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AUTOMATIC TRACKING SYSTEM FOR OPTIMIZING PARATROOPER TRAINING (ATSOPT)

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Abstract: *ATSOPT is an integrated aerial monitoring and automated tracking system that increases objectivity and safety in military paratrooper training. An airborne logger (GNSS, barometric altitude, and inertial sensors) transmits MAVLink (Micro Air Vehicle Link) telemetry to a ground station that performs visible/IR/EO (InfraRed/Electro-Optical) tracking with a dual-camera, two-axis stabilized platform. Fused navigation and inertial data enable reliable phase detection (exit, free fall, opening, descent, landing) and quantitative after-action review. We introduce a graph–image correlation method linking altitude–time trajectories to synchronized video frames to verify opening altitude, stability, separation, and landing accuracy. Field trials at Ghimbav aerodrome confirmed coherent telemetry, robust capture, and practical usability under field conditions and instructor time constraints. Future work targets multi-object tracking and paratrooper manoeuvre recognition. Multi-object tracking can be implemented using SORT (Simple Online and Realtime Tracking) and DeepSORT frameworks [2] [13], with data association commonly formulated via assignment methods [9]. Instructor workload monitoring can leverage multimodal fatigue/attention assessment approaches [11].*
Keywords: *paratrooper training; MAVLink telemetry; EO/IR tracking; pan-tilt stabilization; after-action review.*

1. INTRODUCTION/OVERVIEW

Modern airborne operations require a high level of precision, safety and the ability to objectively evaluate the performance of personnel, especially in the case of military paratroopers, where execution errors can have significant tactical and security consequences. Currently, the monitoring of the performance of jumps is largely based on direct observation, visual evaluation and limited recording tools, which leads to a limited ability to correlate the actual trajectory, kinematic parameters and compliance with standardized procedures.

The development of miniaturized sensor systems, digital radio communications and real-time processing technologies has created the premises for the emergence of integrated solutions capable of providing accurate information on the position, movement and dynamic behaviour of airborne personnel. However, most existing solutions are oriented exclusively towards either navigation or local data logging, without simultaneously ensuring real-time transmission, correlation with video streams and extensive support for post-action analysis [4].

In this context, the paper presents ATSOPT, an integrated aerial monitoring system intended for the surveillance and evaluation of military paratroopers after exiting the aircraft, which combines multi-sensor acquisition, real-time telemetry and video tracking capabilities in the visible and infrared spectrum.

The proposed architecture structured on two main subsystems: an aerial module, responsible for the acquisition and recording of kinematic parameters, and a ground module, dedicated to data reception, visualization and analysis.

The main purpose of the system is to provide an objective framework for real-time monitoring of the conduct of jumps, for conducting post-action analysis, in order to optimize the training process, increase the

safety of personnel, and improve the training of the military.

2. ATSOPT ARCHITECTURE

This section describes the overall architecture of the ATSOPT system, highlighting the modular structure and functional data flows between the air and ground components. The solution is designed as a distributed, scalable system, capable of receiving data simultaneously from multiple airborne platforms, each equipped with its own data acquisition and transmission module. At the airborne level, the system is made up of a set of autonomous modules, each integrating a Data Logger subsystem and a telemetry module (Tx). These modules perform the acquisition of kinematic and positioning parameters, local data storage and real-time transmission to the ground station.

The configuration allows the simultaneous operation of several aerial modules, ensuring the concurrent monitoring of several paratroopers within the same parachute mission. The ground station is composed of a telemetry module (Rx), a video-tracking system and a laptop that displays telemetry data and video data.

This architecture (**Fig. 1.**) allows both real-time surveillance of the performance of airborne activities and the constitution of a complete database for post-action analysis. By clearly separating the acquisition, transmitting, receiving and processing functions, the ATSOPT system ensures flexibility in integration, the possibility of further expansion and adaptability to various operational scenarios.

2.1 Aerial module

The airborne module is the subsystem responsible for the acquisition, primary processing, storage and transmission of the positioning and movement parameters of the airborne user. It is designed as a stand-alone embedded unit, integrating an array of micro-electro-mechanical systems (MEMS) sensors, a radio communication subsystem and local data storage mechanisms to provide real-time monitoring and post-action analysis.

