National Aviation University

Application of Artificial Intelligence in Remotely Piloted Aerial Systems

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The 3rd Drone World Congress
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Agenda:

1. AI and European Strategies
2. Multi-parametric data recovery in unmanned aerial system with multi-choice classification of flight situations
3. Object detection and classification
4. Alternative Positioning, Navigation, and Timing

Artificial intelligence (AI) refers to systems that display intelligent behaviour by analysing their environment and taking actions – with some degree of autonomy – to achieve specific goals.
AI-based systems can be purely software-based, acting in the virtual world (e.g. voice assistants, image analysis software, search engines, speech and face recognition systems) or AI can be embedded in hardware devices (e.g. advanced robots, autonomous cars, drones or Internet of Things applications).

As a scientific discipline, **AI** includes several approaches and techniques, such as machine learning (of which deep learning and reinforcement learning are specific examples), machine reasoning (which includes planning, scheduling, knowledge representation and reasoning, search, and optimization), and robotics (which includes control, perception, sensors and actuators, as well as the integration of all other techniques into cyber-physical systems).”

Source: A Definition of AI: Main Capabilities and Disciplines. High-Level Expert Group on Artificial Intelligence set up by the European Commission, 9 p.

Usage of AI may increase anticipatory and decision making capabilities within complex and uncertain environments. AI systems have high potential in ATM, specifically in areas which involves decision making under uncertainty (e.g. conflict detection and resolution) and prediction with limited information (e.g. trajectory prediction).

These approaches can support the human operators in exploitation of timely and dynamic information on atmospheric hazards, traffic fluctuations, and airspace utilisation.

In addition to developing solutions to support en-route operations, AI can be applied in:

i) speech recognition to act as an additional safety net to detect read-back errors;

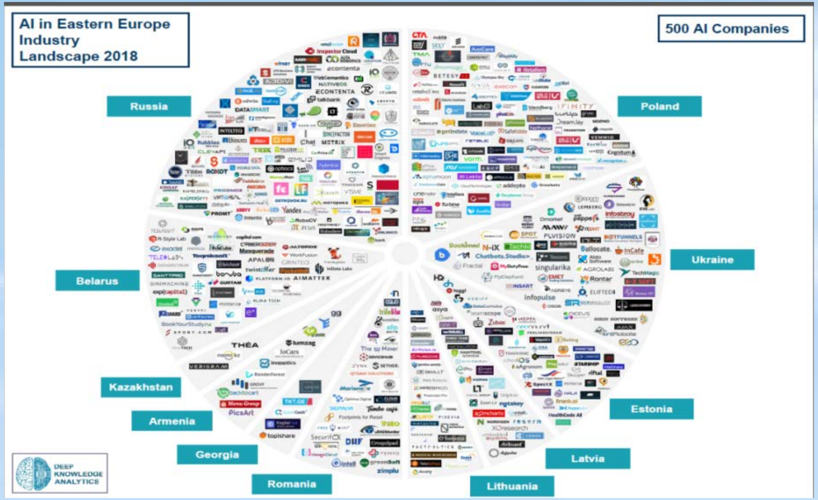
ii) trajectory synchronisation of aircraft ground movements that provide optimised taxiing strategies that comprehensively accounts for arrivals and departures as well;

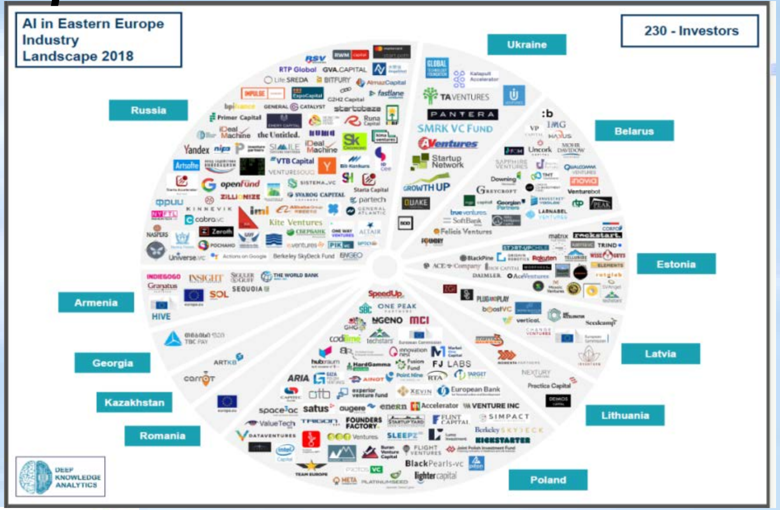
iii) predicting the most optimal runway configuration for a given arrival sequence and departure schedule so as to maximise the runway throughput. With the development of these tools, it is envisioned that AI will be integral to ATM operations in the future to form a highly automated environment capable of supporting high intensity and more complex operations. In similar fashion, these decision-making tools also have the potential to ensure that aviation is not held back by human resource constraints.

There is therefore a need to align research, industry, State regulators and service providers to ensure readiness to face and manage an environment where ATM is supported by highly intelligent automation functions that process and generate advisories in a constantly evolving manner that can even adapt to new airspace users such as unmanned aircraft systems (UAS).

Source: **Potential of Artificial Intelligence (AI) in Air Traffic Management (ATM). ICAO, Working paper, 2018, 3 p.**

AI in Eastern Europe





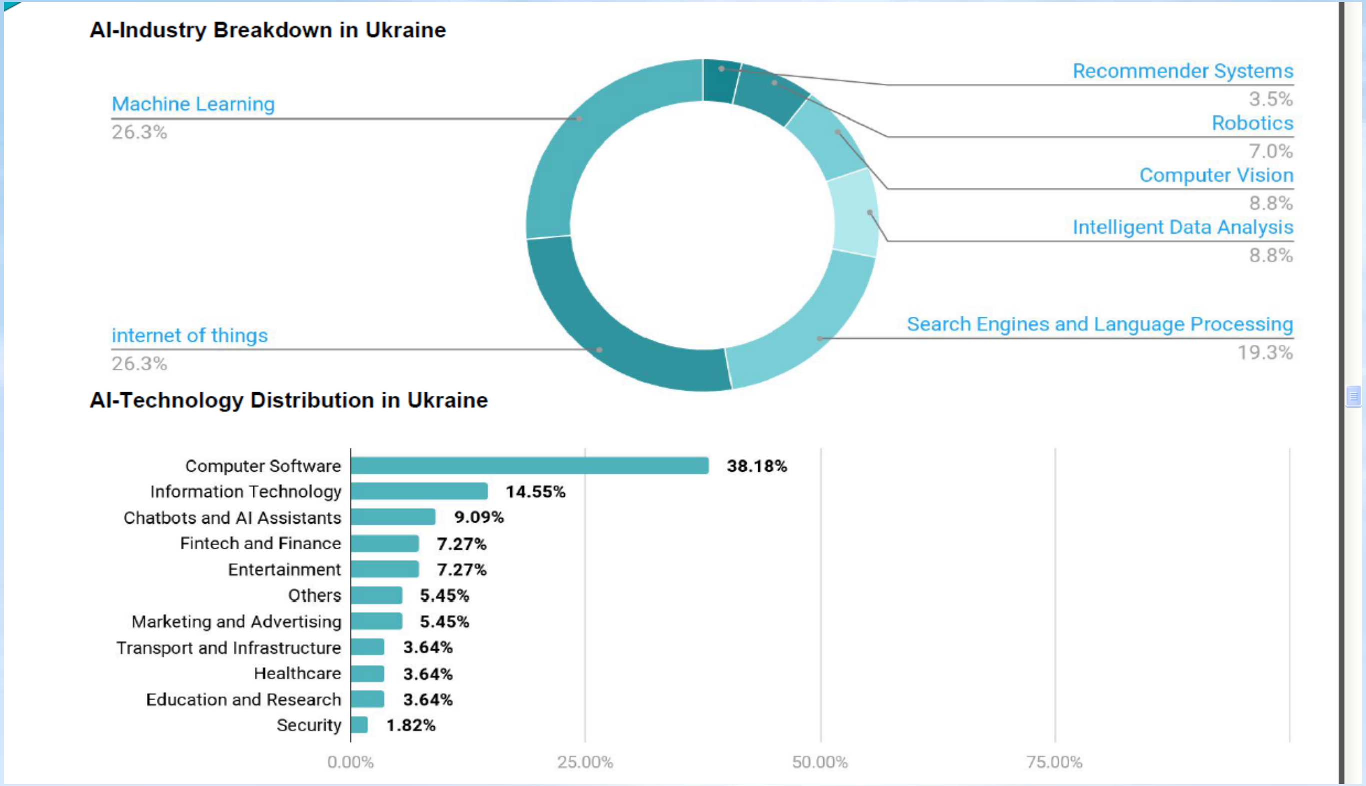
Number of AI-Companies and Investors in Eastern Europe

17

Companies	Country	Investors
12	Armenia	10
47	Belarus	27
46	Estonia	27
4	Georgia	1
4	Kazakhstan	2
26	Latvia	11
29	Lithuania	5
110	Poland	59
32	Romania	1
133	Russia	76
57	Ukraine	11

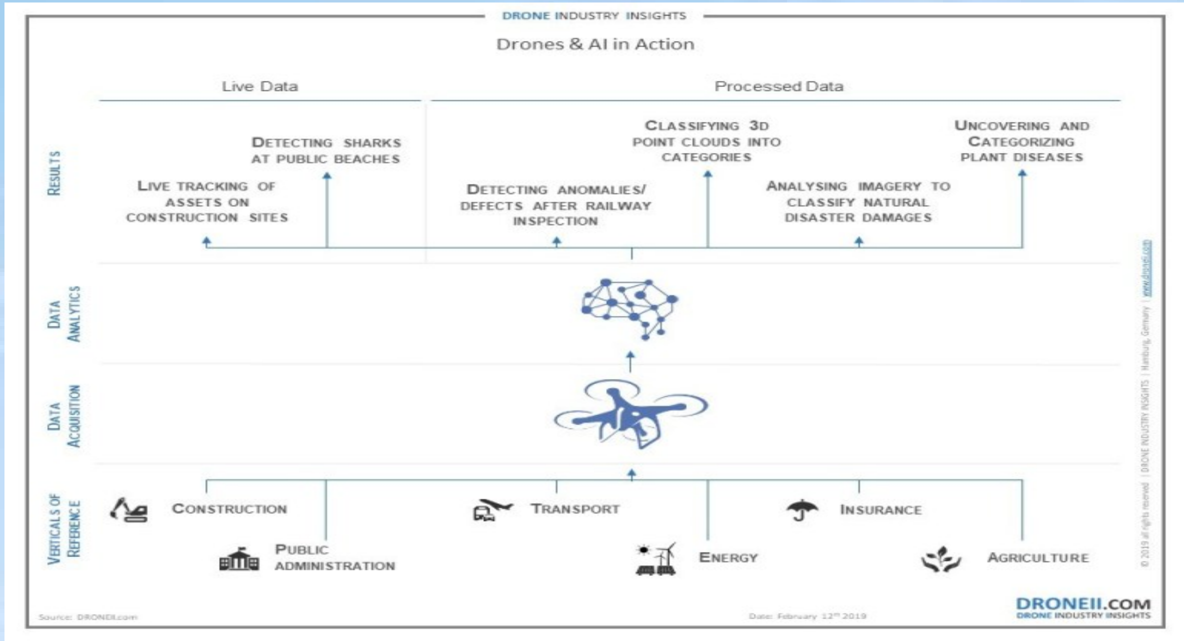
***Source:** AI in Eastern Europe. Artificial Intelligence industry landscape overview 2018. Deep Knowledge Analytics, 2018, 40 p.*

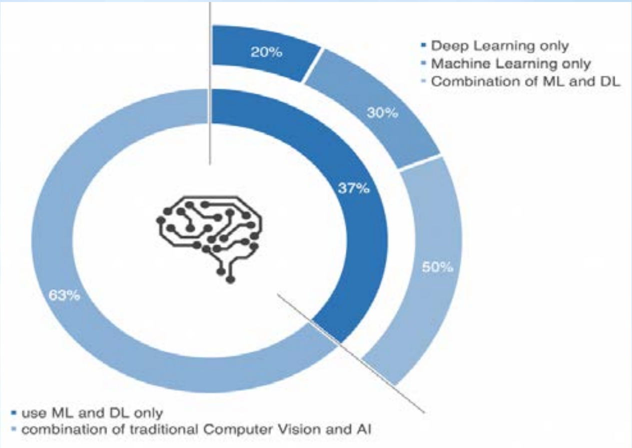
Industry and Technology Distribution in Ukraine (57 Companies)



***Source:** AI in Eastern Europe. Artificial Intelligence industry landscape overview 2018. Deep Knowledge Analytics, 2018, 40 p.*

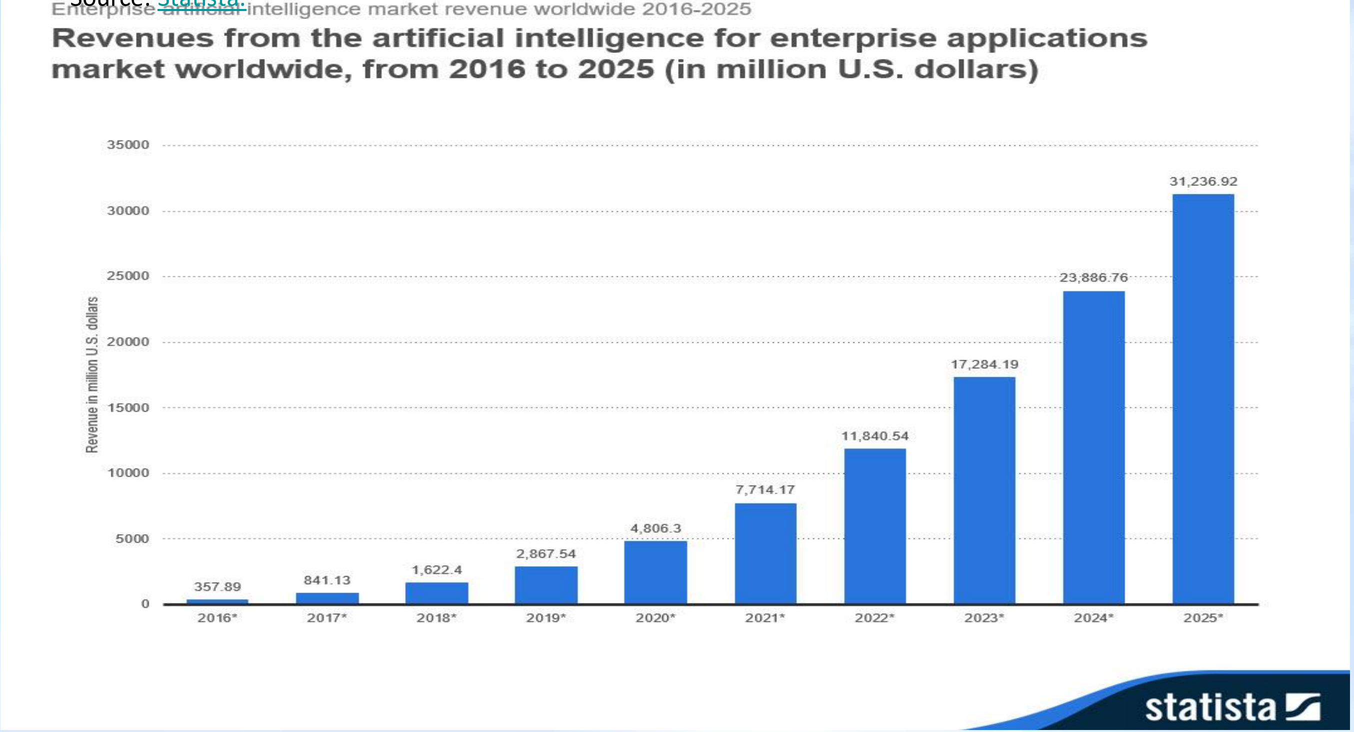
Drones and AI in Action





Source: *DRONEII.com*

- **Global revenues from AI for enterprise applications is projected to grow from $1.62B in 2018 to $31.2B in 2025 attaining a 52.59% CAGR in the forecast period.** Image recognition and tagging, patient data processing, localization and mapping, predictive maintenance, use of algorithms and machine learning to predict and thwart security threats, intelligent recruitment, and HR systems are a few of the many enterprise application use cases predicted to fuel the projected rapid growth of AI in the enterprise. Source: Statista.



