UDC 519
DOI: 10.15587/1729-4061.2024.315525

DEVELOPMENT OF A HEXACOPTER MODEL FOR TRANSPORTING MEDICINES WITH NOISE REDUCTION

Abdumezhit Darayev
PhD, Associate Professor*
Muhabbat Khizirova
PhD, Associate Professor
Department of Telecommunication Engineering
Almaty University of Power Engineering and Telecommunications
Baytursynuli str., 126/1, Almaty, Republic of Kazakhstan, 05000
Anatoly Samsonenko
Senior Engineer
Space Technology Research Laboratory
Institute of Space Technique and Technology
Kislovodskaya str., 34, Almaty, Republic of Kazakhstan, 050061
Serikbek Ibekeyev
Master of Technical Sciences, Senior Lecturer*
Daulet Ilyas
Corresponding author
Master's Student*
E-mail: i.daulet.m@gmail.com
*Department of Electronics, Telecommunications and Space Technologies
Satbayev University
Satbayev str., 22, Almaty, Republic of Kazakhstan, 050013

The object of research is a helicopter-type copter. For the test flight of the prototype, high level of noise in the Wi-Fi block channel was noticed. To solve the problem Kalman filter was installed to the system between the antenna and microprocessor, for noise cancellation. A technical model that takes into consideration the time variation of the interference/signal ratio at the input of the UAV receiver for given trajectories and speeds of movement of objects and the source of interference has been developed that allows the delivery of medications up to 2 kg with a flight range of 5 km when exposed to interference from a moving source.

This article provides a prototype of the hexacopter design for small carriage delivery, used for medicinal transportation. During the test usage of the prototype UAV, such problems as shaking and unstable fixation of the lock mechanism holding the delivered cargo are observed and noted. The article underlines the cause of said problems as electromagnetic compatibility considerations, the methodology of debugging was to measure signals with oscilloscope and servotest, and provides the solution as application of Kalman filter for antennas. The results of the oscilloscope and spectrum analyzer during the debugging process before and after optimization by Kalman filter usage for noise filtering are shown. Signal noise can cause malfunctions of components, during signal decoding. The UAV prototype showed delayed response during test flight for approximately 0.2 s, which can be critical for flight and delivery precision. Telemetry, navigation, control, data, power supply, engine design, and software considerations are given. The results are not yet sufficient for urban usage, where EMI density is much higher, but the current developments make the suburban usage of UAVs for long range transportation

Keywords: hexacopter, unmanned aerial vehicle, noise reduction, frequency spectrum, Kalman filter

Received 03.10.2024
Received in revised form 02.12.2024
Accepted 12.12.2024
Published 30.12.2024

How to Cite: *Darayev, A., Khizirova, M., Samsonenko, A., Ibekeyev, S., Ilyas, D. (2024). Development of a hexacopter model for transporting medicines with noise reduction. Eastern-European Journal of Enterprise Technologies, 6 (5 (132)), 41–48. https://doi.org/10.15587/1729-4061.2024.315525*

1. Introduction

With the intensive development and implementation of new technologies of air-based technical complexes, there is a widespread use of unmanned aerial vehicles in various classes of activities, in particular the use of unmanned aerial vehicles for medical purposes.

Currently, the use cases of unmanned aerial vehicles (UAVs) is growing rapidly and includes many areas of application with a positive impact on society, such as healthcare, construction, visual inspection of structures, live filming, etc. [1, 2]. In the modern world, one of the most popular types is medical UAVs, which can be used for the rapid delivery of medical supplies to disaster zones, conflicts, accidents, as well as to areas difficult to reach due to terrain or weather conditions. Cases often arise when it is necessary to urgently deliver a medical product from one point to another with minimal loss of time, as in such moments, related to the life and health of people, every second is precious, which once again emphasizes the relevance and practical significance of the research issue in the field of UAV use for medical purposes. The use of UAVs for medical purposes can significantly reduce the time for transportation and delivery of biomaterials, devices and medical equipment, while economic costs can be significantly reduced, which will ultimately save human lives. Continued technological advancement may lead to the development of new types of UAVs that can provide more efficient and accurate drug delivery.

Delivering medicines using drones can be significantly faster and more efficient than using traditional methods. Unmanned aerial vehicles are highly maneuverable and precise, making it possible to deliver medicine to places where accessibility and safety are major concerns. Therefore, research on the development of UAVs for medicinal purposes are relevant, specifically, to address accessibility in remote and hard to reach areas.