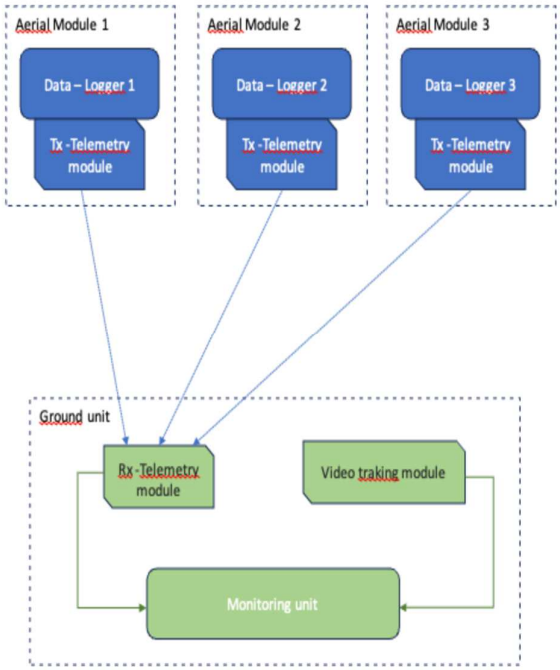


Fig. 1. ATSOPT Architecture

The architecture of the aerial module (**Fig. 2.**) is organized around a processing core that coordinates the interface of the sensors, executes data fusion algorithms and manages the telemetry and local logging streams. Raw data is acquired from sensors at configurable rates, subjected to filtering, and transformed into higher-level kinematic parameters.

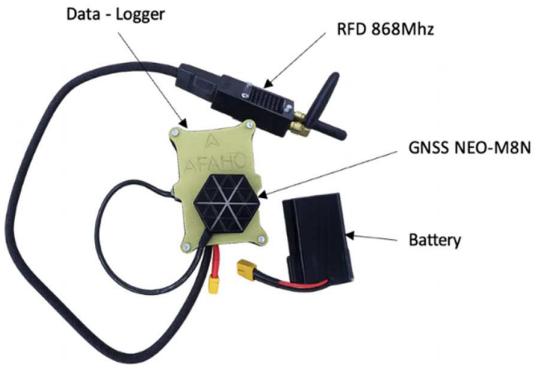


Fig. 2. Air module architecture

For the complete determination of the dynamic state, the aerial module integrates an inertial measurement unit based on the MPU6000 circuit, which includes accelerometer and triaxle gyroscope with selectable measurement ranges and high sampling rate. This sensor provides information on the linear accelerations and angular velocities needed to estimate orientation and motion. The north-facing orientation is supported by the use of a triaxle magnetometer, integrated into a type LSM303D circuit, which also provides redundant acceleration data for the validation of inertial measurements. The determination of relative altitude is carried out with the help of an MS5611 barometric sensor, characterized by high resolution and good stability over time. Positioning is provided by a NEO-M8N u-blox GNSS receiver, with multi-constellation support and refresh rate of up to 10 Hz, capable of providing three-dimensional coordinates and ground speed with metric accuracy.

Data from the sensor array is integrated via an extended Kalman filter, which provides consistent estimates of the filtered three-dimensional position, speed, attitude and accelerations. The resulting parameters are sampled at configurable rates and stored locally in a data logger module as time-stamped packets, ensuring full availability of information for post-action analysis [8] [1].

Telemetry transmission to the ground segment is achieved through a radio link in the (*Industrial, Scientific and Medical*) radio band of 868 MHz, in a point-to-multipoint topology, which allows the simultaneous operation of several overhead modules to a single receiver. The MAVLink protocol is used for data exchange, a binary serial protocol optimized for embedded systems, which uses structured packets with header, data field and error detection code, as well as mechanisms for unique identification of nodes in the network.

The reliability of the radio link is ensured by error correction, transmission rate adaptation and retransmission mechanisms, achieving an optimal compromise between latency, robustness and power consumption. The aerial module operates simultaneously in real-time transmission and local recording mode, ensuring redundancy and data integrity even under conditions of temporary degradation of communication.