SESAR STRATEGY

- **SESAR-ER4-06-2019: Safety and Resilience**
- **SESAR-ER4-31-2019: U-space**

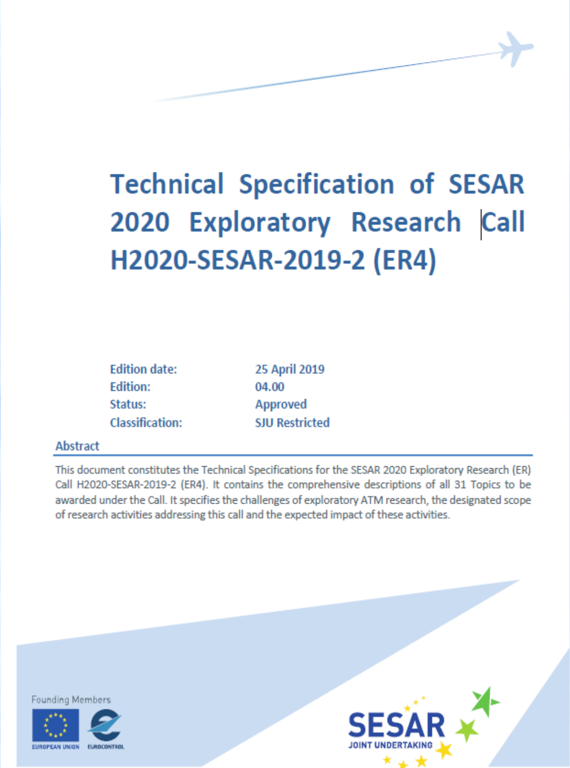
(Application area: Common altitude reference

Application area: flight-planning and demand and capacity balancing for drones

Application area: U-space separation management service)

- **SESAR-ER4-02-2019: Cognitive Support**
- **SESAR-ER4-09-2019: Legal and Regulatory Challenges of Higher Levels of Automation**
- **SESAR-ER4-24-2019: Innovation in CNS to enable Digitalised Operations**

(Application area: Low cost alternative Position, Navigation and Timing (A-PNT) for General Aviation and drones)



Technical Specification of SESAR 2020 Exploratory Research Call H2020-SESAR-2019-2 (ER4)

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Abstract

This document constitutes the Technical Specifications for the SESAR 2020 Exploratory Research (ER) Call H2020-SESAR-2019-2 (ER4). It contains the comprehensive descriptions of all 31 Topics to be awarded under the Call. It specifies the challenges of exploratory ATM research, the designated scope of research activities addressing this call and the expected impact of these activities.

Founding Members

EUROPEAN UNION EUROCONTROL

SESAR JOINT UNDERTAKING

Multi-parametric data recovery in unmanned aerial system with multi-choice classification of flight situations

Research problems:
- “bad” UAV flight data
- uncertainty of flight situation

Research objective:

To develop a method to recover lost UAV flight data and correct its outliers; to develop method of multi-choice UAV flight situations classification.

Research tasks:
- To analyze flight data recovering methods; analyze general principles of flight situations classification;
- To develop a multi-parametric data recovering in Unmanned Aerial System;
- To improve method of multi-choice UAV flight situations classification considering recovered data;
- To verify developed methods by means of computer simulation and experimental tests.

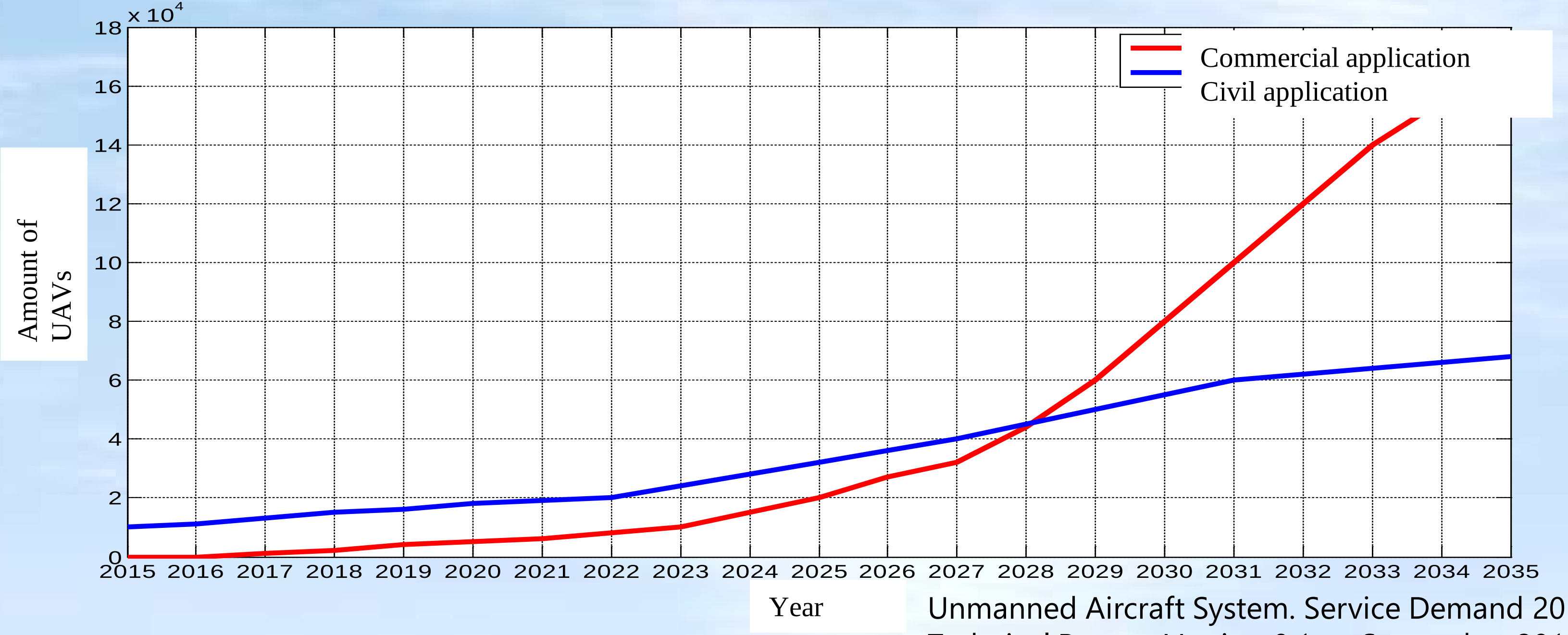
Output:
- method of multi-parametric data recovery
- method of multi-choice classification of flight situations

↓

Situation awareness ➡ **Safety**

UAS tendencies

It is predicted in 2022 – 2023 years the period of UAVs commercial sales, their products and services will begin. In subsequent years, a rapid growth in demand for UAVs will be expected to reach 250,000 units up to 2035. 175,000, of which will have commercial application.



Unmanned Aircraft System. Service Demand 2015 – 2035 / Technical Report, Version 0.1 — September 2013, DOT-VNTSC-DoD-13-01. U.S. Department of Transport. – 2013. – 151 p.

Factors that affect UAS operation

Flight safety depends on a large number of factors, whose actions are difficult to predict and prevent, since most of them have probabilistic nature.

Adverse weather conditions

Inability of collisions detection and avoidance

Navigation errors

Software insecurity

Failures and malfunctions of the functional systems elements

Loss of communication link

Inappropriate UAV technical conditions

Operator failures

Losses and outliers in UAS parameters measurements

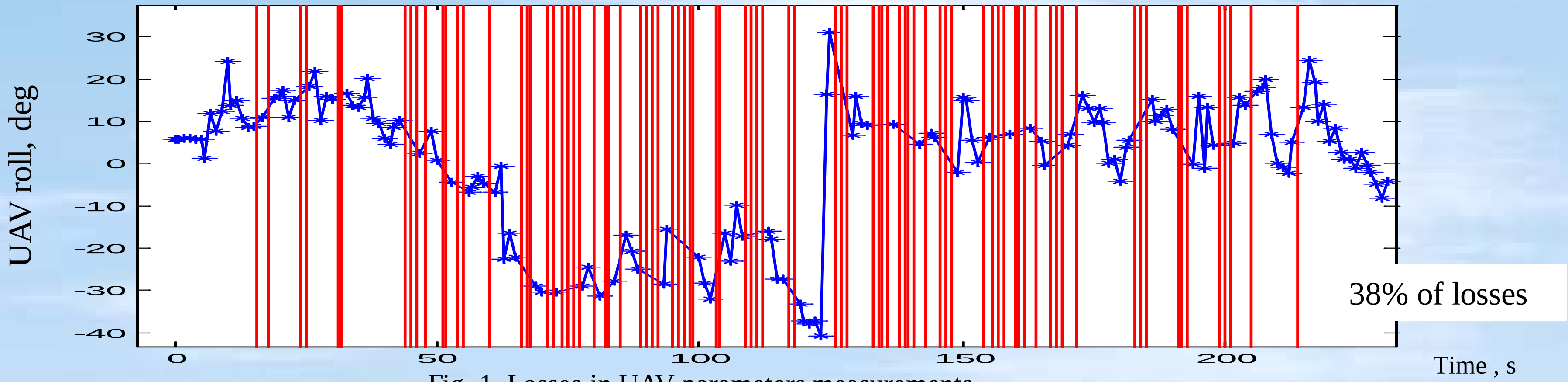


Fig. 1. Losses in UAV parameters measurements

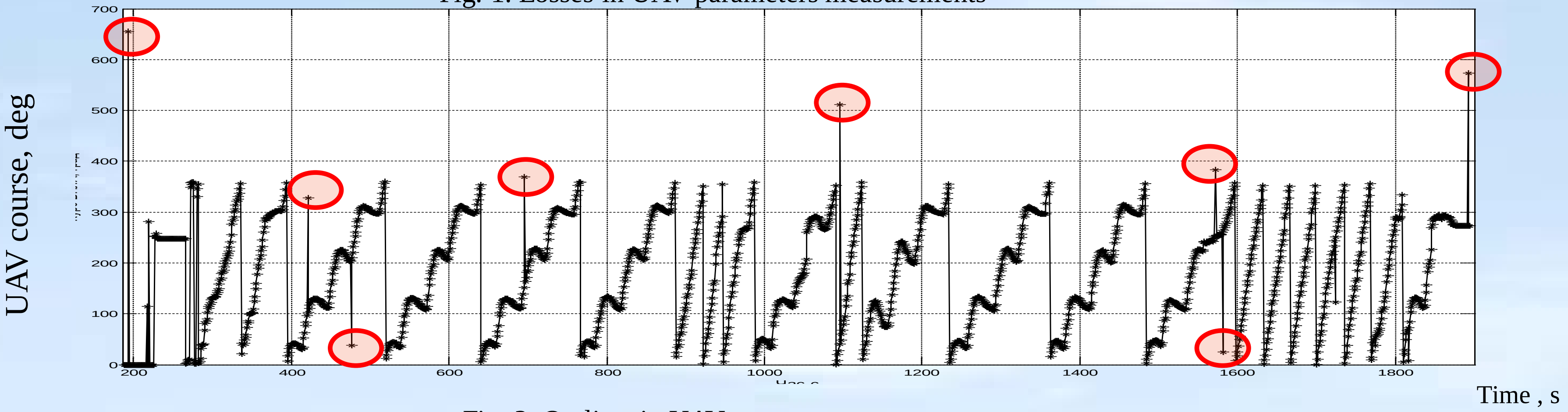


Fig. 2. Outliers in UAV parameters measurements

Analysis of lost data recovery methods

Lost data recovery methods

Common

Statistical methods of data imputation

- Mean value imputation
- Imputation by constant value
- Imputation by last value
- Imputation by regression
- ZET methods (Zet, ZetM, ZetBraid)
- Bartlett’s method
- Resampling method

Methods based on loss nature

- _Expectation-maximization method

Methods based on mathematical model

Uncommon

Methods based on artificial intelligence

- Cluster analysis method
- Factor analysis method
- Neural network method
- Fuzzy logic method