2. Literature review and problem statement

The paper [3] presents a new perspective for classifying disasters and the vision of suitable network architectures that can be effective in each of these cases for disaster management. The difficulty is in creating dependable and efficient UAV networks to guarantee that property and human casualties are kept to a minimum. This outlines developments in UAV technologies to answer demands for disaster management.

The paper [4] reports that the government of Rwanda in Africa had partnered with California-based startup Zipline to deliver medicine to remote hospitals in the country. The company is currently responsible for delivering 75 % of Rwanda's blood supplies outside of Kigali. The delivery process is extremely efficient; when an order comes in from a hospital, everything needed is located, packaged, and placed into the main body of the UAV. It is then placed on a launch pad, where workers quickly attach the batteries, wings, and nose of the UAV. The craft is launched within 90 seconds of the order being placed. Once launched, the craft accelerates from 0 to 100 km/h in a third of a second via a launch ramp. This means that by the time it is launched, it has already reached cruising speed, requiring less energy to keep it in the air. Therefore, it is possible to conclude that UAV usage for medicinal purposes have been successfully implemented in some areas of the world, which can be inferred as proof of concept. Although, the UAV design was optimized to cover vast range, Zipline's "stay in air" approach trades off accuracy and safety.

The paper [5] proposes expanding the existing emergency medical infrastructure with a network of fast and compact drones that have communication capabilities and can carry medical auxiliary equipment. The object avoidance technology for avoiding impediments in the drone's path has to be improved, and the drone has not yet been tested on "real" patients. Still, several medical industry stakeholders have already expressed interest in the initiative. This case further proves the rising demand for UAVs in medicine.

The paper [6] outlines the need for a medium to big multi-rotor UAV to be researched and developed, offering examination for the assembly of paddle holders and auto-tilters for medium- to large-sized multi-rotor UAVs.

[4] share a UAV design, that utilizes horizontal cruise flight for long range applications. However, UAV design for [4] lacks accuracy in cargo landing, while [7–10] combine horizontal cruise flight with VTOL. Such approach for UAV design introduces flight time optimization as one mode of flight for long range, and another for precise operations, but complicates the design and flight operation.

The paper [11] proposes intuitive flight control strategy, which requires no pilot skills, which is a step towards UAV accessibility. Although the paper describes the early stages of the project, it is worth considering such flight strategy algorithms for delivery automatization for future research.

A number of projects [12–16] surveyed UAV application opportunities in medicine specifically. The documents describe the work process of said projects, but prototypes of the UAVs were not provided for further analysis.

All this allows to assert that it is expedient to conduct a study on UAV usage for urban and suburban areas. Current works highlight such demands, as precision, reliability and cost effectiveness. To add on to the current development, electromagnetic compatibility (EMC) considerations for suburban UAV usage needs to be addressed. Further studies are to be aimed towards component design, to ensure reliability and cost effectiveness of the joint work of the electronic components of UAVs.

3. The aim and objectives of the study

The aim of the current study is to design and develop UAV optimized for small carriage transportation. This will make it possible to add on to the usefulness of the UAV technology for public services.

To achieve this aim, many UAV prototypes are to be developed, tested and debugged:

– to apply Kalman filter on the prototype UAV, and take measurements on the effect of noise cancellation;

– to design a simulation of the prototype components on Matlab/Simulink.

4. Materials and methods

The object of research is a helicopter-type copter. The circuit diagram shown in Fig. 1 is used.