2.2 Ground module

The ground module (**Fig. 3.)** is the subsystem responsible for receiving, integrating, processing and viewing in real time the telemetry data and video streams transmitted by the aerial modules. It is designed as a portable and modular system, integrating radio communication capabilities, electro-optical sensors and processing and display software tools, providing the necessary support for the monitoring and tracking of airborne personnel.

The architecture of the ground segment is organized around a central computing platform, implemented on a laptop-type system, which interfaces the radio reception subsystem and the electro-optical tracking unit.



Fig. 3. Ground radio module

The receiving subsystem is based on an RFD868 transceiver configured as a ground receiver, operating in the 868 MHz ISM band and optimized for long-distance telemetry links,

with transmit powers up to 1 W and high receiver sensitivity (up to approximately –121 dBm, depending on modulation). This subsystem allows the simultaneous reception of flows from multiple **airborne modules**, within a point-to-multipoint topology.

The received data is transmitted to the central platform via serial or USB interfaces, where it is decoded using the MAVLink protocol and fed into the software processing chain. The effective data rate is adaptive, depending on the quality of the radio link, typically ranging from a few tens to a few hundred Kbs, which is sufficient for transmitting kinematic parameters, system status, and control messages.

Electro-optical tracking (**Fig. 4.)** is achieved through a video unit mounted on a stabilized tripod, which integrates a FLIR thermal camera and a **Sony Block HD** visible camera in a single housing, equipped with optical zoom up to 10×. The thermal camera enables the detection and tracking of targets based on thermal signature, including in low light conditions or degraded visibility, while the Sony Block HD camera provides high-resolution images in the visible spectrum for visual identification and detailed evaluation [6] [12].



Fig. 4. Tripod system with video unit

The two cameras are mounted on a mechanical assembly with two degrees of freedom, electrically operated, which allows rotation on the azimuth and elevation axes. The angular resolution of the pan-tilt mechanism is fine enough to support accurate tracking of targets at distances in the order of hundreds of meters to several kilometres, and the control loop is implemented in closed mode [7] [10] [5].

The video streams are transmitted to the central computing platform through digital interfaces (USB or Ethernet) and are processed by a dedicated video tracking application. It allows real-time display of images from the visible and thermal spectrum, switching between sensors, applying detection and tracking algorithms, and recording sequences for further analysis.

In parallel, telemetry (**Fig. 5.**) data is visualized through the Mission Planner application, which provides cartographic representations of the position of airborne users, display of kinematic parameters and simultaneous monitoring of several entities.

The system performs the spatio-temporal correlation between the positioning data and the video streams. When the operator selects, in the Mission Planner interface, a paratrooper from whom data is received, its coordinates are used to calculate the azimuth and elevation angles to the ground station position, and these values are automatically transmitted to the pan-tilt unit, determining the orientation of the cameras towards the estimated position of the target and performing automatic telemetry-based tracking.

Through the integration of high-sensitivity radio reception, electro-optical sensors with complementary capabilities and the processing and visualization software platform, the ground segment provides a coherent operational picture of the performance of airborne activities, constituting an essential element for real-time surveillance and post-action analysis.

3. DATA POST-PROCESSING

The proposed post-processing method is based on the correlated analysis of the altitude

variation over time, extracted from the data recorded by the aerial module, and the images captured by the ground video system at the appropriate moments.