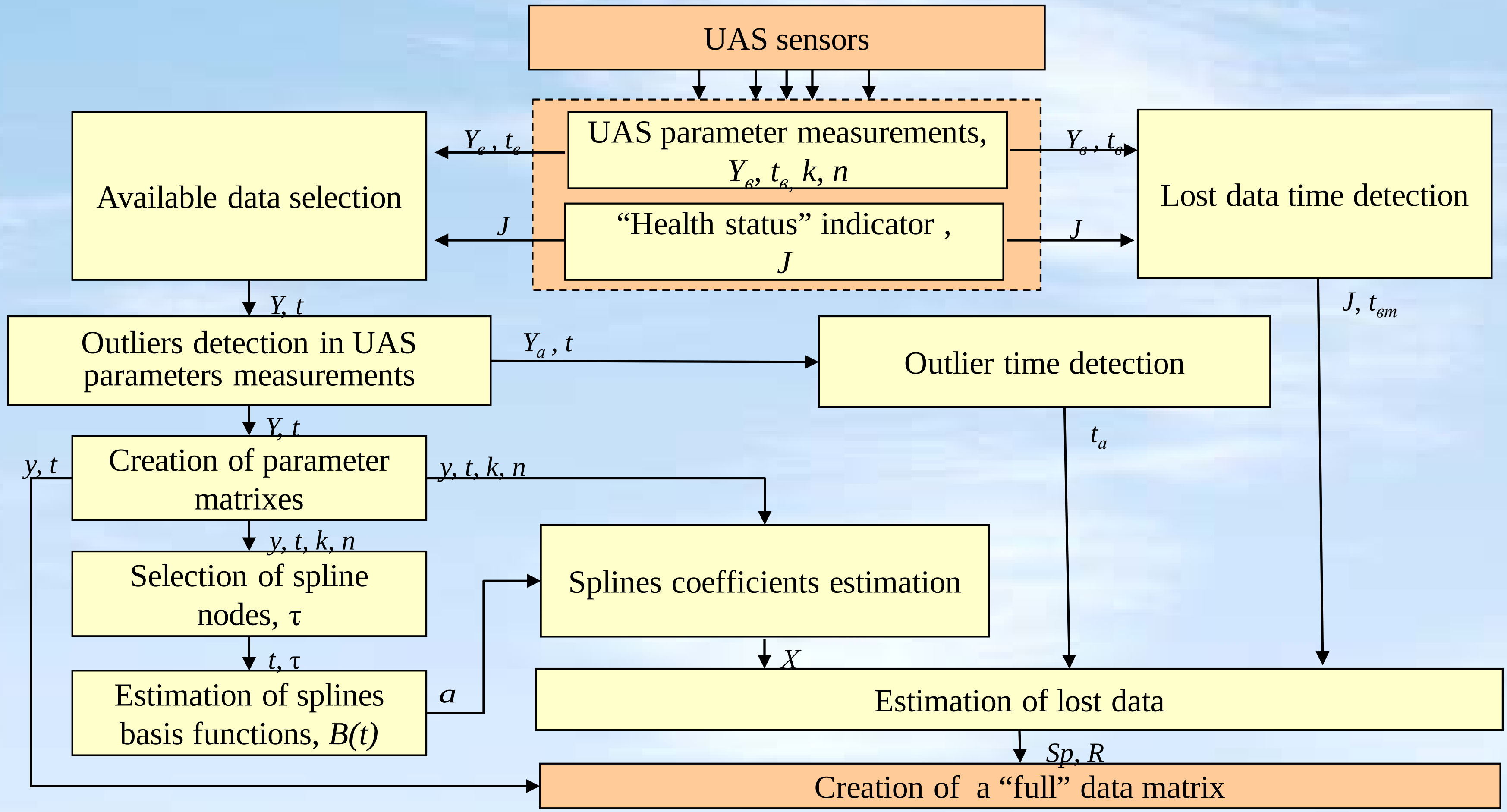
Disadvantages of common methods

- not universal
- require uniform data
- low precision

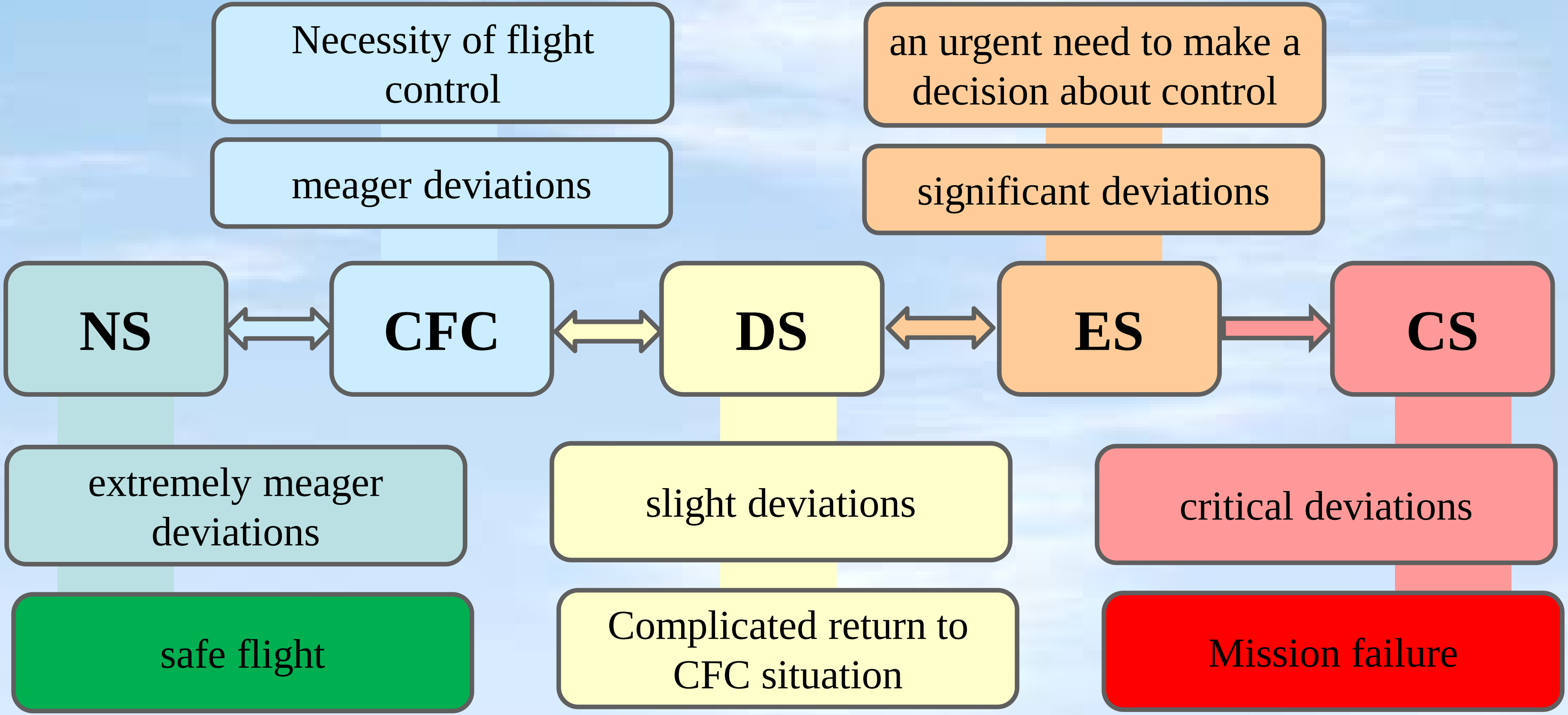
Disadvantages of uncommon methods

- complexity of implementation and verification
- rigid hardware requirements
- long computation time

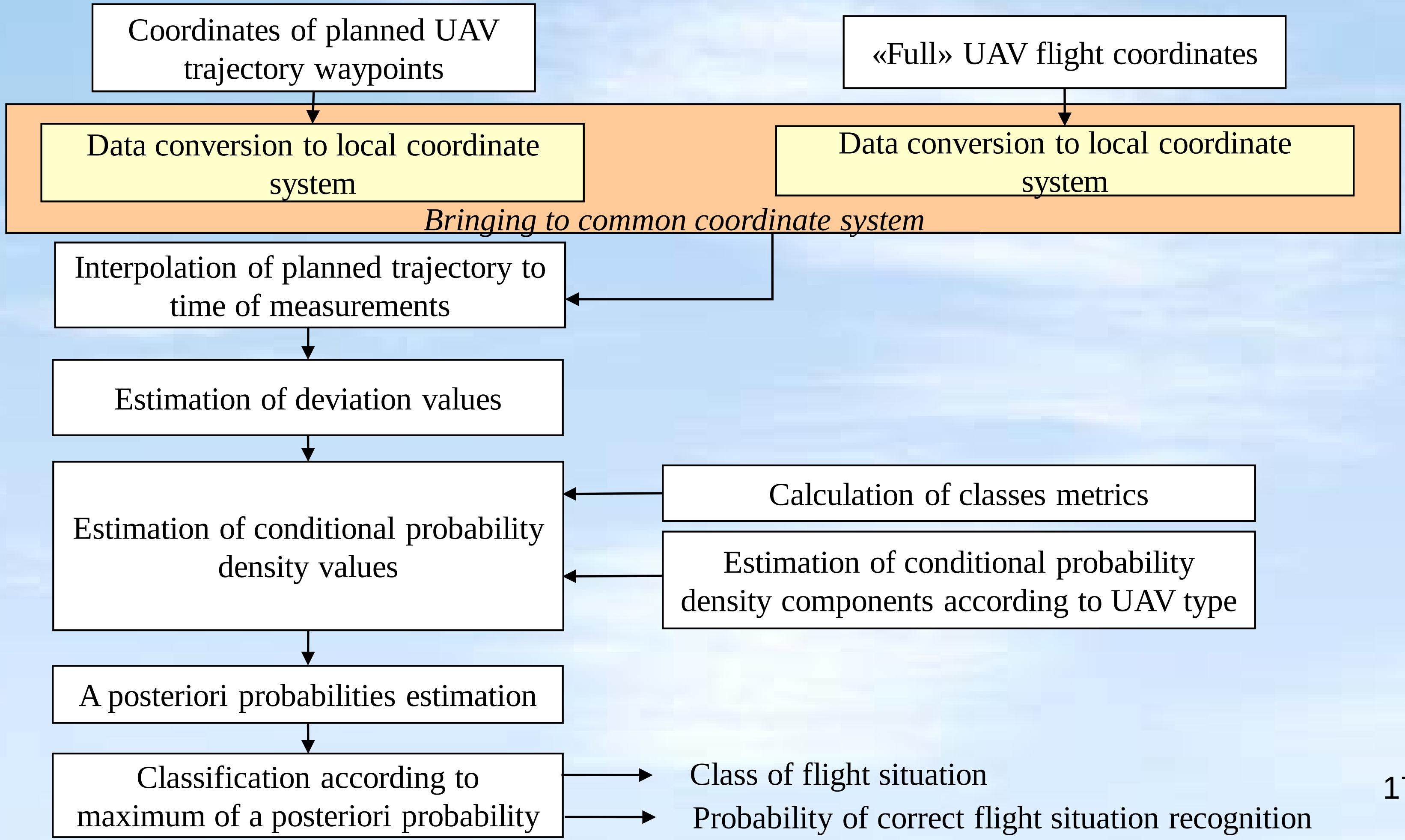
Method of Multi-parametric UAS data recovery



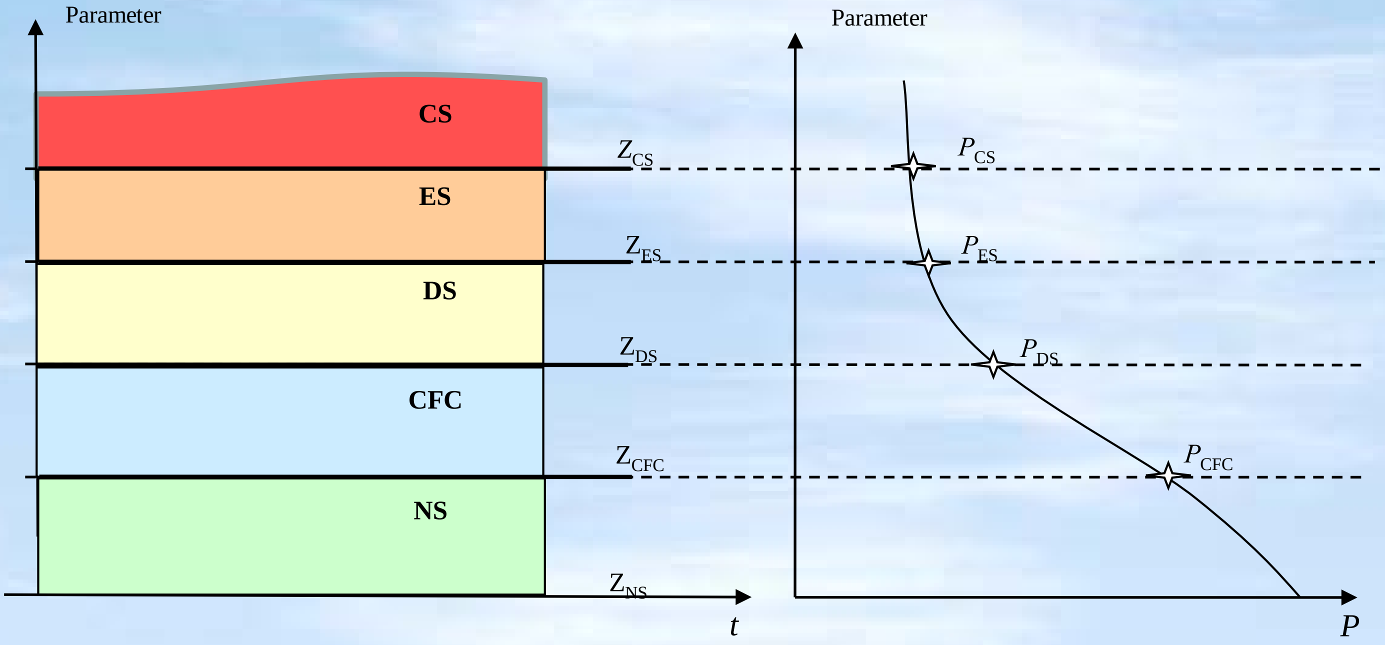
Representation of multi-choice flight situations classification using the degree of deviation from the planned values



Improved method of multi-choice UAV flight situations classification



Construction of UAV flight situations



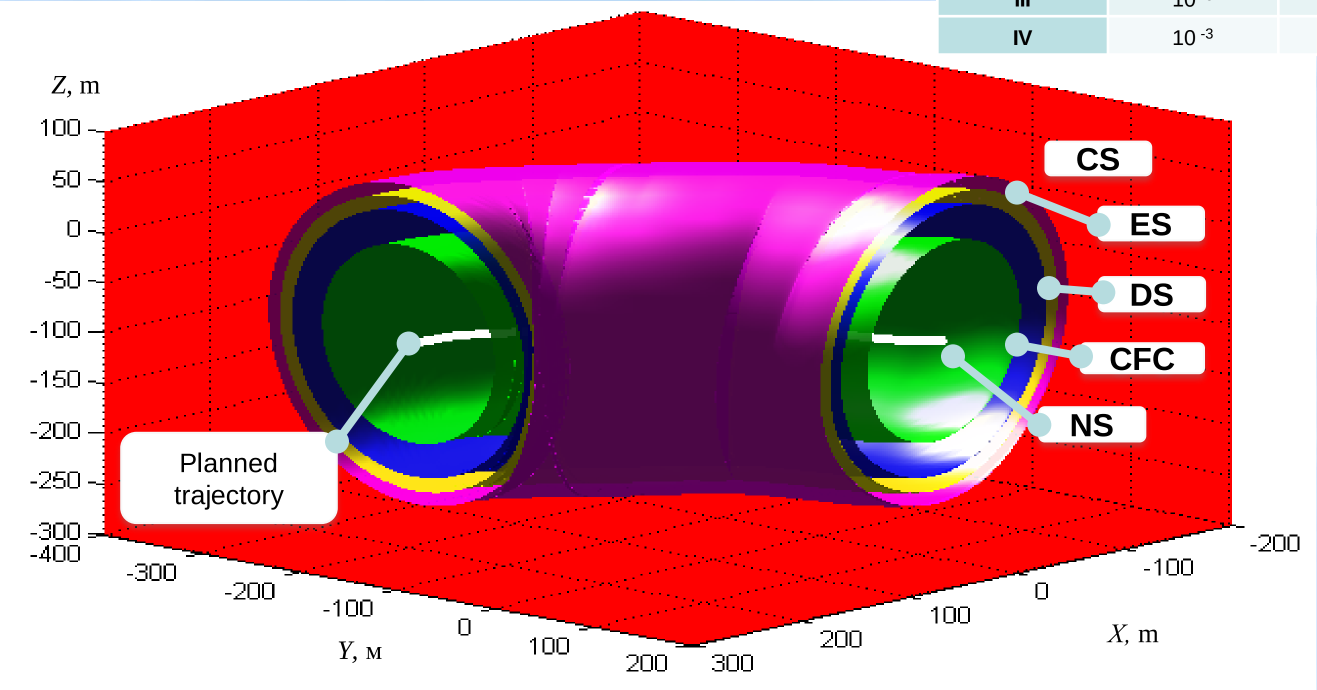
Estimation of flight situation boundaries

$$Z = \Phi^{-1}\left(P - \tfrac{1}{2}\right)\sigma + Z_{NS}$$, where $P = \begin{bmatrix} P_{CFC} \\ P_{DS} \\ P_{ES} \\ P_{CS} \end{bmatrix}$, $Z = \begin{bmatrix} Z_{CFC} \\ Z_{DS} \\ Z_{ES} \\ Z_{CS} \end{bmatrix}$, $\sigma = \dfrac{x - Z_{NS}}{\Phi^{-1}\left(P_{CS} - \frac{1}{2}\right)}$

Visualization of flight situations in 3D space

Safety limits according to flight situation and UAV type

UAV type	CFC	DS	ES	CS
I	10^{-3}	10^{-4}	10^{-5}	10^{-6}
II	10^{-3}	10^{-5}	10^{-6}	10^{-7}
III	10^{-3}	10^{-5}	10^{-7}	10^{-8}
IV	10^{-3}	10^{-5}	10^{-7}	10^{-9}



Range safety criteria for unmanned air vehicles – rationale and methodology supplement. Supplement to document 323-99 / Range Safety Group, Range Commanders Council. – 1999. –75 p.

Estimation of a posteriori probabilities of flight situations

Conditional probability density function of multi-parametric normal distribution

$$\rho_k(x)=\frac{1}{(2\pi)^{K/2}\left|B\right|^{-1/2}}exp\left[-\frac{1}{2}\left(B^{-1}(x-M)^T\times(x-M)\right)\right]$$

$x=(x_1,x_2,...,x_s)$ – vector of parameters measurements,

$M=(\mu_1,\mu_2,...,\mu_s)$ – vector of mathematical expectations for each parameter

B – matrix of MSD

$s=\overline{1,K}$ – index of corresponding parameter,

$k=\overline{1,N}$ – index of corresponding class.

