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Development of Precision Airdrop System based on GKV-6 MEMS-IMU

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This article is focused on the development of an automatic control system for a parachute cargo platform (ACS PCP). The platform construction was designed with the lifting capacity of 240 kg. The mathematic model and software were also developed to guide the system automatically to the target landing coordinates. Software integrates the data from the inertial navigation system (INS) GKV-6 and GNSS. ACS PCP also provides a remote control. Prototype of the system was manufactured and the tests were conducted.

Keywords — MEMS, GNSS, self-driving system, parachute-loading platform, inertial navigation system, Kalman filter

I. INTRODUCTION

In the motion control field one of the inertial navigation systems applications is the automatic control systems for unmanned parachute modules that provide precision cargo airdrop to the required coordinates. "Laboratory of Microdevices" Ltd with the Nano- and Microsystem Technology Institute of National Research University MIET and "ParaAvis" Ltd have developed an automatic control system for a parachute cargo platform. ACS PCP is controlled using the data integration of INS GKV-6 and GNSS-signal receiver.

II. PROBLEM OF CARGO DELIVERY IN THE UNEVEN RELIEF CONDITIONS

In case of uneven relief the precision cargo airdrop to the required coordinates is an important point. However, the parachute is exposed to unpredictable external influences within the descent process. Wind has the most influence. There are some different ways to guide a parachute system: remote control, radio beacon or light signal on the landing coordinates.

A parachute system can also be guided by high-tech methods. For example, GNSS is applicable. Another method is based on image recognition. Control unit uses a map built with the data from a camera installed into the ACS PCP.

Each of these methods has disadvantages. Some of them require a special preparation of the landing point, other ones are limited for use in some specific conditions. For example, bad visibility makes it impossible to use a light signal or image recognition system. A high level of radio interference doesn't allow the use of a GNSS.

III. HISTORY OF PRECISION AIRDROP SYSTEMS

Practical research in the precision parachuting field has been carried out since the 1980s.

The Soviet Union was developing remote-controlled parachute-cargo systems; and the UPGS-500 (Fig. 1) and UPGS-2000 systems were developed and tested at that time [1].

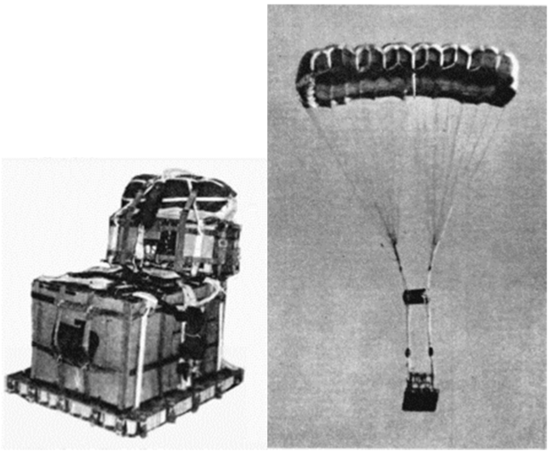


Fig. 1. UPGS-500 in a stacked form and in flight [1]

The first serial products operating in the automatic mode were developed in the middle of the 2000s. It was the first generation of the American Joint-Precision-Airdrop-System (JPADS) [2] (Fig. 2). GNSS was used as a guidance system for these products. A wind map built with the aircraft onboard computer was used as an additional data source [3].

Fig. 2. Reusable JPADS-series system in stacked form [2] and in flight [4]

New generation of JPADS was developed in the USA in the 2010s. These systems used the visual reference points rather than GNSS for guidance [4].

IV. EXISTING PRECISION AIRDROP SYSTEMS (PADS)

Although these systems are in demand, only one product of this type was found on the Russian market. It is HORIZONTAL-4000 that has been developed by Technodinamika Holding [5]. This system was designed for the cargo delivery of 3-4 tons weight [6]. It is currently under tests.

