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# Experimental Research of Wireless Sensor Network Application in Aviation

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## Introduction

Mechanical and electromechanical flight parameter measurement devices are traditionally used for aircraft. It is however rather complicated to collect flight data using such devices. To collect flight data, it is necessary to use electronic devices that can process the flight parameters, which can then be presented to pilots and saved in memory. For the purpose of collecting flight data, measurement devices linked to modern aircraft device systems are used. Such systems used for measurement information collection and processing systems can be called measurement information systems (MIS). In aircraft, all data is collected from a number of sensors and should be processed. The sensors must be protected from disturbances having an impact on measurement precision. Security must be capable of identifying malfunctioning sensors and isolating them from the system. These challenges can be fulfilled with special data fusion and fault detection and isolation algorithms [4, 5, 6, 7, 9] using the Kalman filtering process [3]. Wireless sensors are used to collect data for aircraft MIS Fly-by-wireless aircraft control technology based on transferring the parameters of an aircraft system and the pilot's commands using wireless technologies is being created [1].

This work investigates an aircraft measurement information system including wireless sensors and a device used for data collection. The fly-by-wireless concept is presented in section I. In section II, a MIS designed at the Antanas Gustaitis Aviation Institute of Vilnius Gediminas Technical University is presented. The test performed during free flight time by the Lithuanian glider LAK-20T and its measurement results are provided and discussed in section III. Processing of measurement results obtained by the Kalman filter is given in section IV. The last section provides a discussion about measures that should be taken in order to ensure information security.

## Fly-by-wireless concept

MIS traditionally includes one complex central device used for processing data and a number of processors connected by cables to measuring and controlling devices. This type of connection is not convenient because all components of the system are connected using wire connectors. Wireless technology is an innovative solution enabling wire connections between the processing device and other system devices to be eliminated (Fig. 1).

The method used is called fly-by-wireless [**Error! Reference source not found.**] and its concept is based on the interface between instruments and processing devices using IEEE 802.15.x specifications. At the same time, the traditional complex data processing unit is replaced by several less complex processing devices (nodes) placed around the aircraft. The nodes are located closer to sensors and controlled surfaces, and a wireless network is created among nodes.

This type of system provides the possibility to eliminate a large amount of linking cables, and as a result total aircraft weight is minimized. Measurement and management command transfer using a wireless method require special information security measures [7, 8] that would help to decrease energy consumption [10].

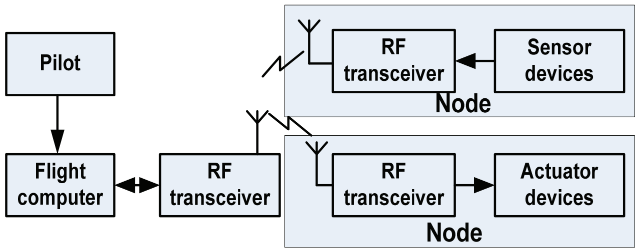



**Fig. 1**. Fly-by-wireless concept

## Selection of communication technologies

A wide range of communication technology networks is used for designing wireless sensor networks.

The selection of radio communication technologies depends on several factors. First, there is a need for a suitable information transfer rate and amount of energy to maintain communication. The selection of technology also depends on factors such as performance frequency, protocol characteristics, number of connected devices, selection of communication modules, and software.

Table 1 presents an analysis of wireless communication solutions such as IEEE 802.15.1 (Bluetooth), IEEE 802.15.4 (ZigBee), and IEEE 802.11 (WLAN) that are operating in the industrial, scientific and medical (ISM) communication frequency range and are currently available in the market. The analysis is dedicated to MIS, which is being designed in the current research.

After a review of the technologies mentioned above, ZigBee technology—which enables the creation of large-scale wireless networks with a transfer rate reaching 250 kbps, low energy consumption, and a simple data transfer protocol—was chosen.

ZigBee standard is optimise to low costs, low need for energy, automation, data collection or control systems. ZigBee is used for mixed mesh, star, and peer-to-peer topology networks connected by a modulation of direct sequence spread spectrum (DSSS). The nominal link range is about 10 m and in direct visibility conditions it is up to 400 m. ZigBee, which is able to link thousand-end devices to the network, uses 64 bit IEEE address, and short 16-bit address is used for local addressing.