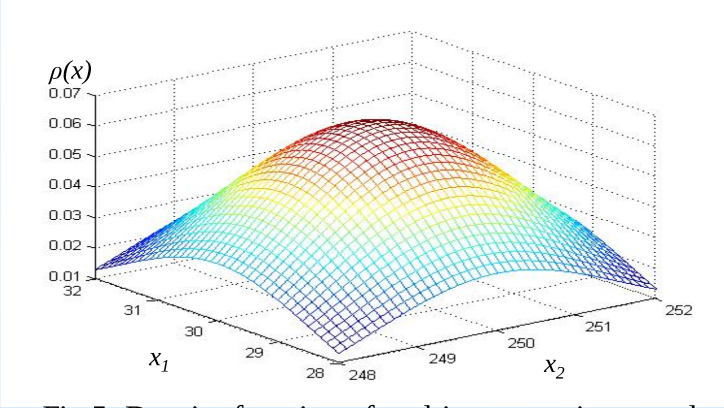


Fig.5. Density function of multi-parametric normal distribution

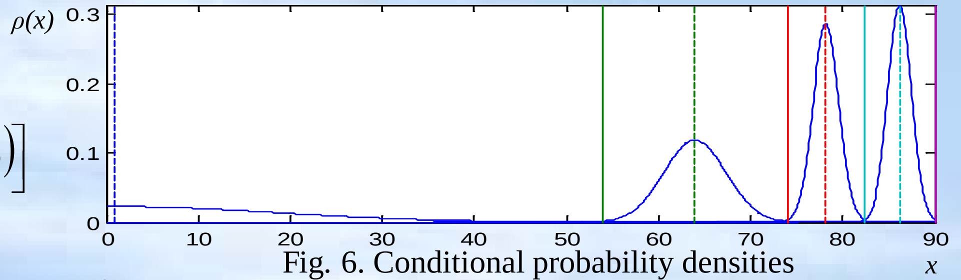


Fig. 6. Conditional probability densities

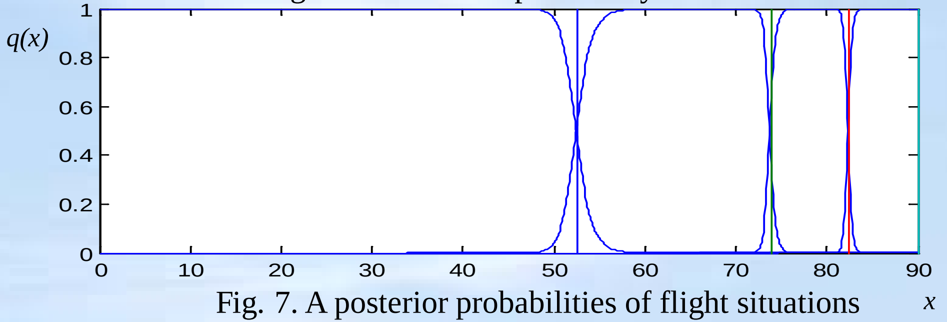


Fig. 7. A posterior probabilities of flight situations

A posteriori probabilities of flight situations are defined as:

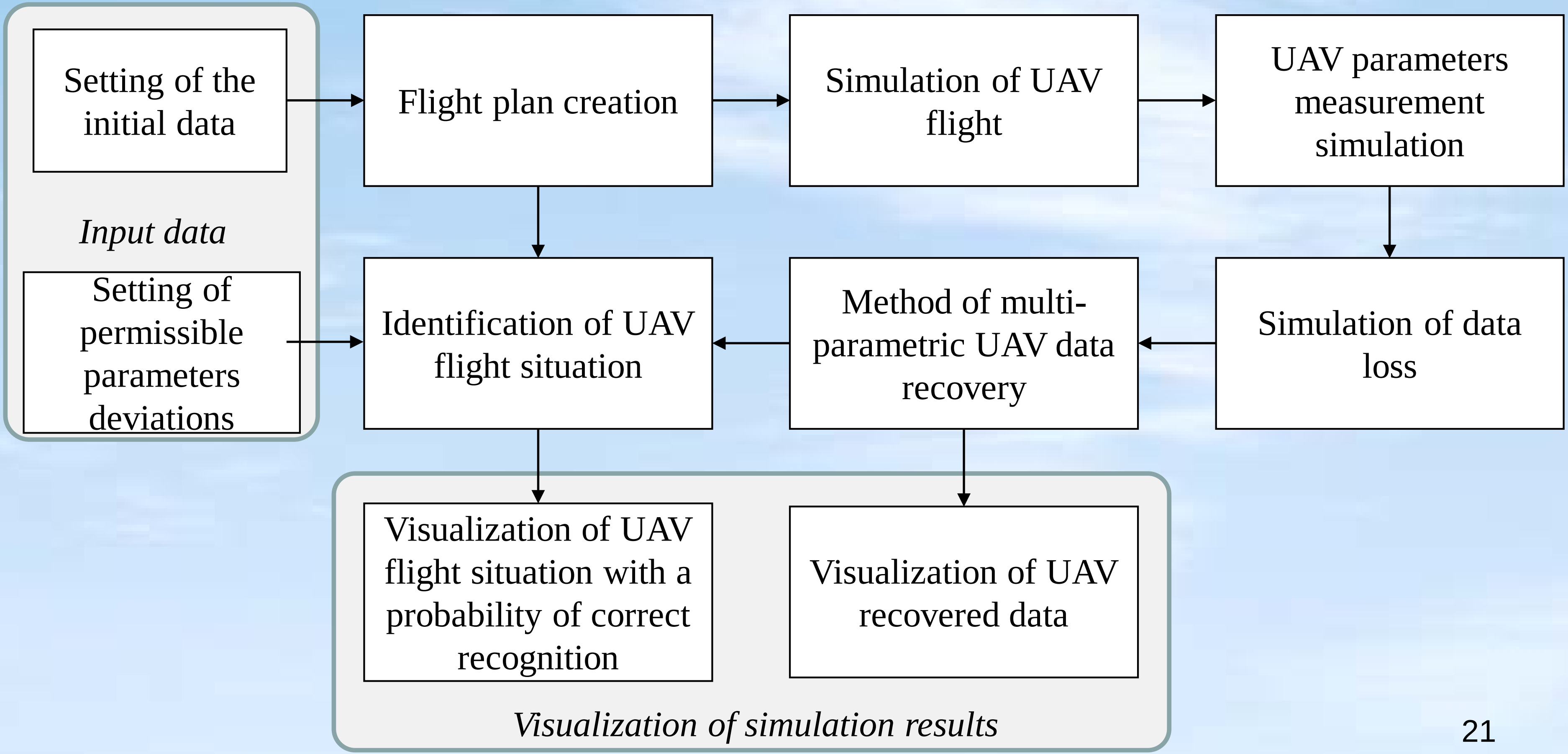
$$q_k(x_s)=\frac{p_k\rho_k(x_s)}{\sum_{k=1}^{N}p_k\rho_k(x_s)}$$

where p_k – a priori probabilities of flight situations

Criterion of recognition:

$q_k(x_s)=max(q(x_s))$

Verification by means of computer simulation



Representation of UAV flight parameters simulation

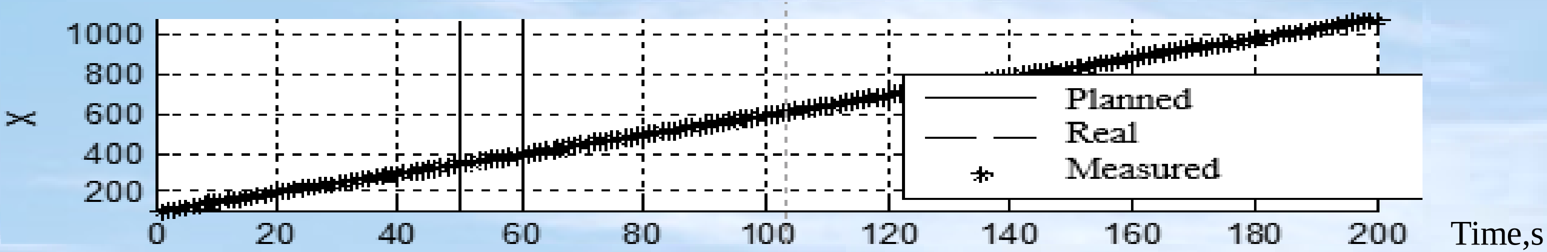


Fig. 8. Simulation of *X coordinate*

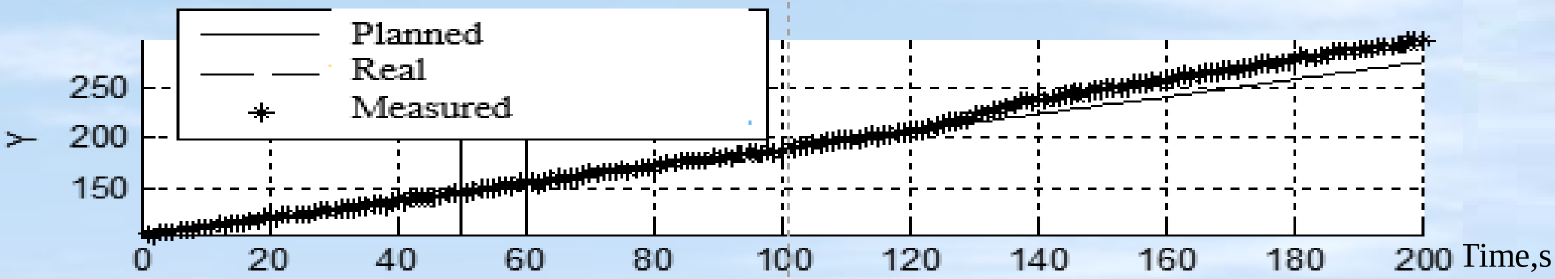


Fig.9. Simulation of *Y coordinate*

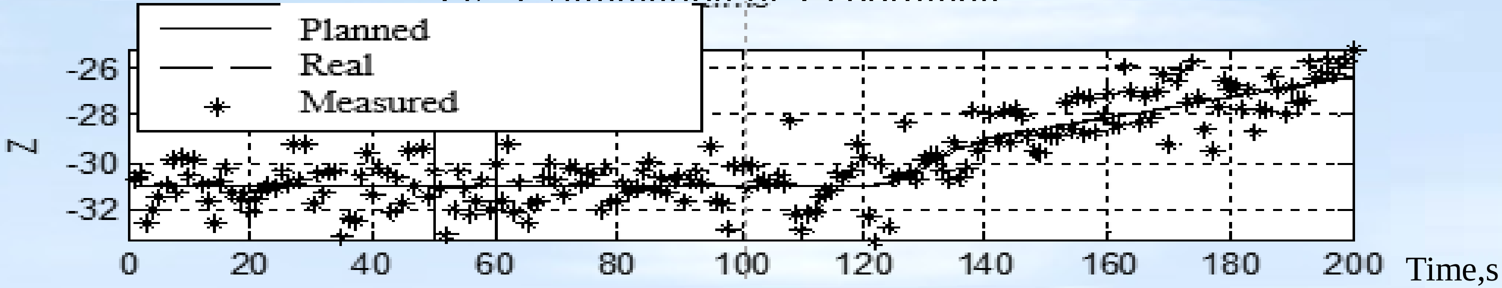


Fig.10. Simulation of *Z coordinate*

Representation of UAV flight data recovery

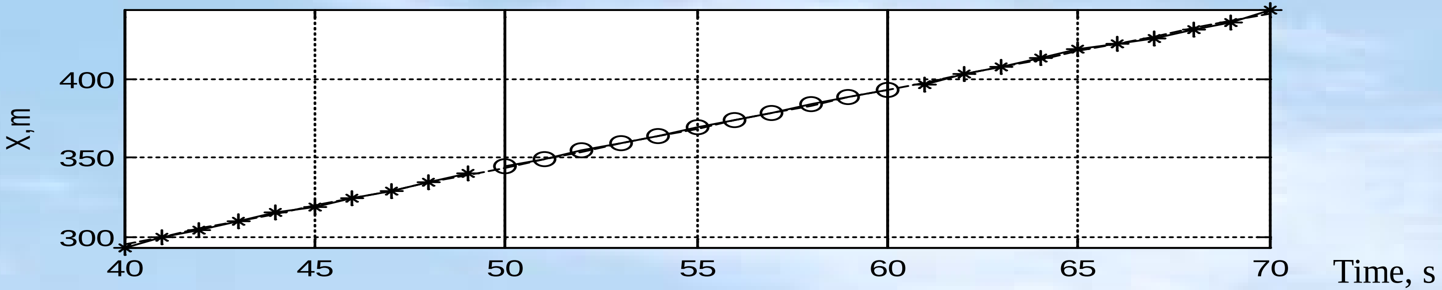


Fig.11. *X coordinate recovery*

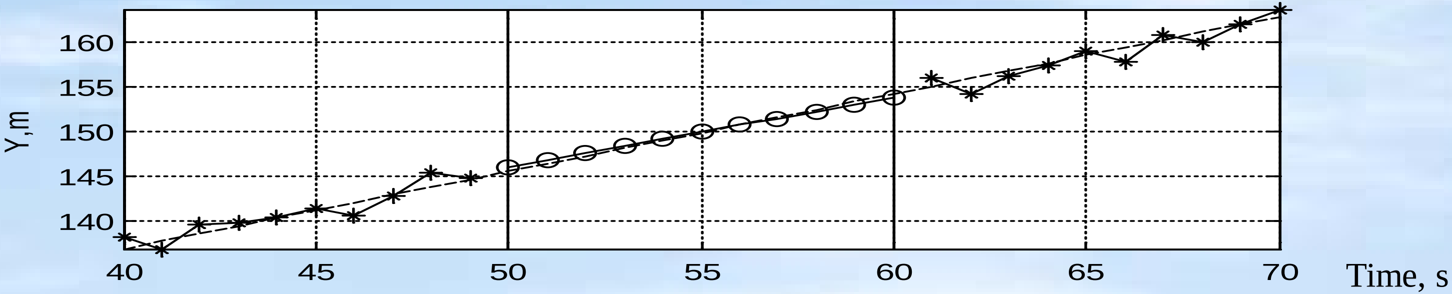


Fig.12. *Y coordinate recovery*

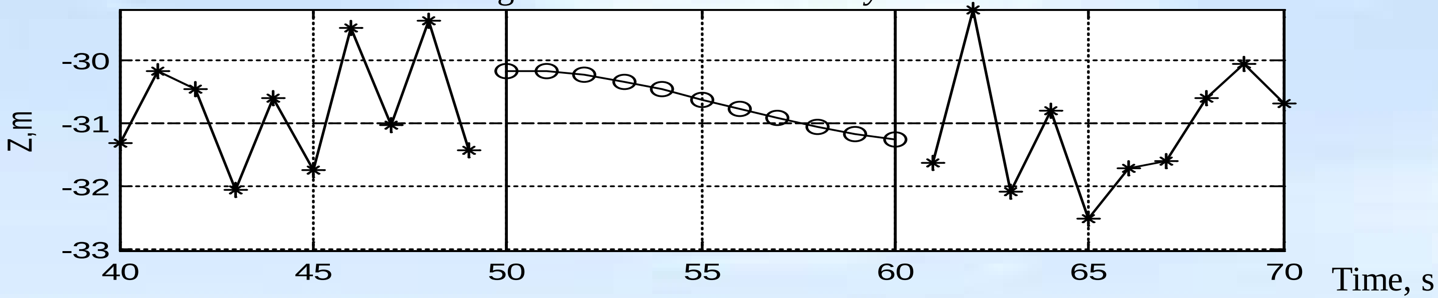


Fig.13. *Z coordinate recovery*

Simulation results of UAV flight situations multi-choice classification

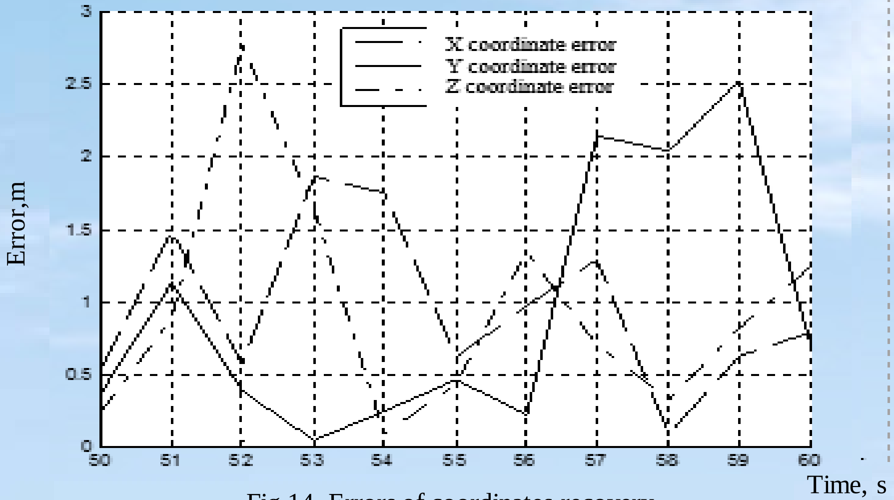


Fig.14. Errors of coordinates recovery

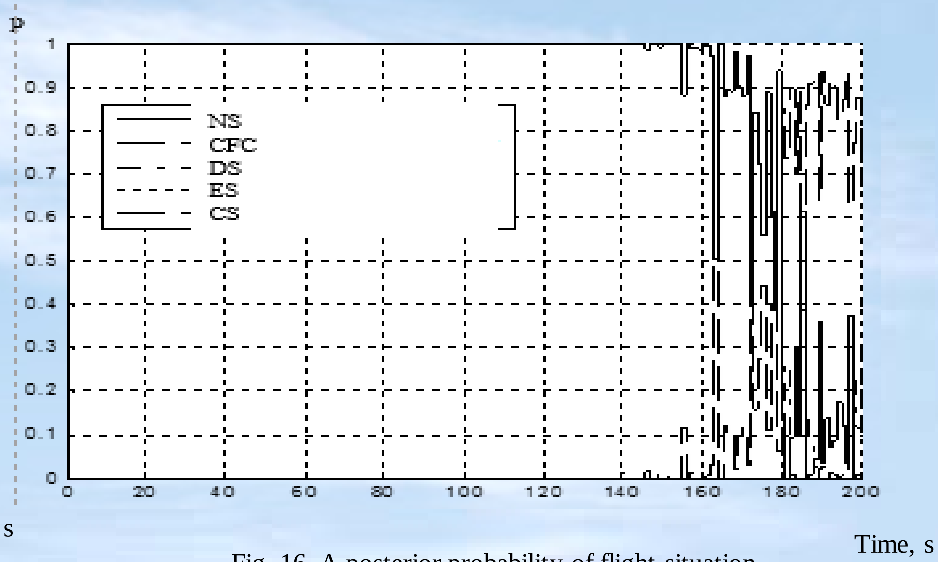


Fig. 16. A posterior probability of flight situation

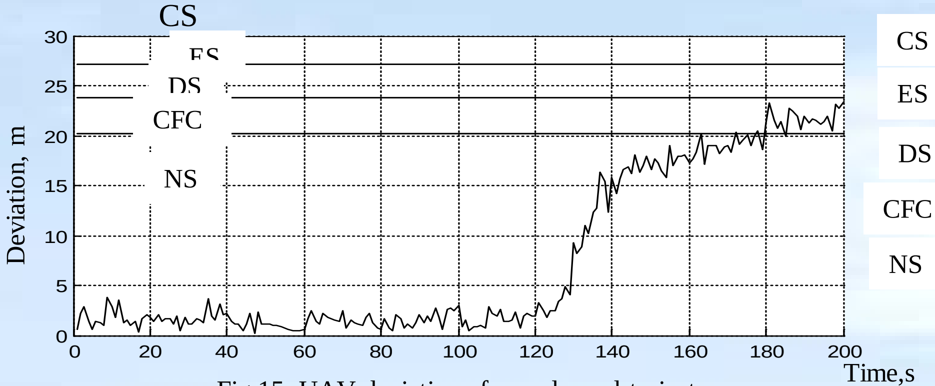


Fig.15. UAV deviations from planned trajectory

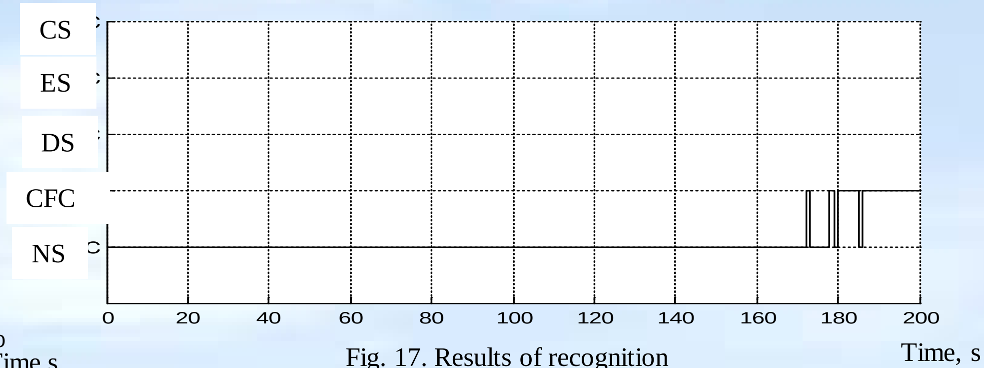
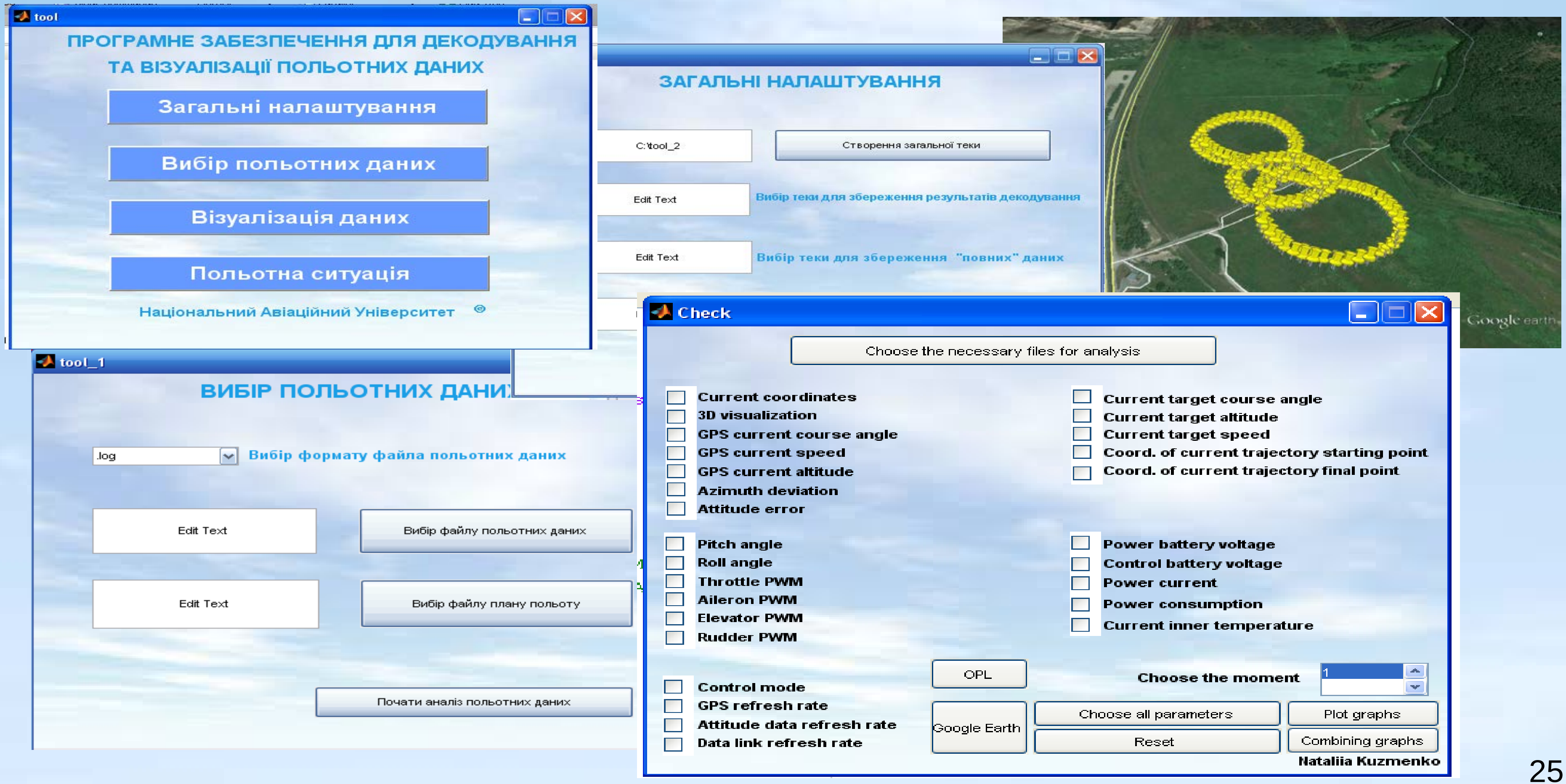
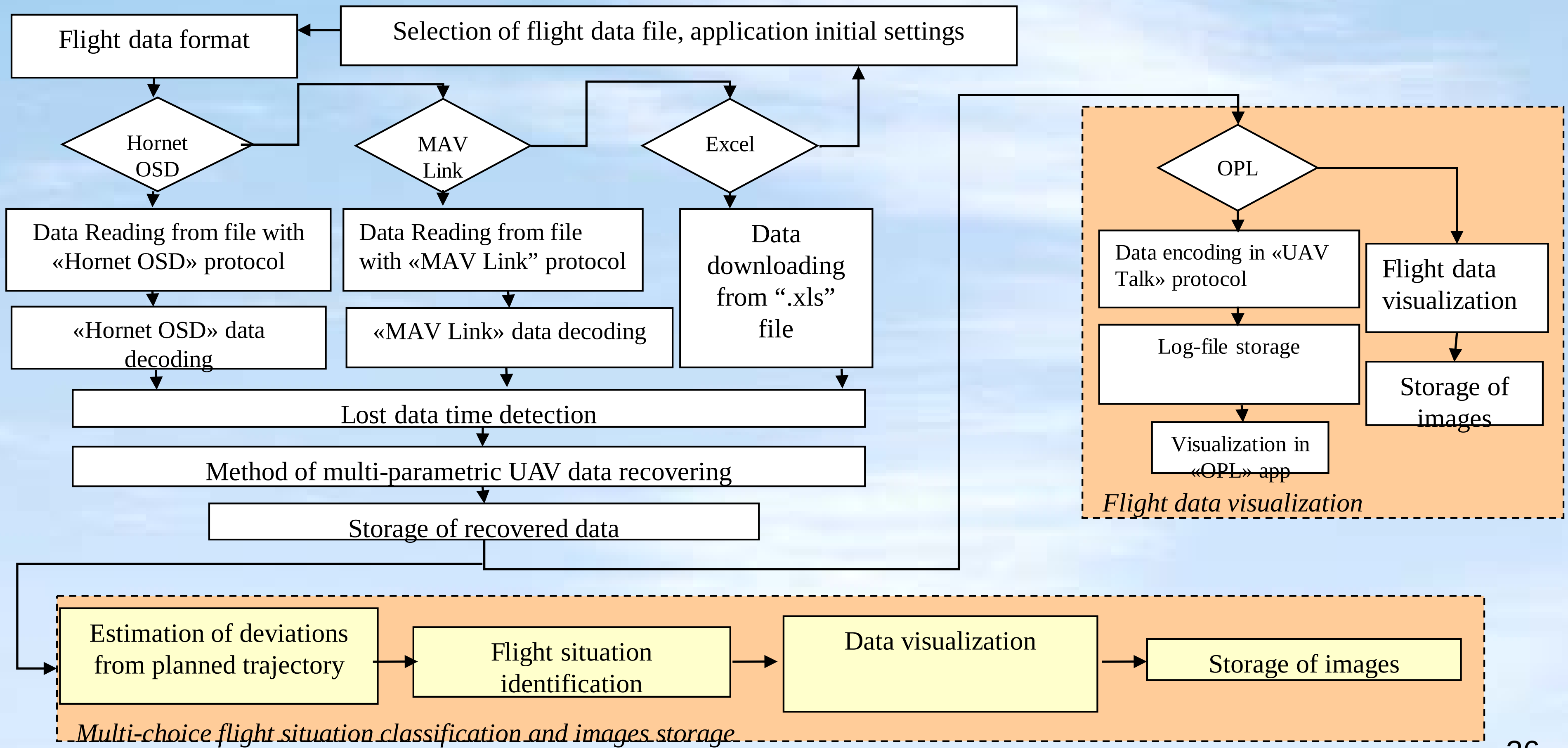


Fig. 17. Results of recognition

Application for UAV flight data decoding and visualization



Application for UAV flight data decoding and visualization



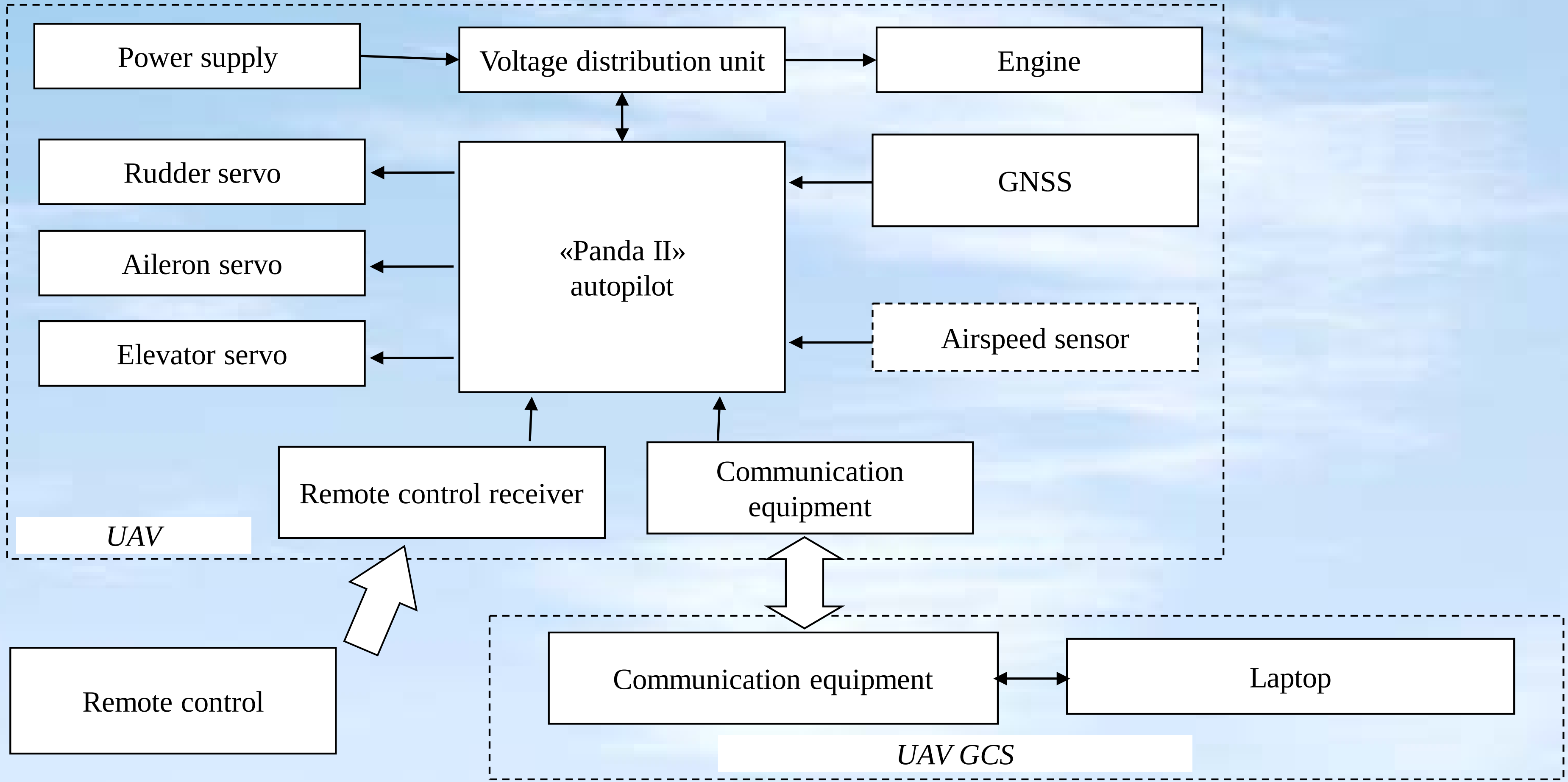
Methods verification through experimental tests

The venue is Khodosivka landfill (latitude 50.27˚ N, longitude 30.53˚ E).