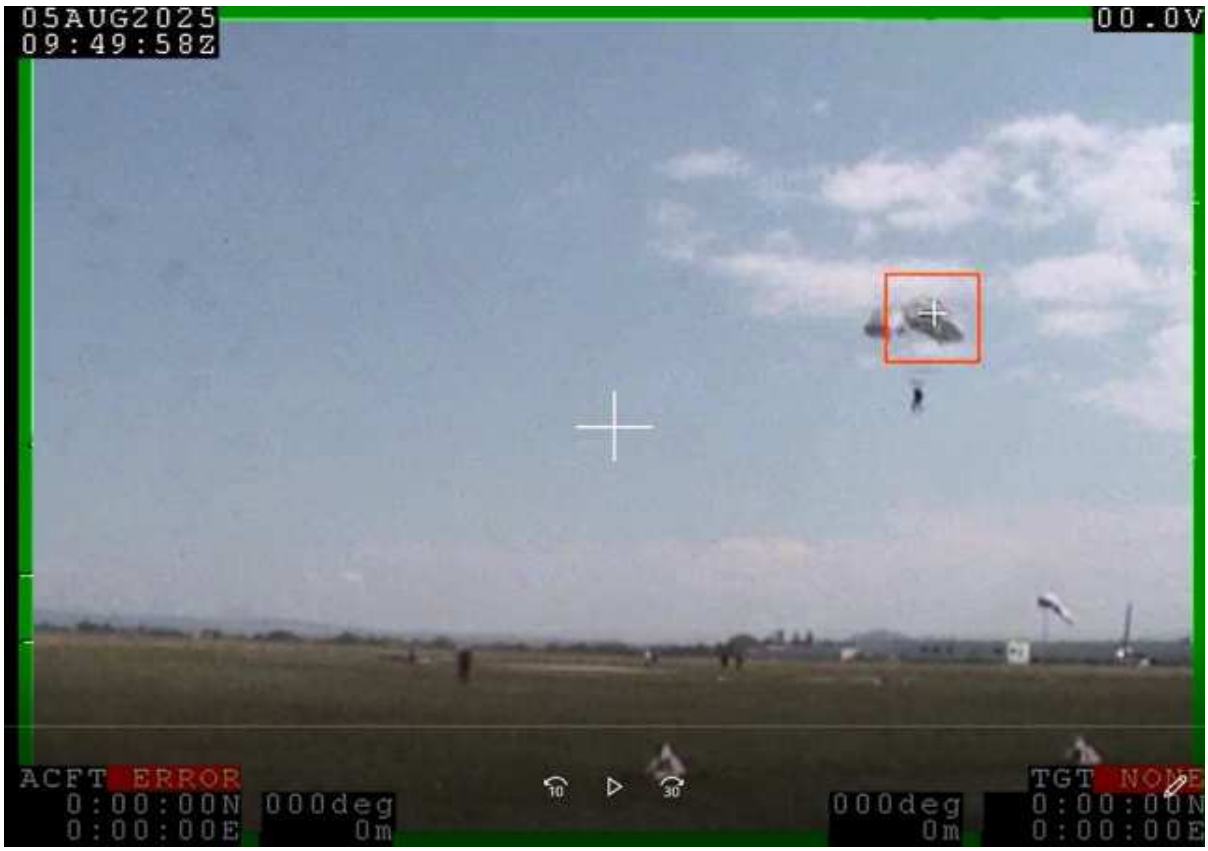


Fig. 5. Interface for viewing parachutes from the ground in real time (Dataset date: 05.08.2025).

The purpose of the method is the automatic and/or assisted identification of the operational phases of the jump and the evaluation of their execution in relation to standard procedures [3]. The data used in the analysis process come from an experimental test carried out on 05.08.2025, during a parachute training activity carried out at the Ghimbav civil aerodrome, with parachuting personnel belonging to the Romanian Air Force

The jump was executed from an IAR-330 helicopter, using a ram-air parachute. The launch took place from about 1600 m altitude, and the opening of the parachute was made after a free fall phase, at about 1000 m. The altitudinal values are reported at sea level, the altitude of the aerodrome being approximately 530 m.

The data is downloaded from the data logger and represented in the form of an altitude–time graph, in which the values are reported at sea level. The aerodrome elevation is used as a reference for interpreting the final phase of descent and landing. In parallel, the video stream is temporally synchronized with the telemetry data, allowing each relevant point on the graph to be associated with a frame or video sequence.

Five characteristic points are identified on the graph (**Fig. 6.**), corresponding to distinct operational moments, also marked in the associated images. Based on the altitude–time profile and vertical speed variations, the jump is divided into five operational phases:

- Leaving the aircraft
- Free Fall
- Opening the parachute
- Descent with the open parachute
- Landing

This segmentation allows the precise location of critical moments in the course of the jump.