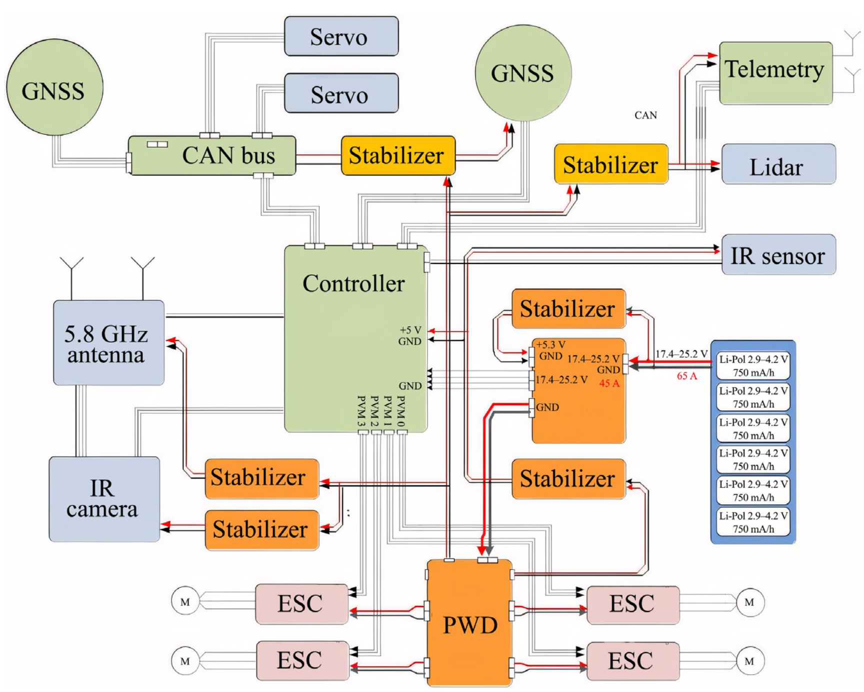


Fig. 1. Schematic diagram of the hexacopter under development

Based on Fig. 1, it is possible to assemble a technical model for a specialized UAV for the delivery of medicines, such as a copter designed for the delivery of medical cargo, up to 2 kg, as shown in Fig. 2.

Fig. 2. Close-up look of the UAV prototype

It has a bright yellow top cover, multiple propellers for stable flight, and a white box on the bottom for carrying goods. The various components of the aircraft are labeled, including the background board and camera system, antenna transponder, camera, analyzer, final control system and telecommunication system. This copter is equipped with various technologies for accurate and efficient delivery of medicines.

The electronic part of the UAV includes:

1. CUBE Pilot flight controller.
2. Radio control receiver FrSkyR9M.
3. GPS receiver M8.
4. Telemetry receiver/transmitter; Holybro (100 mW).
5. Lithium-ion battery, SONY 22 V; with the capacity of 9 A/h.

The technical characteristics of the copter (Fig. 1) are:

1. Take-off weight: up to 6 kg.
2. Payload: Medical cargo, weighing up to 2 kg.
3. Flight speed: 0–70 km/h.
4. Takeoff/landing: vertical.
5. Flight altitude: 2–1000 m.
6. Operating frequencies: 915 MHz, 5.8 GHz.
7. Satellite positioning systems: GPS, GLONASS, BEIDOU, GALILEO.
8. Size of the take-off/landing area: 2×2 m.
9. Diameter along the motor axes: 850 mm.
10. Number of engines: 6.
11. Motor type: brushless 3-phase BLDC.
12. Control: semi-automatic, automatic (take-off/landing, route flight).
13. Route planning: via PC using a modem.
14. Positioning accuracy up to 0.6 m.
15. Software: QGroundControl.

Fig. 3 shows a copter with a complex structure and functionality that has six rotor motors located on six arms extending from a central body.

The prototype components:

1. The frame of this copter is a lightweight and durable structure made of aluminum and textolite, which provides a solid foundation for installing motors, electronics, and batteries.
2. The power frame is made of fiberglass, the screws are composite, carbon fiber.
3. Payload compartment design (payload, servomechanism). Servo drive EMAKH, 6V; ESOSA (1.8 kg/cm, 0.12 sec/600).
4. The model uses 6 brushless motors T-MOTOR 4006; 380 kV; 22 B; 240 W.
5. The battery ensures continuous operation of the motors and electronics.
6. Motor controller: TURNIGY Plush 60A.
7. Control panel: FrSky HORUS x10.

Fig. 3. Hexacopter

The hypothesis of the study is that the current prototype configuration would need means noise cancellation for reliable usage. As such, Kalman filter is provided as a solution for noise cancellation.

The given prototype is designed to operate in suburban areas, with relatively sparse EMI. The study assumes usage in optimal weather conditions, such as absence of rain, fog, snowfall.

The research methods are: a test flight in a suburban are just outside Almaty city, shipping a 500 g cargo to 5 km by operated flight; injection test to sensor components with oscilloscope and spectrum analyzer; Matlab/Simulink model testing.