**Testing of measurement information system**

An aircraft wireless MIS [**Error! Reference source not found.**] was designed for an experimental study. A frequency range of 2.4 GHz, IEEE 802.15.4 (Zigbee) protocol, transferring data rate of 250 kbps, and performance range of up to 400 m was chosen for the MIS. The star network topology scheme where up to 15 end nodes can be linked to one network coordinator (as presented in Fig. 2) was chosen.

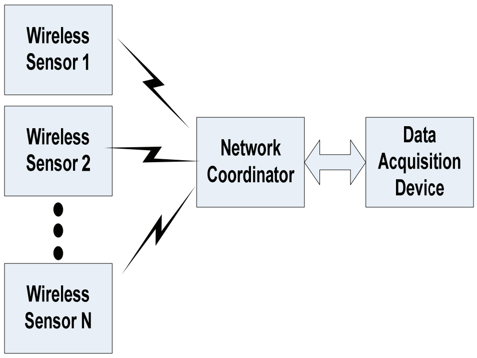


**Fig. 2**. Measurement information system

The MIS was designed to test electromagnetic disturbances that may have an impact on experimental measurement accuracy caused by the minimal amount of electronic equipment. Since a glider is the best solution to achieve this aim, a LAK-20T glider was chosen for the experimental studies. The glider is equipped with a minimal amount of electronic equipment such as a GPS receiver and communication station. Flight parameters—including speed, height and vertical speed—are measured with the help of mechanical instruments.

**Table 1**. Review of wireless technologies

| Name | Range | Network Topologies | Bit Stream (kbps) | Power | Band (MHz) | Module Dimentions (mm) | Target Battery Life |
|---|---|---|---|---|---|---|---|
| Bluetooth | 1–100 m | adhoc, point to point, star | 24000 | 100 mW | 2400 | 31x16x2,2 | Days-months |
| WLAN | 300 m | mesh, adhoc, star | 11000 | 100 mW | 2400 | 10x10x1 | Days |
| ZigBee | up to 400 m | mesh, adhoc, star | 250 | 30 mW | 2400, 868, 915 | 28x18x2 | 6 months – 2 years |

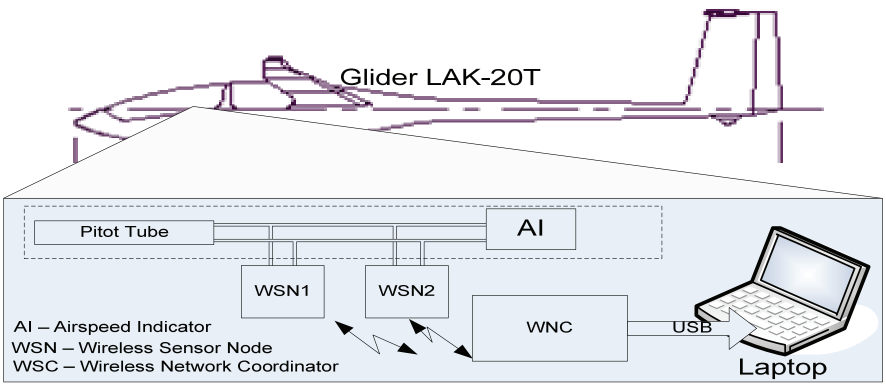


**Fig. 3**. MIS component arrangement in aircraft

In order to perform the test, we choose glider speed measurements. As fig. 3 shows, the aircraft speed measurement system is equipped with the MIS. The aircraft speed measurement system includes a Pitot tube, aircraft speed indicators, two wireless sensors with their network coordinator, and a laptop with special software (Fig. 4). As there is a strong focus on aviation safety, two speed sensors are used to increase the reliability of the speed measurement system. Measurement frequency of 2 Hz was used because the maximal aircraft flying speed reaches 300 km/h. Measurements are performed synchronously, i.e. measurements start when a synchronisation signal is sent by the network coordinator. End nodes synchronously transfer unprocessed measurement results for network coordinator (Fig. 4).

The MIS has three parts (Fig. 2): a wireless sensor unit, wireless sensor network coordinator, and data acquisition device i.e. laptop.