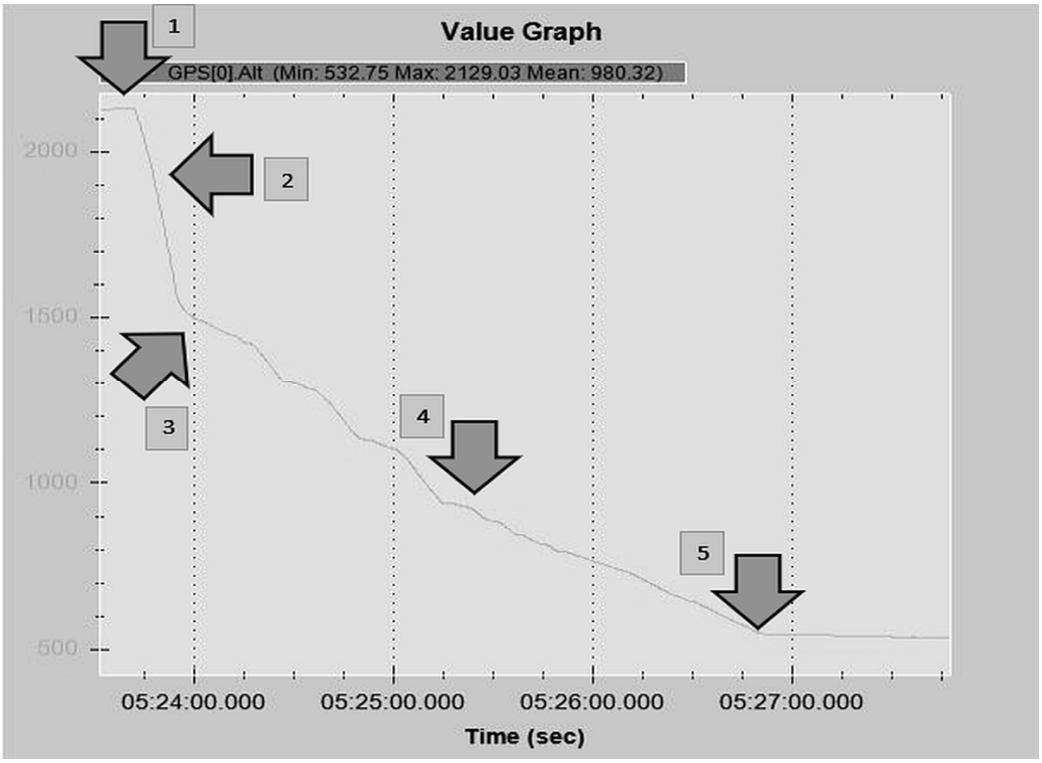


Fig. 6. Altitude–time graph used to identify the five operational phases of the jump

Point 1 – Leaving the aircraft

This point is identified on the graph by the beginning of the rapid variation in altitude. The associated image (**Fig. 7.**) highlights the moment of the parachutist exiting the aircraft. The analysis of this point allows you to check the timing of the launch and the initial position of the body. Significant deviations may indicate problems with coordination or positioning at the exit.

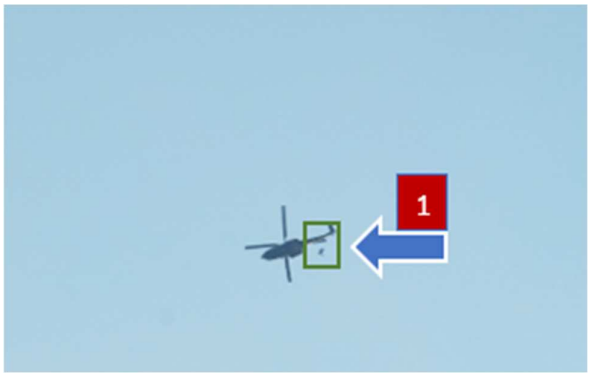


Fig. 7. Graph–image correlation for Point 1: aircraft exit

Point 2 – Free Fall

In this area of the graph, a steep slope is observed, corresponding to a high vertical speed. The associated image (**Fig. 8.**) allows the evaluation of the position of the body in free fall. The method aims to verify stability, which is considered optimal when variations in acceleration and orientation are reduced. Unstable positions are identified both by irregularities on the chart and by visual analysis.