UAV - "Cessna N877S", completed with on-board "Panda-II" equipment.

Flight data was transmitted over the radio channel to the GS and processed in specialized software GCS for Panda-II.

UAS block-diagram



Results of experimental tests

UAS parameters
GPS coordinates
GPS current course angle
GPS current speed
GPS current altitude
Azimuth deviation
Attitude error
Roll angle
Pitch angle
Throttle PWM
Aileron PWM
Elevator PWM
Rudder PWM
Control mode
GPS refresh rate
Attitude refresh rate
Datalink refresh rate
Power battery voltage
Control battery voltage
Power current
Power consumption
Current inner temperature

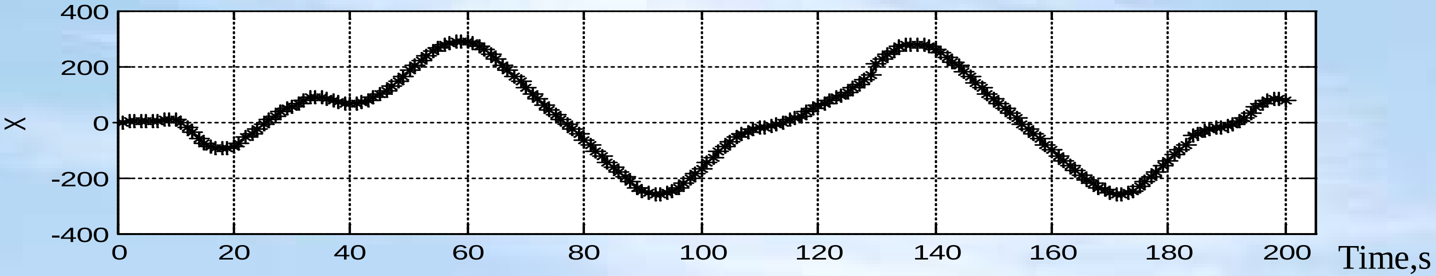


Fig. 18. UAV X coordinate

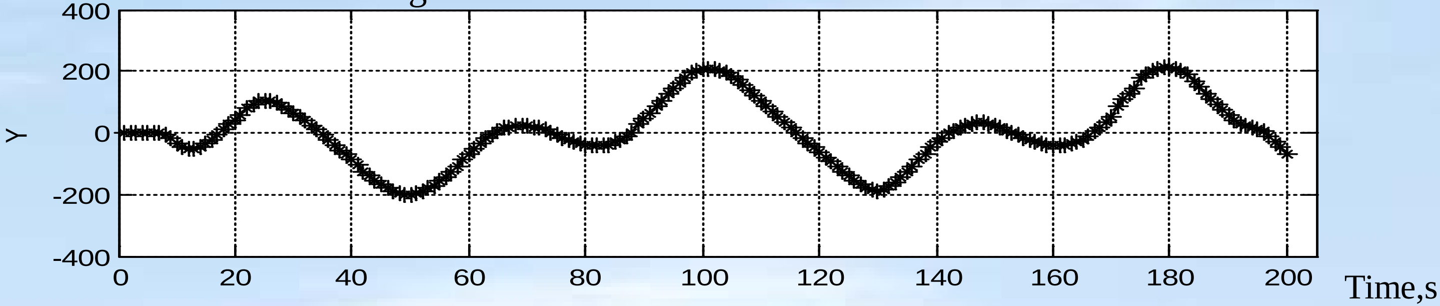


Fig. 19. UAV Y coordinate

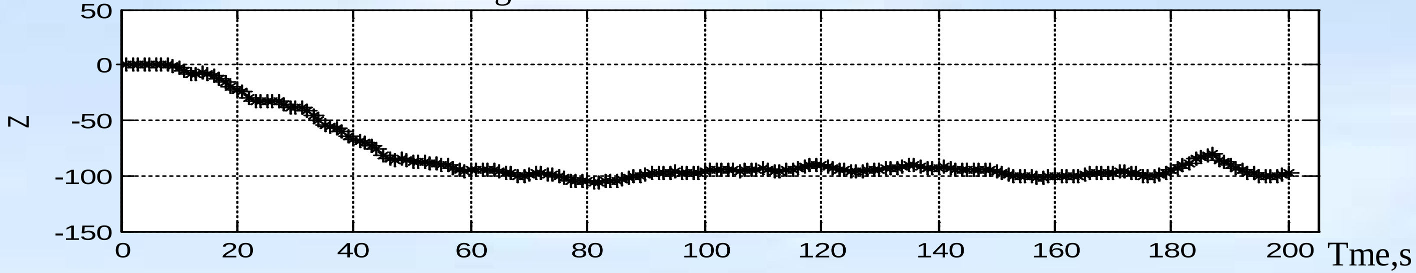


Fig. 20. UAV Z coordinate

Results of experimental tests

UAV trajectory

Representation of UAV flight data recovery

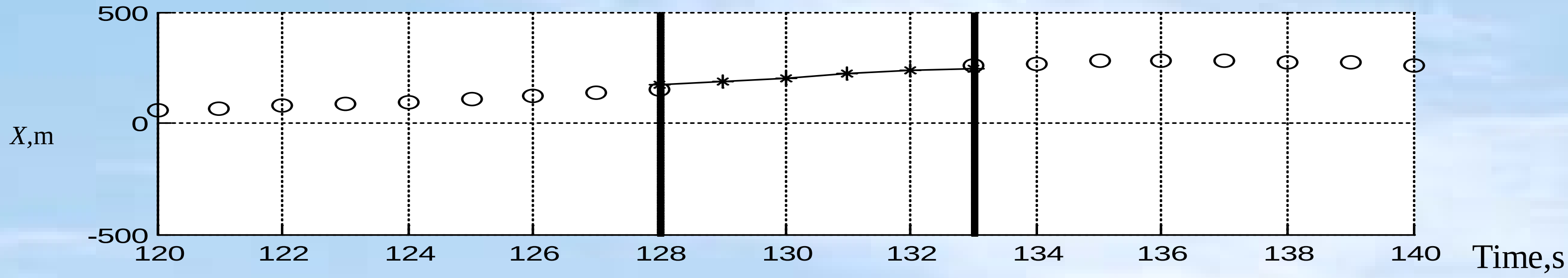


Fig. 21. Recovery of UAV X coordinate

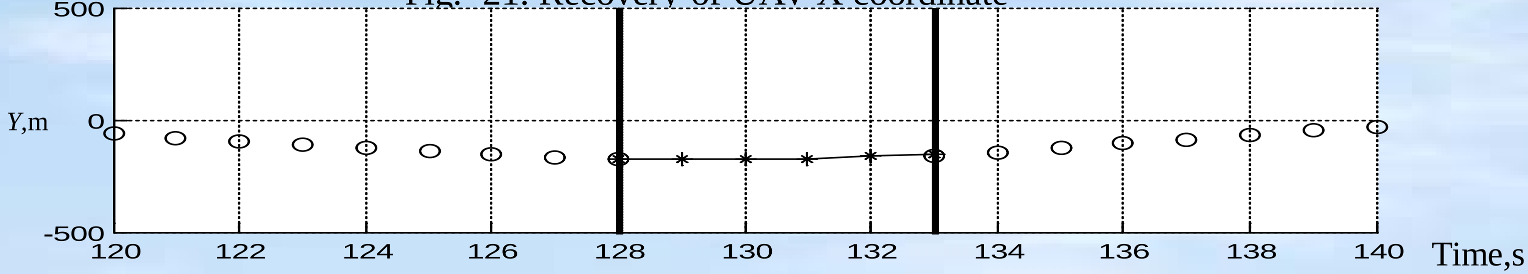


Fig. 22. Recovery of UAV X coordinate

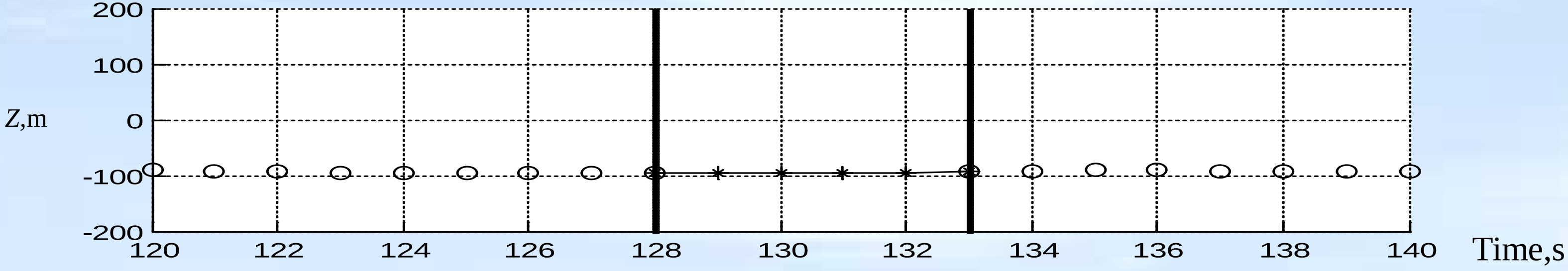


Fig. 23. Recovery of UAV X coordinate

Representation of multi-choice classification of UAV flight situations

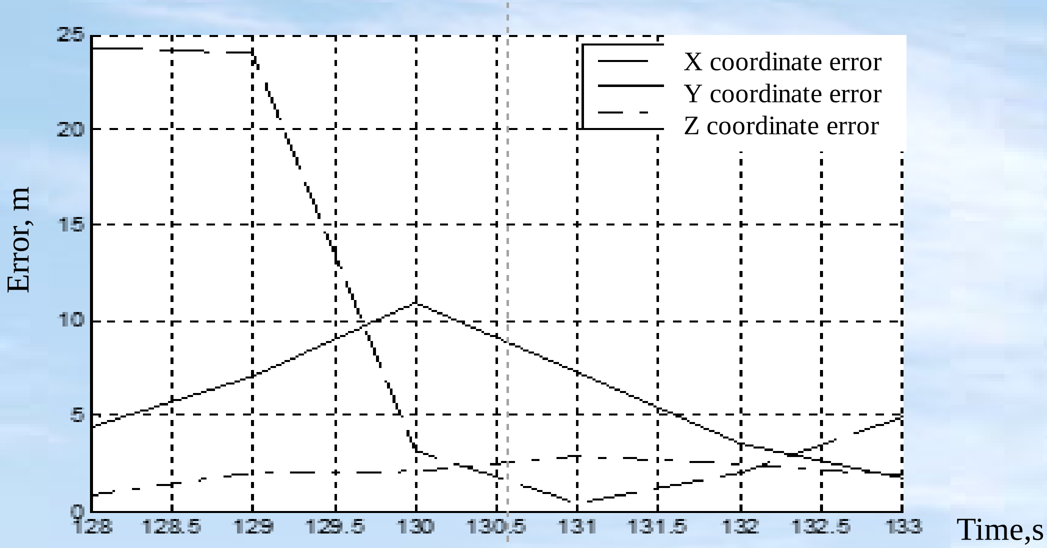


Fig. 24. Errors of coordinates recovery

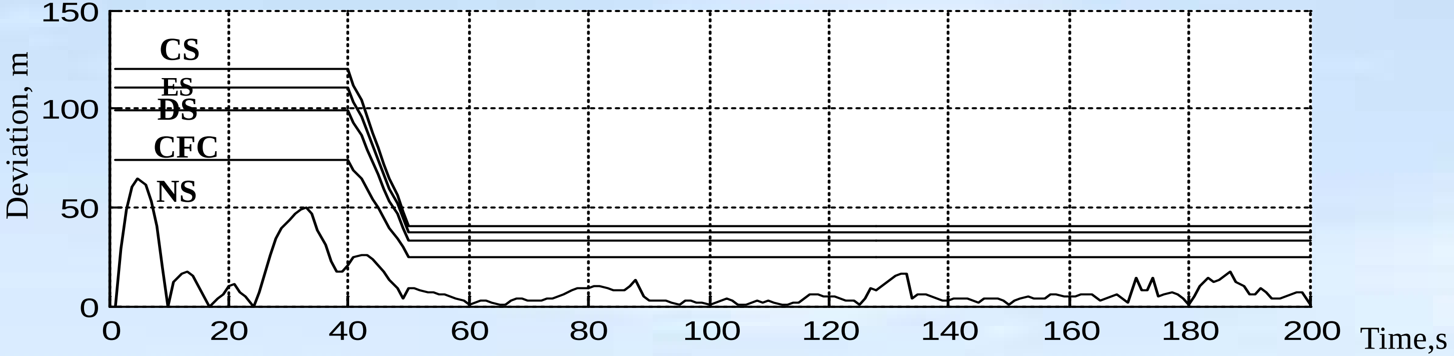
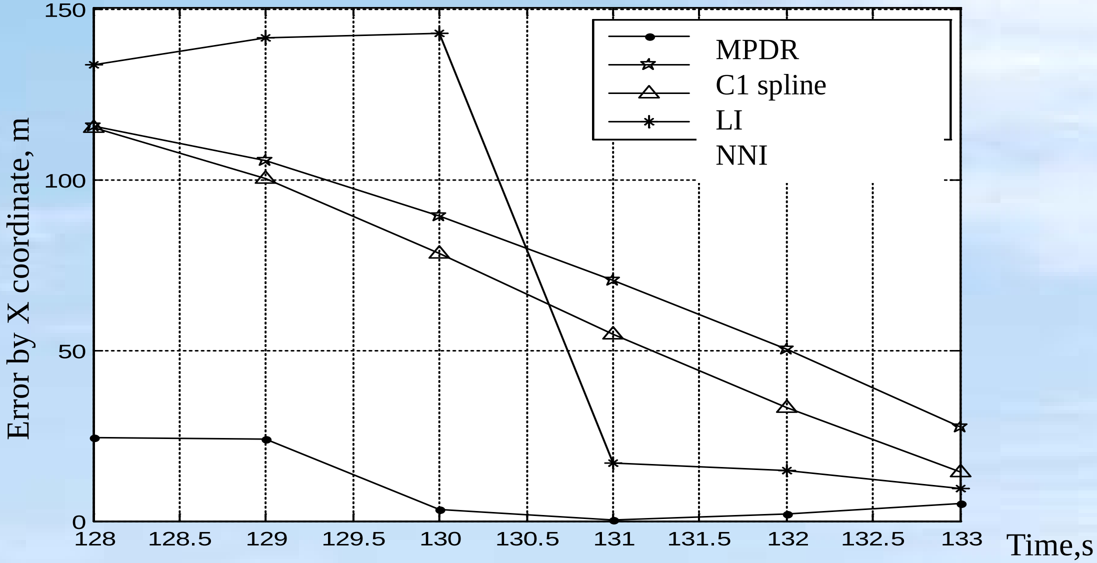
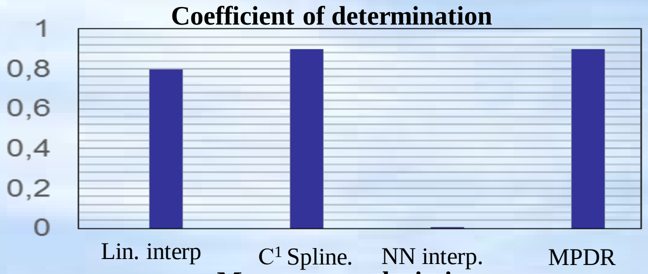