A few free flights were performed during the experiment. The measurement results were stored in the computer memory for further processing. Since data was stored only by electronic sensors, it was impossible to compare stored data with indications provided by the mechanical speed indicator in a more objective way.

The next section provides an analysis of data collected during a flight and processing of data by the Kalman filtering process.

**Measurement data analysis and processing using discrete Kalman filter**

During free flight, speed measurement data was collected. The flight took about 10 min and as a result 1400 measurement samples were collected (Fig. 5).

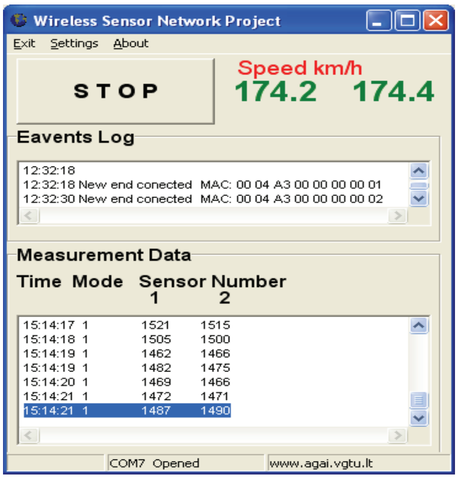



**Fig. 4**. Window of program WISNEP

According to the analysis results, it was estimated that noise caused by the wireless sensor, the non-linearity of pressure change function, the voltage instability of the power source, analogue digital converter conversion error, imbalance of air flow that incomes through the sensor, and other factors had an impact on the data. Although the measurement system is based on wireless technologies, the reliability of measurement data is influenced by errors that occur during the process of data transfer such as loss of data pockets or illegal direct intervention in the communication session performed by third parties. The latter assumption can be rejected because during the experiment this act was not performed.

As we can see from the results obtained during the flight (from the 60th second to the 100th second), both speed indicators suffered a significant loss of data pockets, i.e. there were communication disturbances. The first anomaly of an indicator (failure of the first indicator) was observed from the 300th second to the 350th second. This situation was particularly dangerous for the control systems, including controlled surfaces, engine thrust levers, etc. In the process of designing fly-by-wireless, it is necessary to take into account the loss of data pockets that may be caused by electromagnetic disturbances.

Let us use the Kalman filtering algorithm [3] in order to process the data collected. The Kalman filter is based on recursive statistical evaluation. This means that to estimate the current state it is only necessary to get a state obtained from a previous time reference and current time references that are being measured. Unlike the other evaluation technologies, observations of the past are not required. The Kalman filter is a time domain filter and therefore it is suitable for real-time systems.

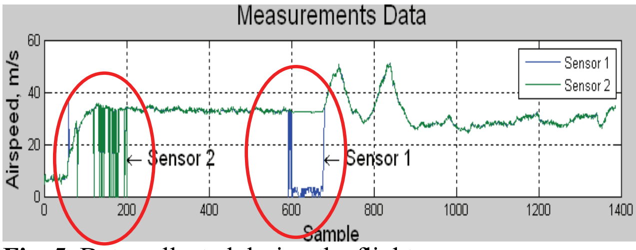



**Fig. 5.** Data collected during the flight

The Kalman filtering algorithm includes two steps: prediction step and correction step [3].
Prediction:

$$\hat{x}_{k|k-1} = F_k \hat{x}_{k-1|k-1}, \tag{1}$$

$$P_{k|k-1} = F_k P_{k-1|k-1} F_K^T + Q_k, \tag{2}$$

Correction:

$$\tilde{y}_k = z_k - H_k x_{k|k-1}, \tag{3}$$

$$S_k = H_k P_{k|k-1} H_k^T + R_k, \tag{4}$$

$$K_k = P_{k|k-1} H_k^T S_k^{-1}, \tag{5}$$

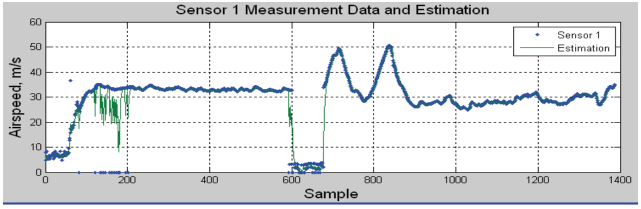
$$x_{k|k} = x_{k|k-1} + K_k \tilde{y}_k, \tag{6}$$