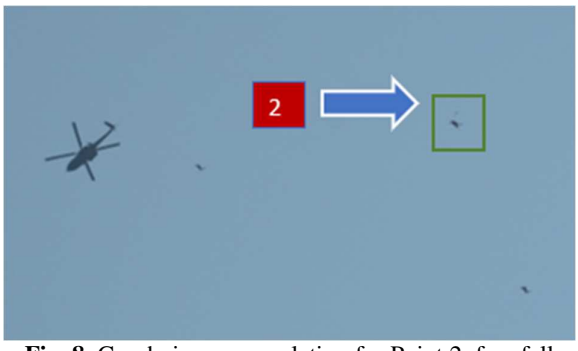


Fig. 8. Graph–image correlation for Point 2: free fall

Point 3 – Opening the parachute

The moment of opening is highlighted on the graph by a sudden change in the slope, corresponding to the rapid reduction of the vertical speed. The associated image (**Fig.9.**)

captures the position of the body at the time of initiation of the opening. The method makes it possible to verify compliance with the ordered opening height and the stable position prior to this moment. Any deviation is quantified by the difference between the measured altitude and the value set in the briefing.

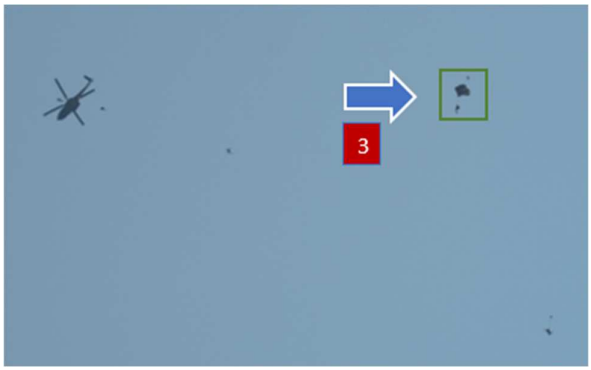


Fig. 9. Graph–image correlation for Point 3: canopy opening

Point 4 – Descent with the parachute open

This phase is characterized on the graph by a slow and almost linear variation in altitude. The associated images (**Fig. 10.**) allow the evaluation of the staggering between paratroopers and the piloting manoeuvres. The method aims to identify the overall trajectory and compare it with a reference descent profile.



Fig. 10. Graph–image correlation for Point 4: open-canopy descent

Point 5 – Landing

On the graph, the landing is identified by bringing the altitude value closer to the altitude of the aerodrome and subsequent stabilization. The associated image (**Fig. 11.**) allows the evaluation of the direction of approach to the wind and the execution of the braking manoeuvre. The position of the ground contact point is extracted from GNSS data and used to assess the accuracy of the landing.

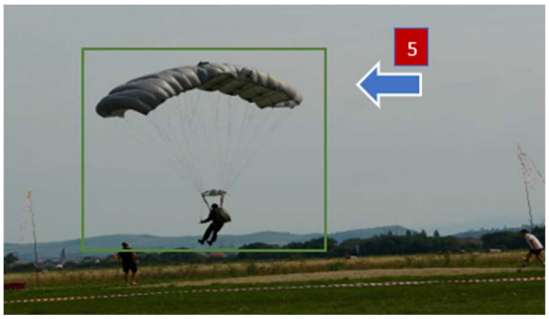


Fig. 11. Graph–image correlation for Point 5: landing

Integration of results

For each point marked on the graph, at least one relevant image is associated, constituting a graph-image pair. This pair allows mutual validation of information and reduces the subjectivity of the evaluation. The result of the method consists of a set of indicators on compliance with procedures (opening height, stability in free fall, staggering, landing accuracy), which are included in the post-action report.

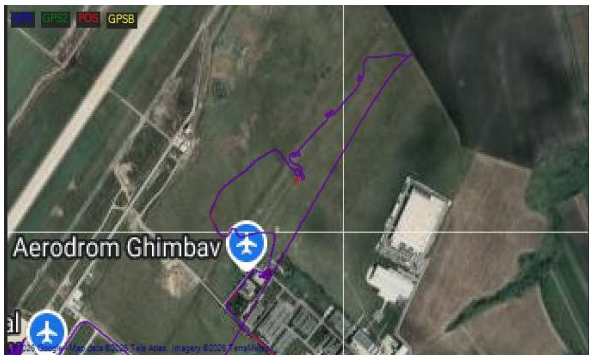


Fig. 12. The skydiver's trajectory obtained from the flight logger

Ethics and Institutional Approval

This work uses operationally non-sensitive telemetry and video recordings collected during routine military training. The data acquisition setup was authorized by the competent military chain of command and institutionally agreed for research and training-evaluation use. The monitoring configuration was strictly observational (no commands were transmitted to the aircraft, parachutists, or safety-critical

systems) and did not alter standard flight safety, parachuting procedures, or the conduct of the training event. To comply with data-protection requirements, no personal identifiers were recorded; participants were represented only through anonymized labels, and raw files were stored with access restricted to the research team. Only aggregated engineering results are reported in the manuscript.

