013901 at epoch 7
Train
Validation
Test
Best
Mean Squared Error (mse)
13 Epochs



All: R=0.83106
Data
Fit
Y = T
Output ~= 0.69*Target + 0.018
Target



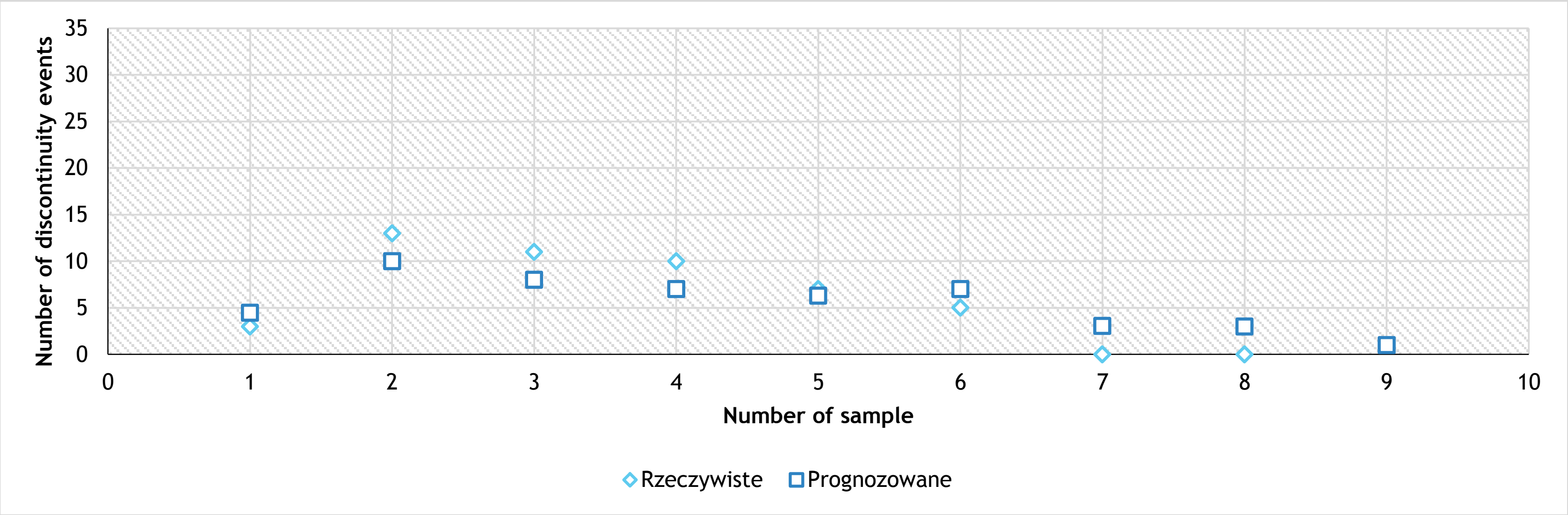
Number of discontinuity events
Number of sample
Rzeczywiste
Modelowane

Results – conclusion

Results show that it is possible to model continuity by ANN using input data on preciptation & solar activity and historical data on accuracy; availability & integrity.

How to prevent loss of satellite navigation continuity? By forecast

The last stage of the research was forecasting the value of continuity. The model values were demonstrated by the last nine samples that were forecasted and compared with real values.



Summary & conclusions

- the number of discontinuity events **increases with changing rainfall**;
- there could be **various types of precipitation**, which affected the satellite signal to varying degrees (precipitation falls into the so-called hydrometeors, such as: rain, drizzle, snow, snow peaks, snow grains, ice seeds, hail);
- continuity **measurements can also be burdened with errors of type**, to which they contribute, e.g.: variability of the state of aggregation (rain, snow, hail); presence of a melting layer; presence of echoes of disturbances; wave suppression in rainfall; different concentration and droplet size;

Summary & conclusions

- it is **possible to predict the continuity** of the satellite beacon used in air transport by artificial neural networks;
- practical aspect of research refers to the development of a solution that allows **aircraft operator to choose a navigation method**;
- prediction of satellite signal continuity **may warn the aircraft operator before using this form of navigation** in flight, providing information on the failure by meeting parameter requirements, e.g. about a possible event of signal discontinuity resulting from an upcoming, intense precipitation;
- presented **model is open to expansion**, especially with new input variables that could be of even greater importance and quality of the proposed solution

Thank You for Your attention!

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