$$P_{k|k} = (I - K_k H_k) P_{k|k-1}, \tag{7}$$

where $\hat{x}_{k|k-1}$ – predicted state, $F_k$ – state transfer matrix, $\hat{x}_{k-1|k-1}$ – previously adjusted projected state, $P_{k|k-1}$ – predicted state covariance,$P_{k-1|k-1}$ – adjusted predicted state covariance, $\tilde{y}_k$ – measurement error, $z_k$ – actual measurement value, $H_k$ – Jacobian, $S_k$ – error covariance, $R_k$ and $Q_k$ respectively measurement and process noise covariance matrix, $x_{k|k}$ – adjusted predicted state, and $P_{k|k}$ – adjusted predicted covariance.

Let us evaluate measurement data collected using the discrete Kalman filter (Fig. 6).

The noise that influences the measurements was filtered out after obtaining measurement data processed by the discrete Kalman filter. The results obtained show that data lost during the process of data transmission may be partially restored by the Kalman filter. In case of longer data transmission (Fig. 6, sensor 1), the data lost by the Kalman filter cannot be restored.

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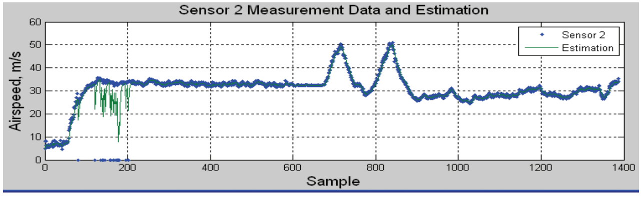


b)

**Fig. 6**. Measurement data processed by the discrete Kalman filter

## Conclusions

In this paper, an aircraft measurement information system was designed and tested using the method of wireless data transfer. A LAK-20T glider was chosen for the experiments.

After the performance of free-flight experiments, it was proven that two types of disturbances, measurement noise and disturbances affecting the communication channel influence the reliability of measurements. Data transfer reliability of the measurement information system is affected only by communication channel disturbances.

To increase MIS reliability, redundant wireless sensors are used. The data obtained is processed using the discrete Kalman filter.

Sensor redundancy is necessary in order to ensure MIS reliability. Error detection and isolation techniques should be used when process measurement information.

## Future work

For the purposes of the wireless data collection method, it is appropriate to apply a method of complex measurement data merge. There is also a need for estimating errors and their causes (sensor errors or communication channel disturbances) that occur in measurement information.

## Acknowledgement

We would like to express our gratitude to Vytautas Sabeckis, director of the Kaunas Aviation Sport Club, who provided LAK-20 glider for the experiment. We are also thankful for Vytautas Mačiulis, director of JSC Sportinė Aviacija and KO, for flight organization and payment for glider take off.

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**J. Stankunas, D. Rudinskas, E. Lasauskas. Experimental Research of Wireless Sensor Network Application in Aviation // Electronics and Electrical Engineering. – Kaunas: Technologija, 2011. – No. 5(111). – P. 41–44.**

The paper presents the application of wireless sensor networks in aviation for measuring and transferring flight parameters. IEEE 802.15.4 standard ZigBee of low price, which operates in the low range of the ISM frequency band, was chosen. Experiments were performed during free flight. Evaluation of measurement results using Kalman filtering algorithm is provided. Ill. 6, bibl. 10, tabl. 1 (in English; abstracts in English and Lithuanian).

**J. Stankūnas, D. Rudinskas, E. Lasauskas. Bevielių jutiklių tinklų taikymo aviacijoje eksperimentinis tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 5(111). – P. 41–44.**

Darbe pristatomas bevielių jutiklių tinklų taikymas aviacijoje skrydžio parametrams matuoti ir perduoti. Tyrimams buvo pasirinktas nebrangus, mažu nuotoliu ISM dažnių ruože veikiantis IEEE 802.15.4 standartinis protokolas ZigBee. Eksperimentai atlikti laisvojo skrydžio metu. Pateiktas matavimų rezultatų vertinimas rekursiniu Kalmano filtravimo algoritmu. Il. 6, bibl. 10, lent. 1 (anglų kalba; santraukos anglų ir lietuvių k.).