During the practical debugging of the UAV in some operating modes, shaking and unstable fixation of the lock mechanism holding the delivered cargo are observed. A servo-based lever-type mechanism is located at the bottom of the UAV. In normal mode, the lock should operate upon the operator's command. In the maximum power mode of the connected on-board transmitter of the UAV (approximately 1 W), located nearby, the servomotor with the lever and the lock rod goes into a self-oscillating parasitic mode, as a result of which the rod does not sufficiently fix the load [6].

Compared to the irradiation test, the injection test offers improved test efficiency for the same input power, and allows for the better control of interference signal parameters, resulting in more accurate data.

Since computer arithmetic has advanced so quickly, simulation technology has been used extensively in scientific study. Modeling and simulating the study object's electromagnetic performance is known as electromagnetic simulation. To examine and compute different factors, researchers use proven models rather than real prototypes. This makes it possible to investigate structural features, heat and force distributions, and field changes in electronic systems, devices, and circuits under various electromagnetic conditions. Researchers are able to identify the fundamental laws and damage processes that control their behavior.

5. Component adjustments with test results consideration

5. 1. Kalman filter for noise cancellation

The UAV's onboard transmitter emits bursts of high-frequency (HF) pulses with a frequency hop (from 5 to 20 per second) in the region of 900 MHz. It is likely that this radiation can lead to electromagnetic interference in the servomotor control circuits.

The study used instruments from Keysight:

1. InfiniVision DSO2012A oscilloscope with 100 MHz analysis bandwidth and 2 GSa/s sampling with a set of 10/1 probes.

2. Fieldfox 9915 spectrum analyzer with an analysis bandwidth of up to 9 GHz, measuring antenna 900 MHz.

Let's move on to the experiment. First, let's assemble a research workstation with the developed copter. A photograph of the measuring stand with instruments and a UAV on the mounting table is shown in Fig. 4.

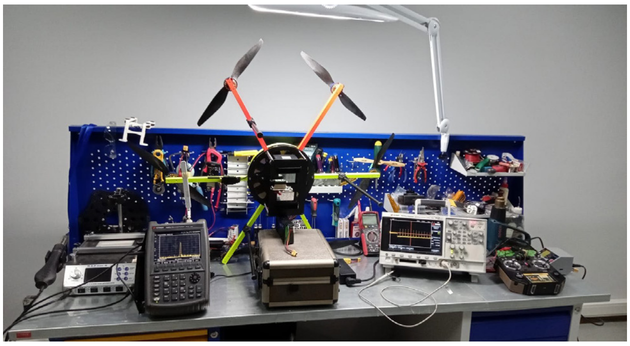


Fig. 4. Photo of a measuring stand with instruments and an unmanned aerial vehicle on the assembly table

According to this installation, measurements were taken on engine starting and interference affecting it. It was discovered that interference appeared on the InfiniVision DSO2012A Oscilloscope (Fig. 5).