4. CONCLUSIONS

In this paper, the ATSOPT system was presented, an integrated aerial monitoring solution intended for the surveillance and evaluation of military paratroopers after leaving the aircraft, which combines multi-sensor acquisition, real-time telemetry and video tracking capabilities in the visible and infrared spectrum. The proposed modular architecture, based on the clear separation between the aerial module and the ground segment, allows simultaneous monitoring of several users and provides support for both real-time operational surveillance and post-action analysis.

The results obtained from the experimental test carried out at Ghimbav aerodrome (**Fig. 12.**) demonstrate the feasibility of the solution and the ability of the system to provide coherent data on the evolution of altitude, trajectory and operational phases of the jump. The correlation of the altitude-time graph with the associated video images allowed the clear identification of critical moments: leaving the aircraft, free fall, opening the parachute, descending with the parachute open and landing. This approach reduces the subjective nature of the evaluation and provides instructors with an objective tool for analyzing execution.

The proposed post-processing method, based on graphic-image pairs, proved to be effective in verifying compliance with the opening height, free-fall stability, staggering between paratroopers and landing accuracy. In addition, the use of GNSS and inertial data allows the quantification of deviations from standard procedures and the provision of individualized, performance-oriented feedback. By integrating the radio link in the 868 MHz band, the MAVLink protocol and the electro-optical tracking system with complementary cameras, the ATSOPT provides a coherent operational picture of the performance of airborne activities and contributes to increasing the level of safety in training and in real applications.

The future development directions aim to expand the automatic analysis functions by introducing quantitative performance indicators, implementing algorithms for automatic recognition of positions and maneuvers and integrating additional mechanisms for securing communications. These developments can transform ATSOPT into a complete decision support platform for the training and evaluation of military paratroopers.

In addition, we plan to extend ATSOPT to low-altitude static-line/automatic parachute jumps (e.g., Delta), where free-fall is absent and the full sequence unfolds over a much shorter time window (≈300 m AGL). This scenario will require faster target acquisition and phase logic adapted to immediate canopy deployment, while preserving the same telemetry–video correlation for objective after-action assessment.

Multi-object tracking can be implemented using SORT and DeepSORT frameworks [2] [13], with data association commonly formulated via assignment methods [9]. Instructor workload monitoring can leverage multimodal fatigue/attention assessment approaches [11].

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Sistem de tracking automat pentru optimizarea instrucției parașutiștilor

Rezumat: Această lucrare prezintă ATSOPT, un sistem integrat de monitorizare aeriană și urmărire automată, conceput pentru a crește obiectivitatea și siguranța instruirii parașutiștilor militari. Un logger aeropurtat (GNSS, altimetrie barometrică și senzori inerțiali) transmite telemetrie MAVLink către un segment la sol care realizează tracking electro-optic în vizibil și infraroșu cu o platformă stabilizată pe două axe, cu cameră dual. Fuziunea datelor de navigație și inerțiale permite identificarea fiabilă a fazelor (ieșire, cădere liberă, deschidere, coborâre, aterizare) și evaluarea cantitativă post-eveniment. Propunem o metodă de corelare grafic–imagine care leagă traiectoriile altitudine–timp de cadre video sincronizate pentru verificarea altitudinii de deschidere, stabilității, separării și preciziei aterizării. Testele la aerodromul Ghimbav au confirmat telemetrie coerentă, captură robustă și utilizabilitate practică în condiții de teren. Lucrările viitoare vizează tracking multi-obiect și recunoașterea manevrelor parașutiștilor. Urmărirea multi-obiect poate fi implementată utilizând cadrele SORT și DeepSORT, asocierea datelor fiind formulată în mod obișnuit prin metode de atribuire. Monitorizarea volumului de muncă al instructorului poate utiliza abordări multimodale de evaluare a oboselii/atenției.

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