There are some products of various load capacities on the world market: the Sherpa by the Canadian company MMIST, the JPADS series by Airborne Systems described above, as well as the German SLG Sys. However, all these products are not aimed for the civil sector, so they are unavailable to be bought freely. Additionally, the cost of an item of such a system is about $ 30-40 thousand [2].

Fig. 3. Precision Airdrop System SLG Sys [2]

V. THE INEXPENSIVE PADS DEVELOPMENT TASK

In this case the main task is to develop an inexpensive system that allows automatic cargo delivery to the required coordinates.

Therefore in 2020 LMD Ltd, specializing in the field of INS based on MEMS-sensors, together with “ParaAvis” Ltd and the Nano- and Microsystem Technology Institute of the National Research University MIET started the development of an automatic control system prototype for a parachute cargo platform.

The functional diagram of the ACS PCP control unit is shown in Fig. 4.

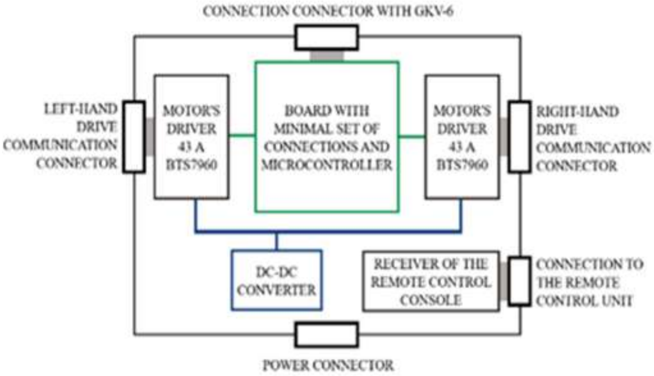


Fig. 4. Functional diagram of the ACS PCP control unit

VI. PADS CONTROL OPTIONS

The simplest way for automatic PADS guidance to the target coordinates is the use of GNSS. When this method is used, the control system has the current coordinates of the parachute system, the target coordinates and the heading as the input. Heading is determined using the trajectory of the PADS. However, the heading may differ from the azimuth due to the wind influence on the airdrop platform, which makes it difficult to determine the necessary control actions for the cargo delivery to the target coordinates.

As an additional data source, a wind map or integrated data from two GNSS receivers is applicable; it allows azimuth determination. However, the most effective way is the INS and GNSS data integration, which makes it possible to obtain a navigation solution on the initial parachute turn. The obtained solution includes coordinates, speed and orientation.

VII. INS AND GNSS DATA INTEGRATION ALGORITHM

In general, INS and GNSS data integration algorithm is an extended Kalman filter. The state of filter contains the estimates of

- Orientation quaternion;
- System coordinates (latitude, longitude, height) according to the WGS84 model;
- Linear velocities;
- Rate sensors bias instabilities;
- Accelerometers bias instabilities.

The control unit calculates the system dynamic parameters at a frequency of 100 Hz using the linearized deviation model. The computed deviations determine the updated parameter values of the filter state. The system state updates on every GNSS data sample (10 Hz).

Inertial data processing scheme is shown in Fig. 5

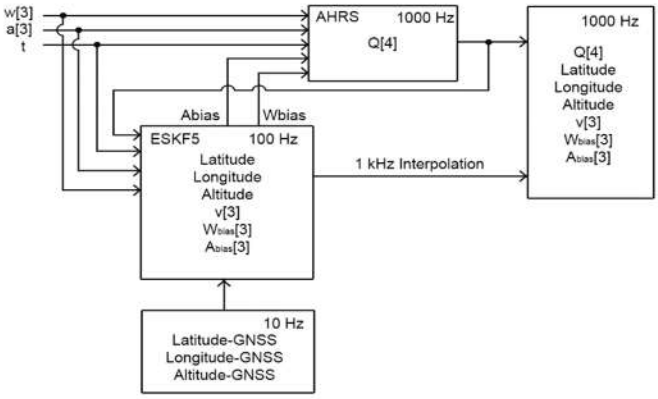


Fig. 5. Scheme of the INS and GNSS data integration algorithm, where “w” is the vector of the rate sensors data, “a” is the vector of accelerometer data, “Q” is the orientation quaternion, “v” is the linear velocity vector, “W_{bias}“ is the zero signal offset of the gyroscope, “A_{bias}“ is the zero signal offset of the accelerometer, “t” is the temperature sensor data