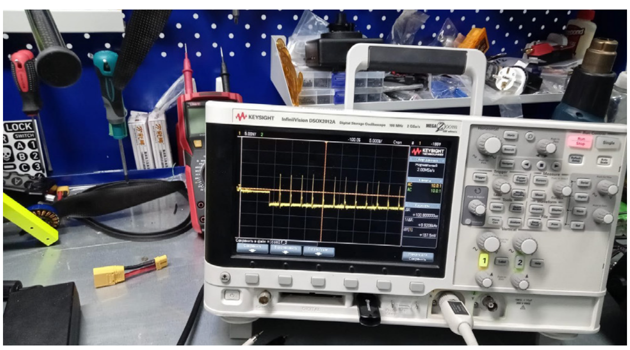


Fig. 5. Bouncing frequency interference

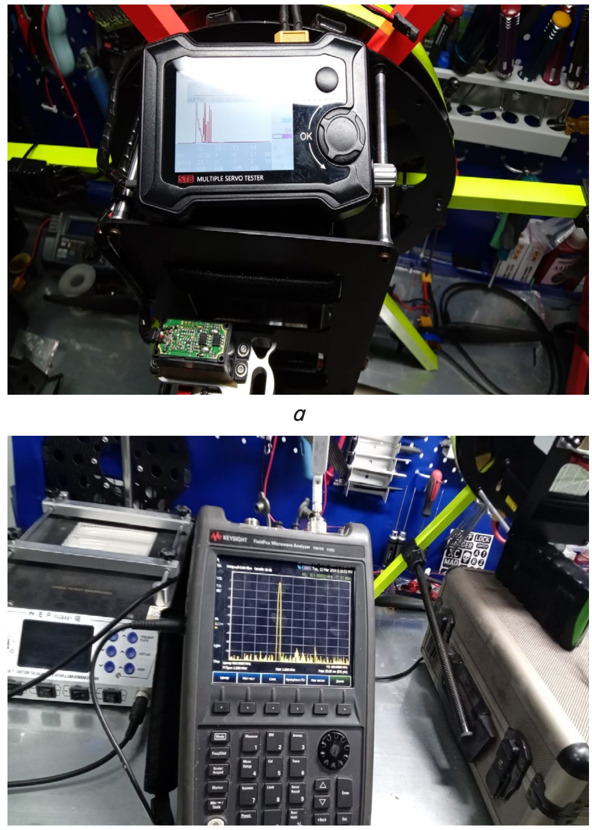
Bouncing frequency interference, which is shown in Fig. 5, is also shown by the spectrum analyzer (Fig. 6) on the complex itself.

Oscillograms taken at the contacts of the servomotor at the moment of trembling (Fig. 6) show the presence of false impulses leading the motor to false triggering.

According to the data in Fig. 6, a control pulse was sent to the engine. That is, they installed a noise suppressor. The noise suppressor, in turn, cleared the interference in the signal propagation and the interference disappeared (Fig. 7).

The same signal unfolded in time with traces of interference in the intervals between pulses is shown in Fig. 8.

The servomotor control system perceives the high-frequency (HF) signal of the transmitter as interference, goes into an unstable state and generates false signals similar in amplitude to the standard pulse-width modulation (PWM) pulses of the servomotor control.



a

b

Fig. 6. Spectrum analyzer interference: *a* – on servotester; *b* – on oscilloscope

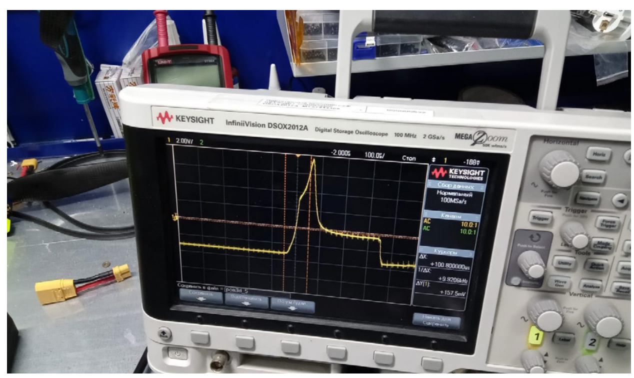


Fig. 7. Noise-free signal after inserting noise reduction

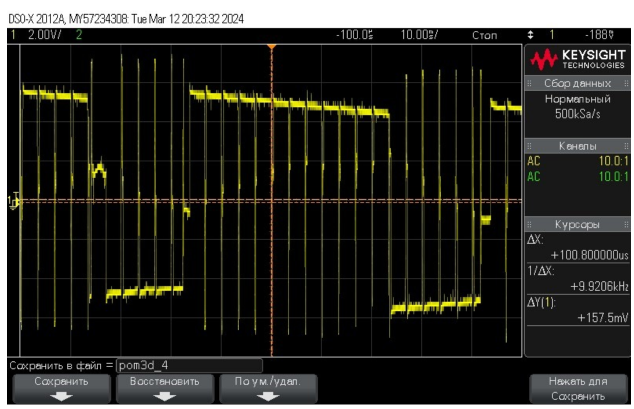


Fig. 8. Traces of radio frequency interference between pulses, highlighted in red

Fig. 9 shows the PWM pulses of the servomotor drive without parasitic RF interference.

Fig. 9. Pulse width modulation pulses of the servomotor drive without parasitic radio frequency interference

As a result of the experimental studies on RF interference, the control system no longer leads to a parasitic self-oscillating mode and the servomotor can operate in normal mode with a PWM drive at the operator's commands.

5. 2. Kalman filter application for noise cancellation in Matlab/Simulink

Let's consider a technique for simulating a hexacopter control system in the Simulink/MATLAB environment for drug delivery.

A model describing a copter-type UAV, built in the Simulink/MATLAB environment, is presented in Fig. 10.