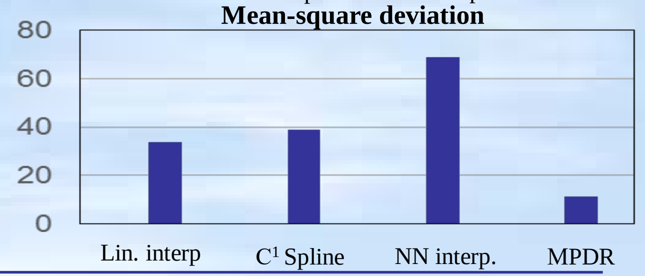
Fig. 25. Deviations from planned trajectory

Comparison of *X* coordinate recovery by different methods



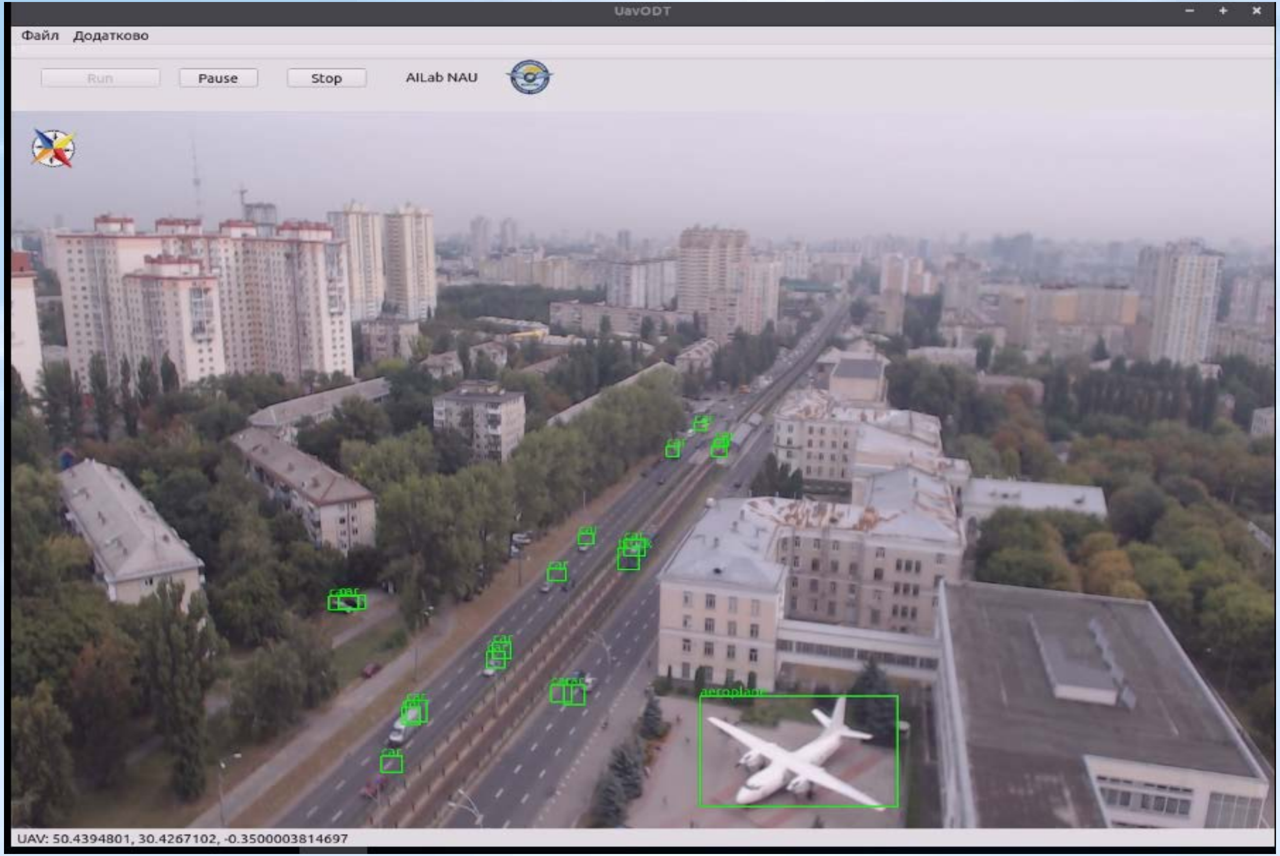
Comparison of data recovery methods





Recovery method	MSD, m	ME, m	Maximum error, m	Minimum error, m	Coefficient of determination
Linear interpolation	33,7	76,5	115,6	22,3	0,8
C^1 spline interpolation	39,0	65,9	114,9	14,4	0,9
Nearest neighbor interpolation	68,8	76,4	142,9	9,4	0,002
MPDR	11,2	9,8	24,3	0,4	0,9

Object detection and classification

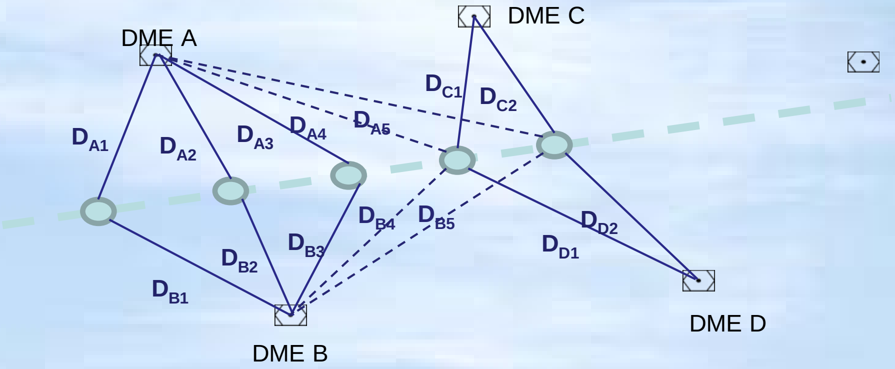


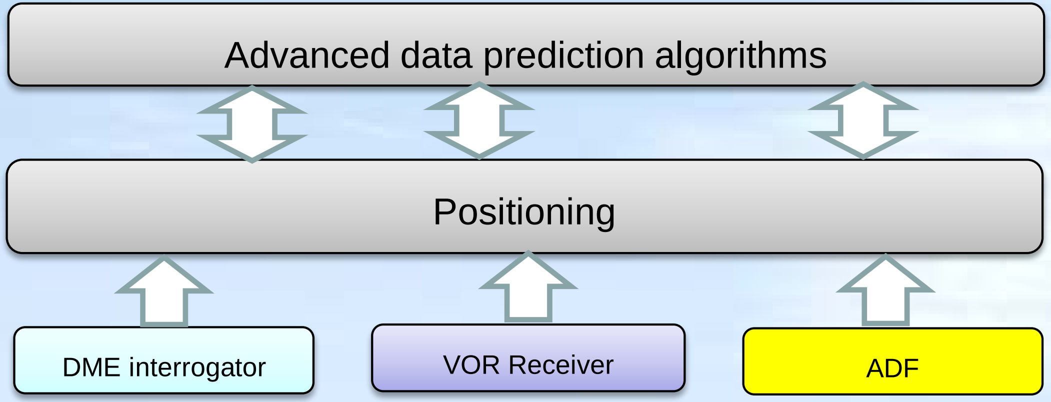
Alternative Positioning, Navigation, and Timing

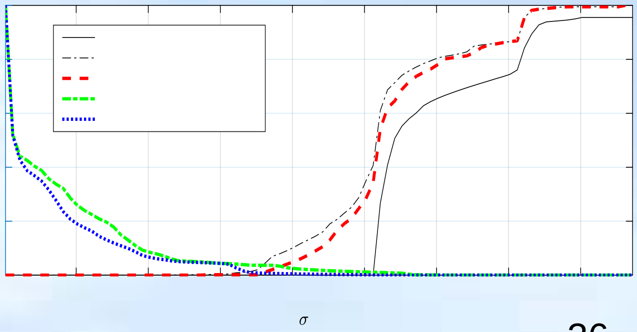
- Performance improvement of positioning by multiple Navigational aids (DME/DMEs, VOR/DMEs, VOR/VORs) by integration advanced methods of sensor data prediction and filtering
- Passive methods of positioning by multiple signals in space
- Location detection by Airborne Collision and Avoidance System data
- Vision based navigation system with image processing algorithms and its integration with GNSS and Inertial reference system
- Implementation of low-cost sensors in advanced data processing to ensuring safety and security levels and the desired performance gains in terms of resilience and cost efficiency
- An airspace performance analysis using advanced methods

APNT. Performance improvement of positioning by multiple Navigational aids

Performance improvement of positioning by multiple Navigational aids (DME/DMEs, VOR/DMEs, VOR/VORs) by integration advanced methods of sensor data prediction and filtering







APNT. Passive methods of positioning by multiple signals in space

Passive positioning by data from
- Distance Measuring Equipment
- Automatic Dependent Surveillance Broadcast
- VOR

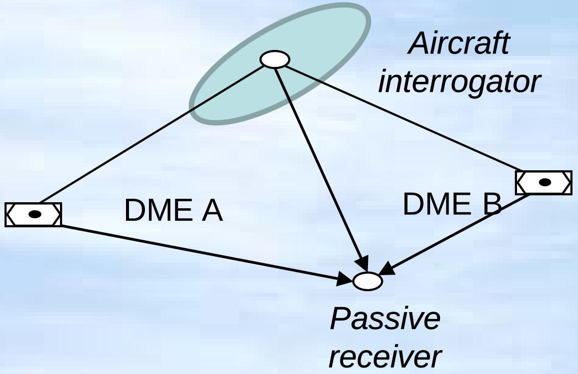


Fig. Receiving available signals in space by SDR

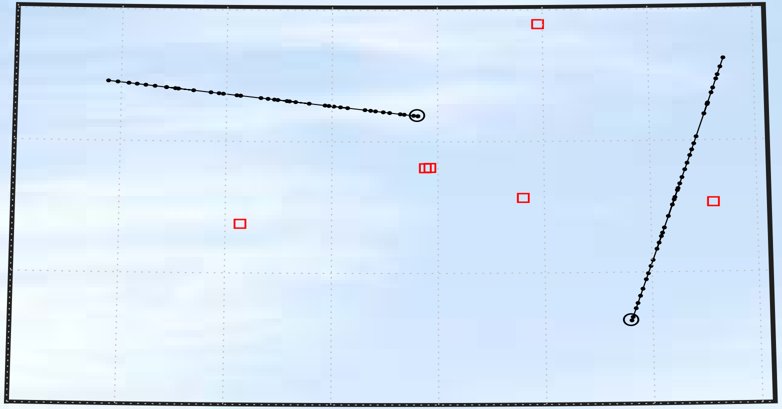


Fig. Ground tracks of “5082EF” and “4BBC81”

APNT. Positioning by ACAS X data

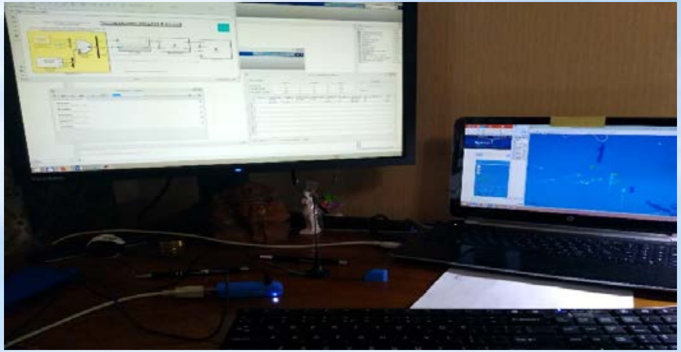
ACAS X variants

ACAS X_A – The general purpose ACAS X that makes active interrogations to detect intruders. ACAS X_A is the baseline system, the successor to TCAS II. The Standards are expected to be ready by 2018 and ACAS X may become operational in 2020.

ACAS X_O – ACAS XO is an extension to ACAS X_A designed for particular operations, like closely spaced parallel approaches, for which ACAS X_A is less suitable because it might generate a large number of nuisance alerts. The MOPS are jointly with ACAS X_A MOPS and also are expected to be ready by 2018.

ACAS X_U – Designed for Remotely Piloted Aircraft Systems (RPAS), incorporating horizontal resolution manoeuvres. Work on Standards has started in 2016 and is expected to be finished in 2020.

ACAS X_P – A future version of ACAS X that relies solely on passive Automatic Dependent Surveillance Broadcast (ADS-B) to track intruders and does not make active interrogations. It is intended for general aviation aircraft (that are not currently required to fit TCAS II).