VIII. DESIGN OF THE DEVELOPED PROTOTYPE

Design of the prototype developed by LMD Ltd and its components are shown in Fig. 6:

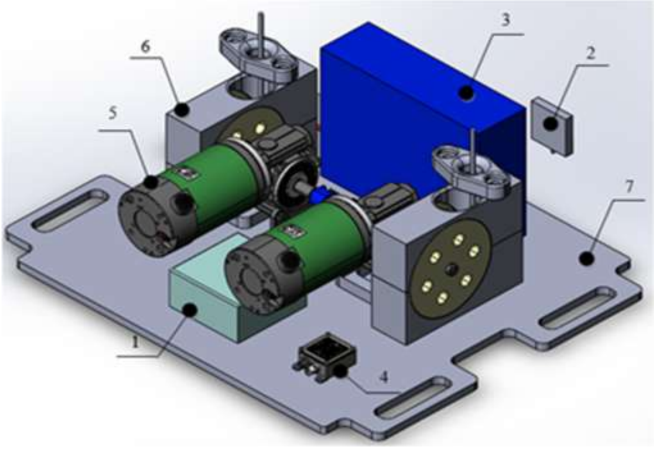


Fig. 6. Visualization of the ACS PCP. 1 – control unit; 2 – navigation antenna; 3 – power supply; 4 – inertial module; 5 – servos; 6 – pulley; 7 – housing

ACS PCP contains:

- INS GKV-6 that includes a 3-axis MEMS gyroscope, a 3-axis MEMS accelerometer, a 3-axis MEMS magnetometer, a barometer, a GNSS signal receiver, as well as a microcontroller computing navigation solution;
- Two gear motors with encoders feedback that control the parachute lines;
- Radio signal receiver for remote control;
- Control unit;
- Recorder of all the device system data during flight (“black box”);
- Parachute opening signal button;
- Battery.

Assembled ACS PCP prototype is shown in Fig.7

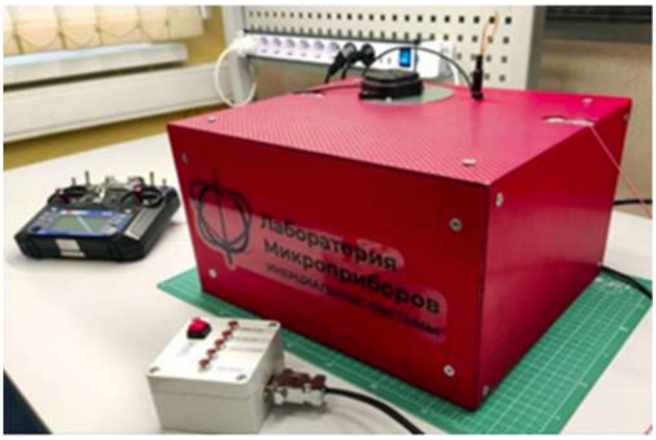


Fig. 7. Appearance of the ACS PCP prototype

IX. GENERAL SYSTEM OPERATION ALGORITHM

The system has the following operating modes (Fig. 8):

A. Standby mode

The actuators are fixed; the system is waiting for the parachute opening signal.

B. Uncoupling mode

Once parachute opens its control lines are set to the uncoupling position.

C. Remote control mode

In case a remote control signal is received the parachute control lines position can be set manually by an operator. Mode C has higher priority compared to the modes D and E.