The simulation model shown in Fig. 10 takes into account the connections, but the influence of some elements, such as screws and nuts, has a negligible effect on the final result. Calculating the interaction of these parts with the frame requires additional time.

Since our task is noise reduction using a Kalman filter, it is necessary to assemble a similar circuit shown in Fig. 11.

Fig. 12 shows noise filtering for a copter with the following values: frequency: 900 MHz, power: 1 W, amplitude: 5 V.

Based on Fig. 10, 11, it is possible to present the results of modeling false impulses that lead to false triggering of the motor, comparing the results of the experiment as shown in Fig. 10 (Fig. 13).

Similarly, it is possible to simulate the hopping frequency interference, which is shown in Fig. 5. The simulation result of the spectrum analyzer hopping frequency interference is shown in Fig. 14.

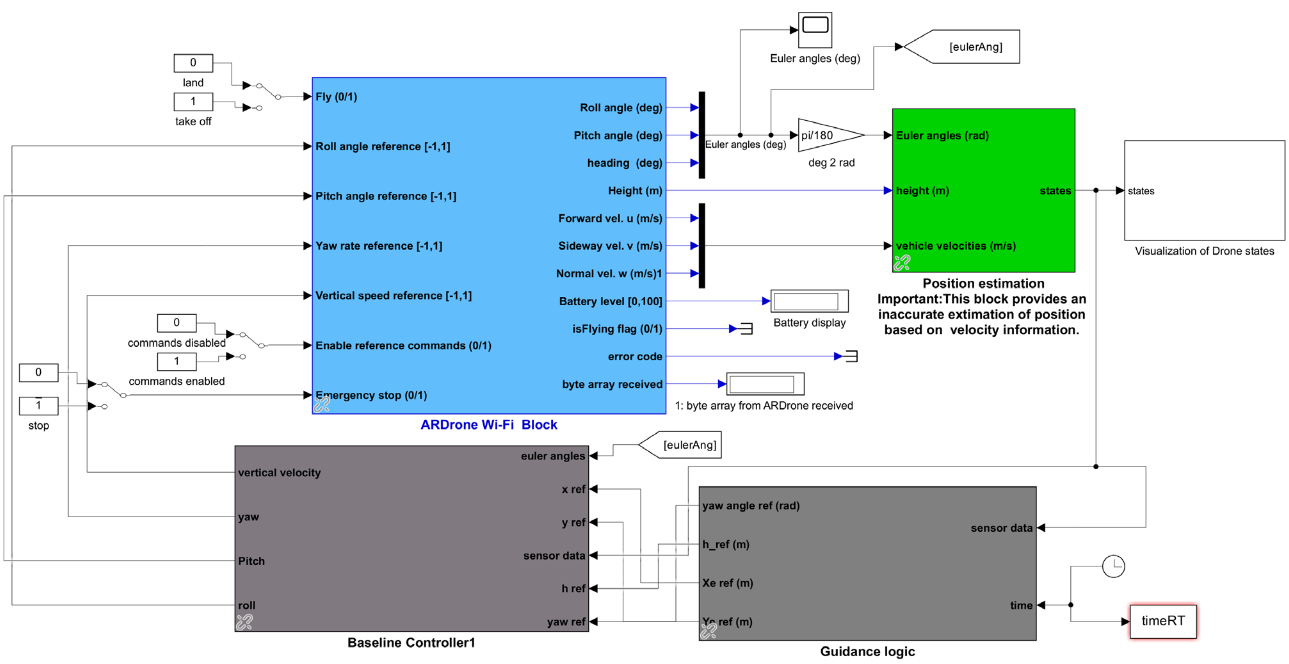


Fig. 10. Simulation model of the copter in the Simulink environment