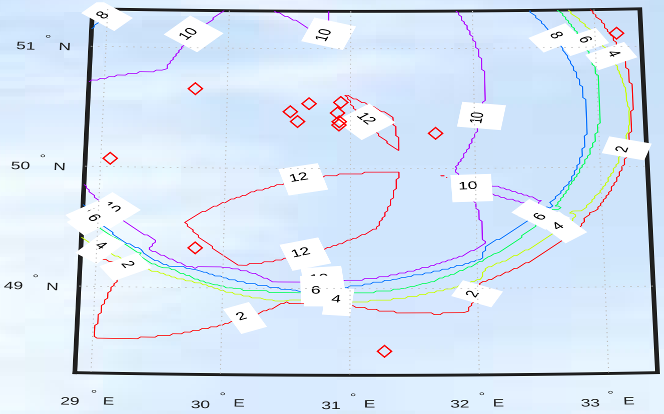
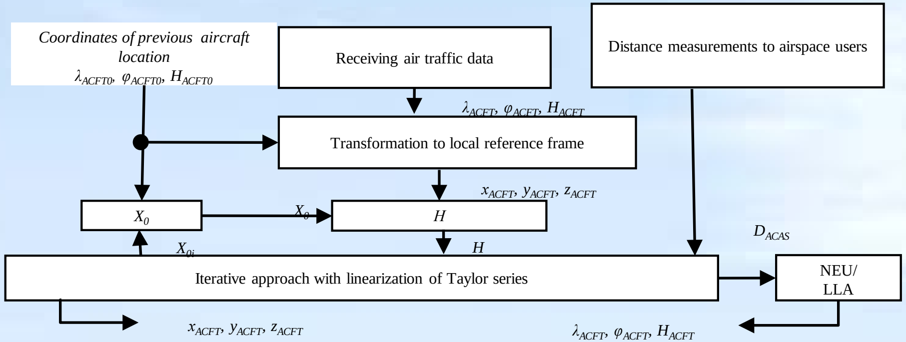


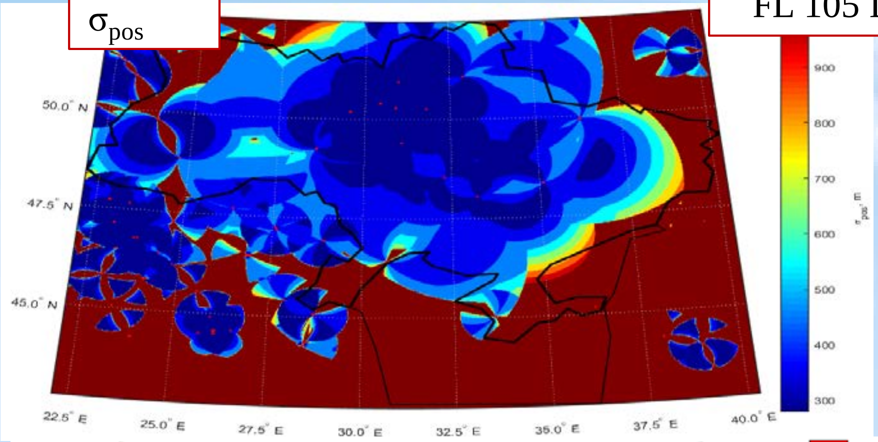
Fig. Availability of ADS-B data for positioning



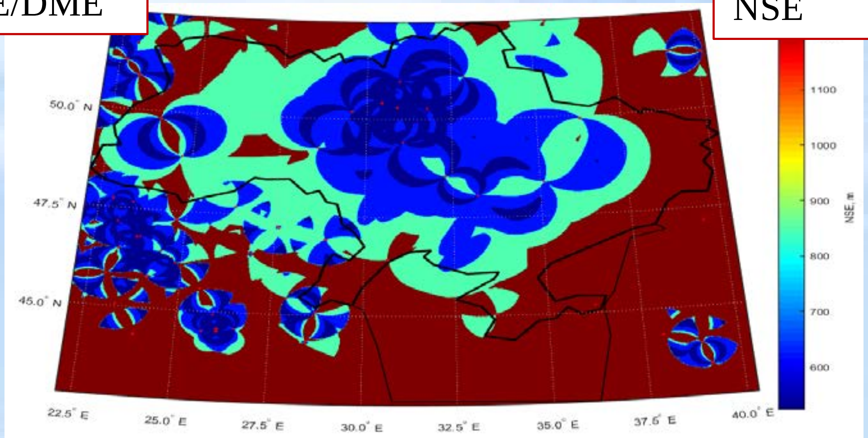
An airspace performance analysis using advanced methods

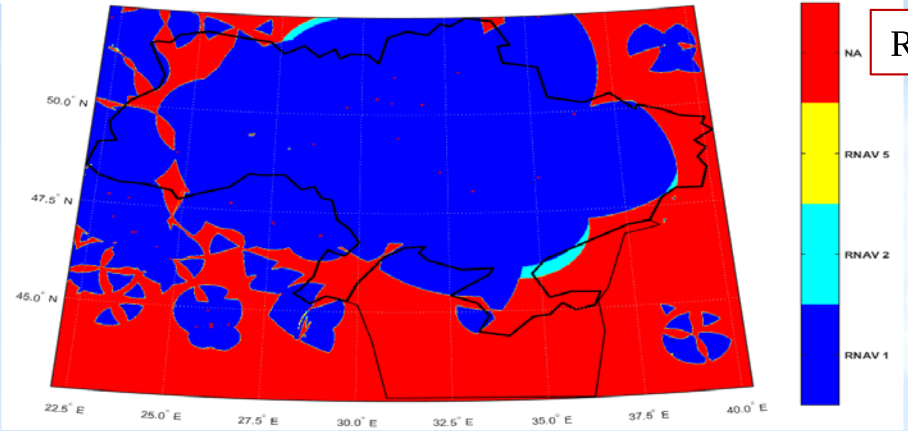
FL 105 DME/DME

σ_{pos}

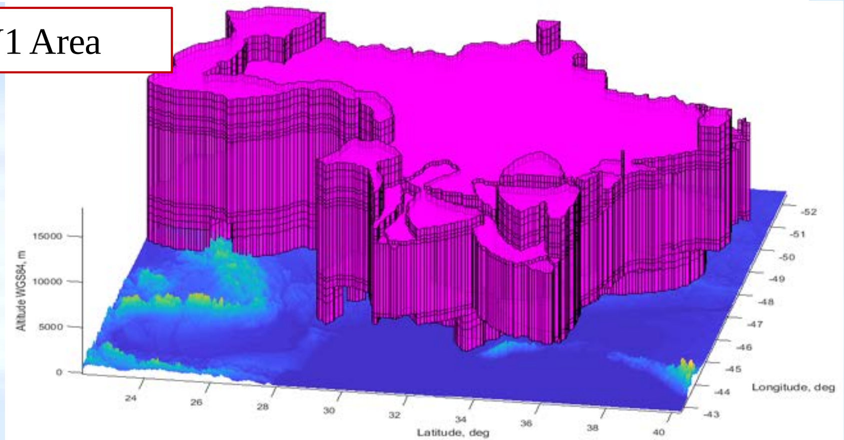


NSE

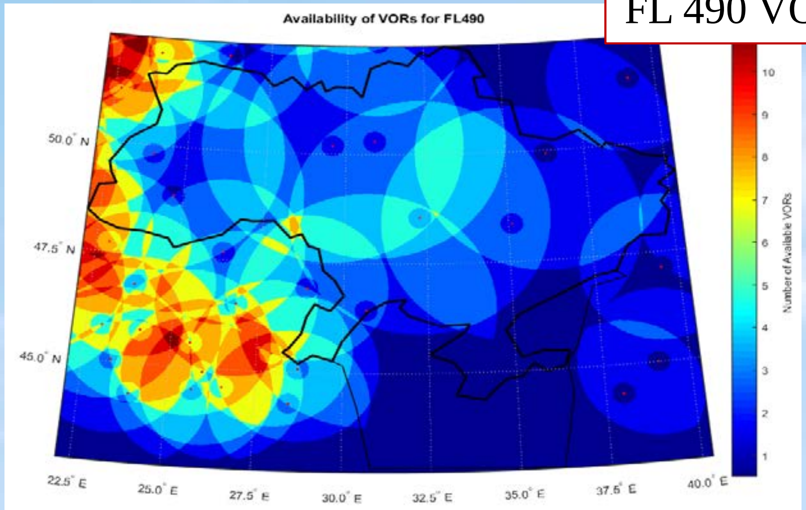


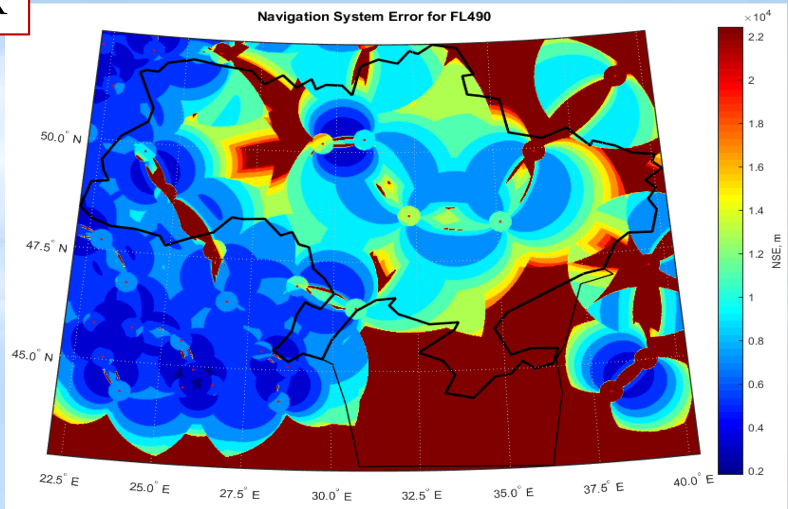


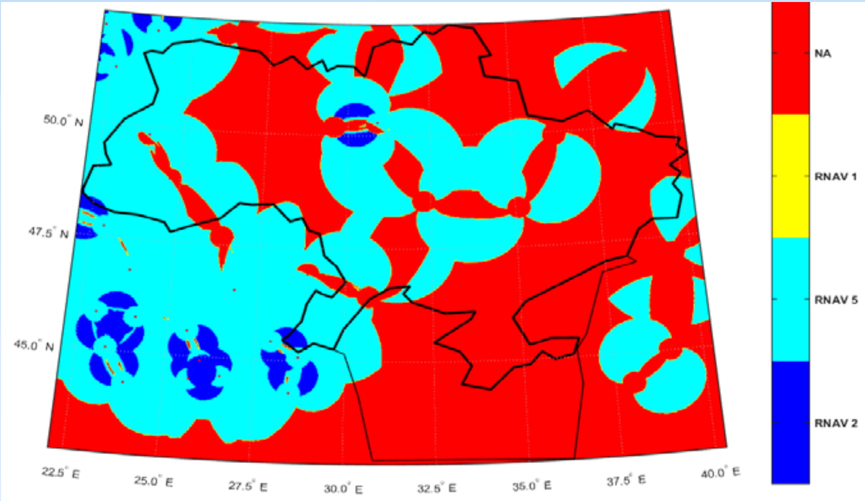
RNAV1 Area



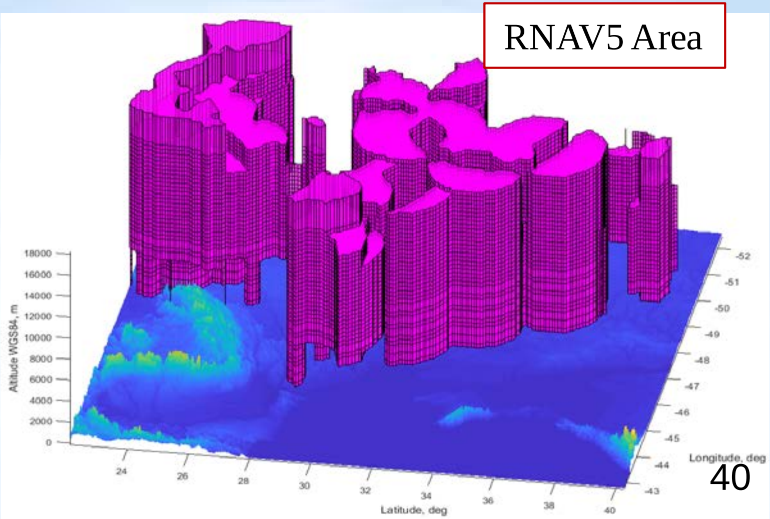
FL 490 VOR/VOR





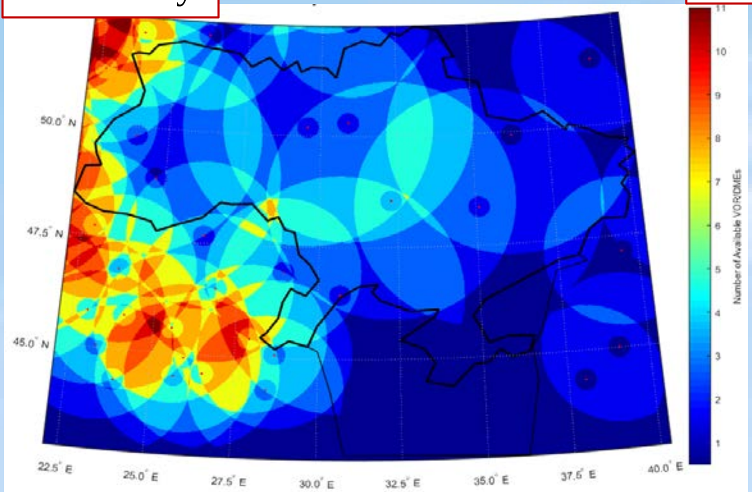


RNAV5 Area

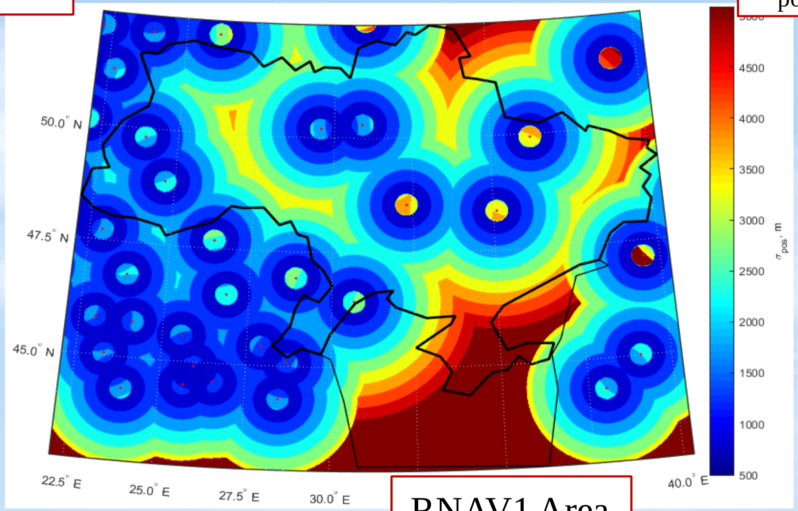


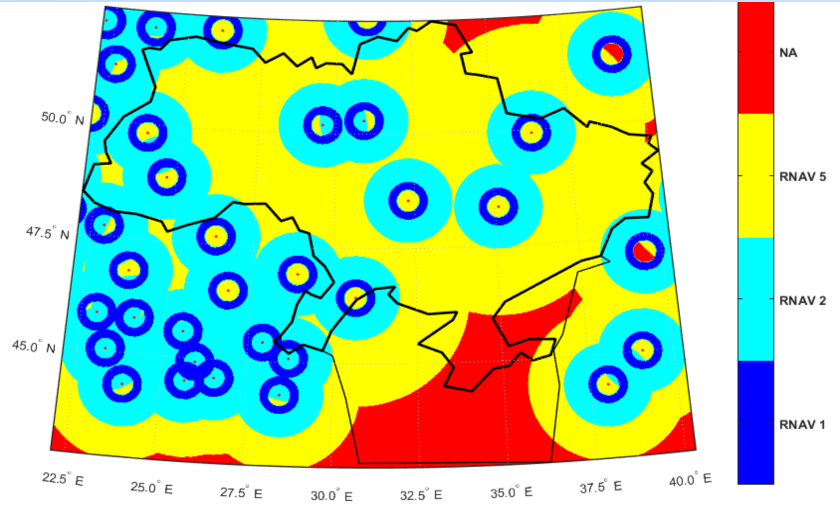
FL 490 VOR/DME

Availability

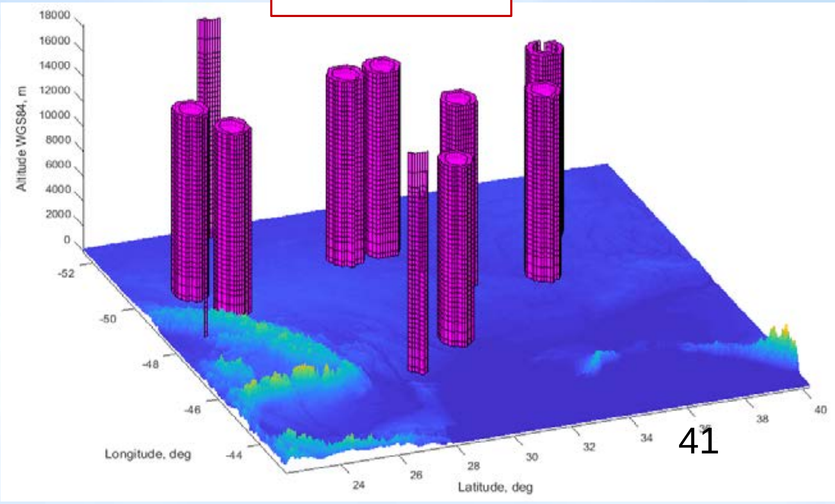


σ_{pos}





RNAV1 Area



The 9th World Congress "AVIATION IN THE XXI-st CENTURY"

National Aviation University, Kyiv, Ukraine

October, 2020

Thank you for attention!