D. Automatic control mode

Once GKV-6 calculates a navigation solution, the parachute control lines position can be set by the ACS PCP automatically based on the required target coordinates, the current coordinates of the parachute, and unit orientation quaternion.

E. "No control" mode

In case there is no remote control signal or navigation solution the ACS PCP starts the “no control” mode. The left parachute control line is set to 20% of its range. Thus the parachute is descending by a spiral trajectory.

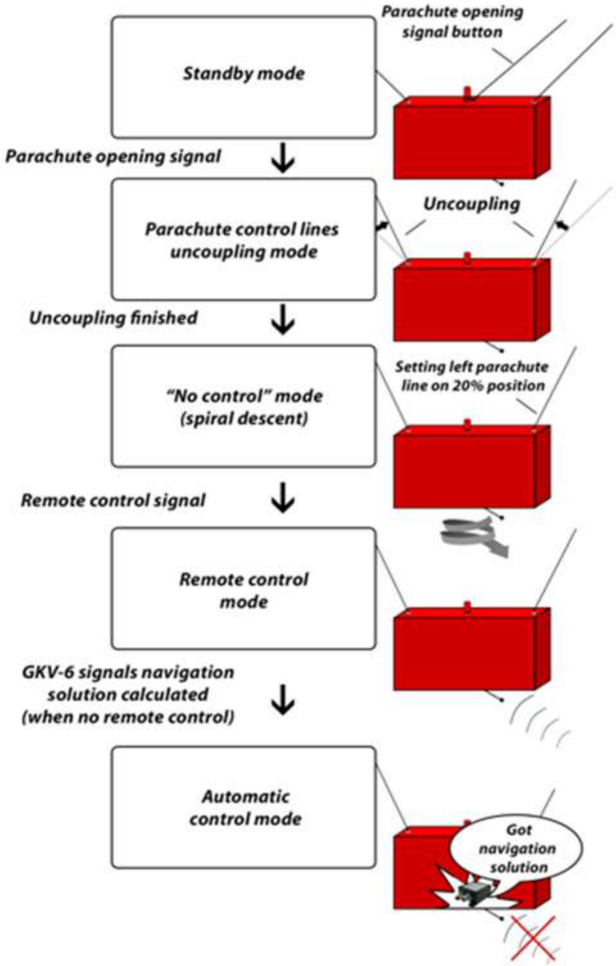


Fig. 8. General scheme of the ACS PCP algorithm

X. SCHEME OF THE SYSTEM OPERATION IN FLIGHT

The system operation after airdrop is shown in Fig. 9.

Once the ACS PCP has dropped from an aircraft and the parachute is opened, the control unit starts the uncoupling mode. After the uncoupling is completed, "no control" mode starts while the system is expecting for a navigation solution signal from the GKV-6.

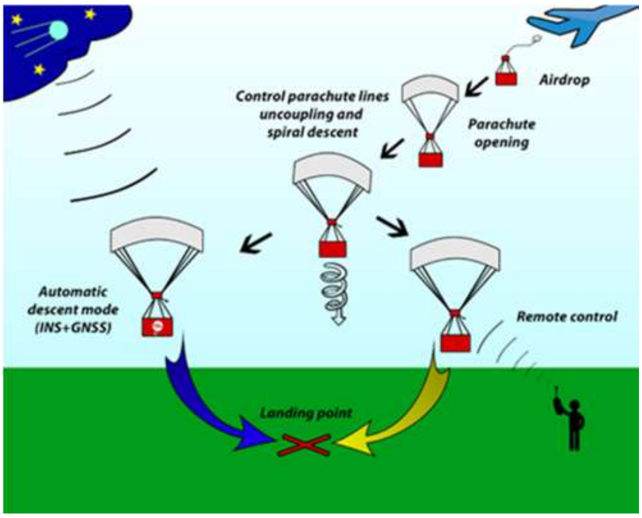


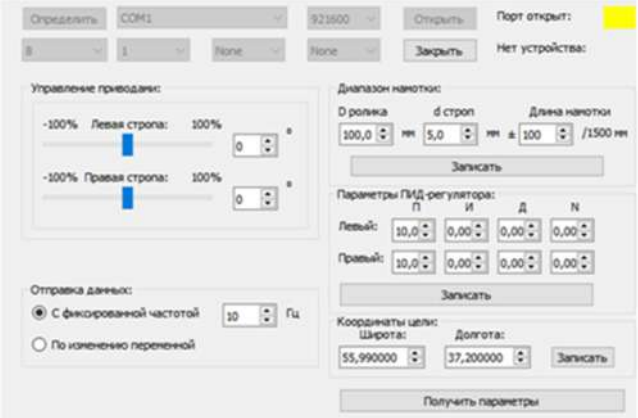
Fig. 9. ACS PCP descending scheme after airdrop

During the turn GKV-6 is calculating a navigation solution. Once the solution is found the system switches to the automatic control mode. In this mode the ACS PCP and the target coordinates are translated from the LLA (radians) to the NED (meters).

Using the calculated direction and distance, the ACS PCP is aimed at the target coordinates. Once a radius to the target is less than 30 m, the system switches to the "no control" mode.

XI. PC APP FOR CONFIGURING THE UNIT OPERATION PARAMETERS

For the initial device configuring (target coordinates, parachute control lines length and engine PID controller parameters), a GUI application for PC has been developed.



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Управление приводами:
-100% Левая стропа: 100% 0 °
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Диапазон намотки:
D ролика 100,0 мм
d строп 5,0 мм
Длина намотки ± 100 /1500 мм

Параметры ПИД-регулятора:

	П	И	Д	N
Левый:	10,0	0,00	0,00	0,00
Правый:	10,0	0,00	0,00	0,00

Отправка данных:
● С фиксированной частотой 10 Гц
○ По изменению переменной

Координаты цели:
Широта: 55,990000
Долгота: 37,200000

Fig. 10. App interface for the PCP ACS initial configuring

XII. PRELIMINARY PROTOTYPE TESTING

LMD Ltd and "ParaAvis" Ltd provided a preliminary prototype field testing at the Vatulino airfield in August 2021 (Figs. 11, 12).

The remote control system operation as well as the calculation of the navigation solution during airdrop were tested within the 6 airdrops. Device was airdropped at 600 m height. In the 4 cases the remote control mode was used. In the other two cases the automatic control mode was tested.

As a result of the tests, all the airdrops in the remote control mode were carried successfully.

Fig. 11. Airdrop of the prototype

Fig. 12. Prototype landing at the target point

Unexpected situations occurred during both airdrops in the automatic control mode. In the first case the operators had to switch ACS PCP into manual control mode as the system initially followed a wrong azimuth. In the second case a try of switching to manual control mode was unsuccessful so ACS PCP landed at a distance of 600 m from the required landing point (fig. 13).

Fig. 13. Required landing coordinates and the actual ACS PCP landing coordinates after six airdrops

XIII. SUMMARY

After the "black box" data analysis it was concluded that in all the six cases of airdrop the GKV-6 successfully found the navigation solution and provided correct navigation data. Table 1 shows the time and height of finding the navigation solution from the moment a parachute opens.

It was also concluded the system error in automatic control mode had been caused by a control unit flash memory module failure. Therefore the coordinates of the target were reset to default values.

That problem was fixed by the following way: the remote control module was replaced and a backup memory module in the PCP ACS control unit was installed.

The modified version of the prototype is planned to be tested again later in the 2022 to check the system operation in the automatic mode.

TABLE I.

Drop number	**1**	**2**	**3**	**4**	**5**	**6**
Time from the parachute opening moment to finding the navigation solution by GKV-6, sec	22.7	30.4	28.5	20.4	25.2	23.6
Height of the point where the navigation solution was found (barometric altimeter), m	252	211	223	264	231	256

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