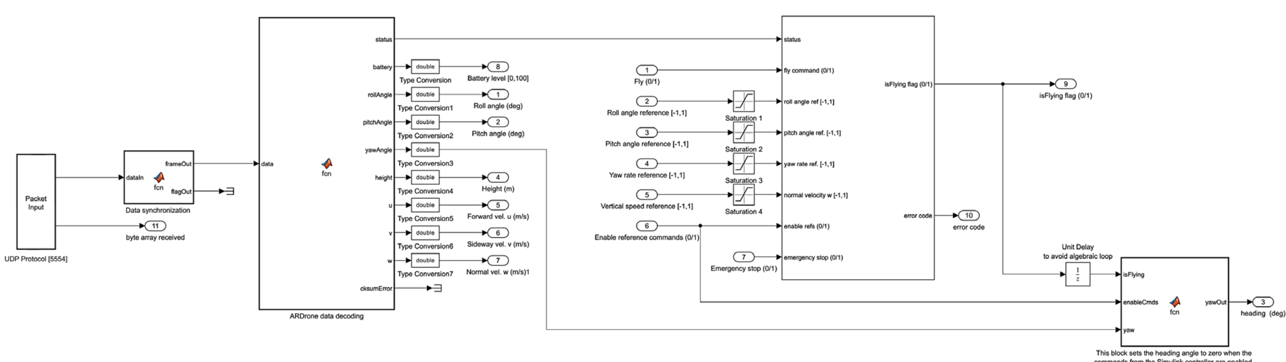
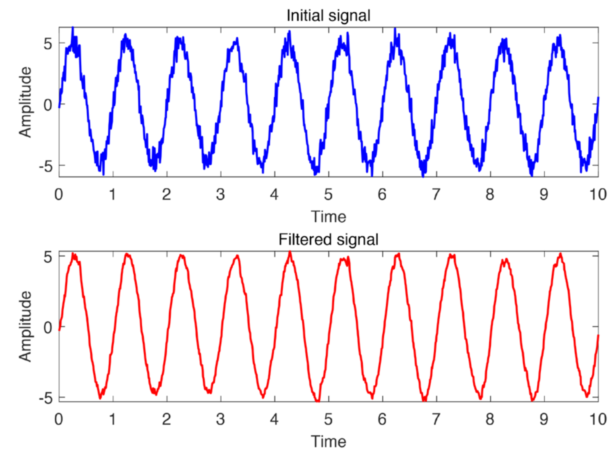
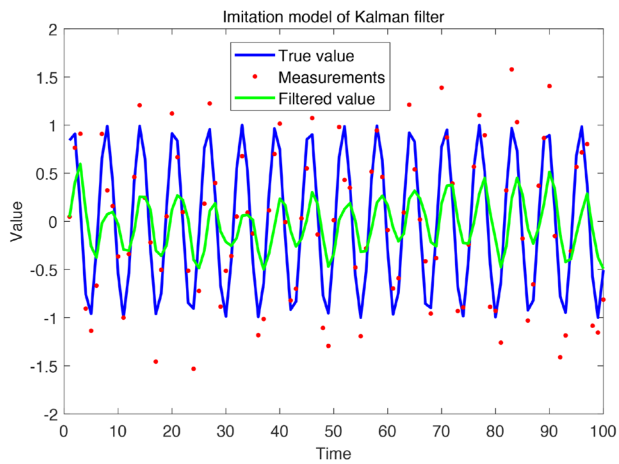


Fig. 11. Wi-Fi block with Kalman filter to suppress noise for input signals in the copter



a



b

Fig. 12. Kalman filter:
a – noise filtering results; *b* – imitation model

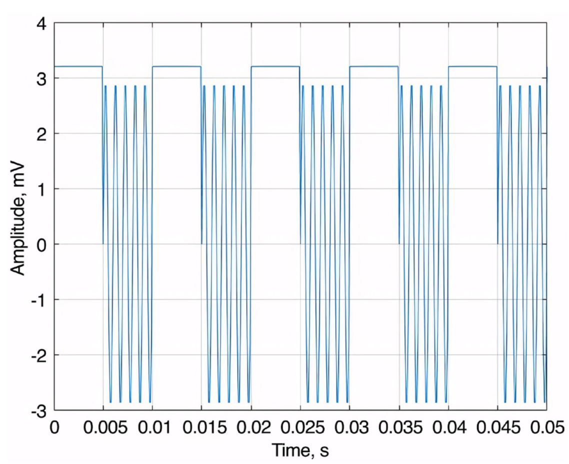


Fig. 13. Results of simulation of false impulses leading the motor to false alarms

Fig. 15 shows the simulation plots, in the presence of noise and denoising with a Kalman filter, compared to the experimental value shown in Fig. 7.

With filtered signal, system components can precisely measure start, peak and end of a signal, which is crucial specifically for a PWM control signals, where width of an input signal translates to amplitude of output signal. Overshoot of output signal towards UAV components, such as BLDC motors, can impact flight performance, component overcharge, battery usage and etc.

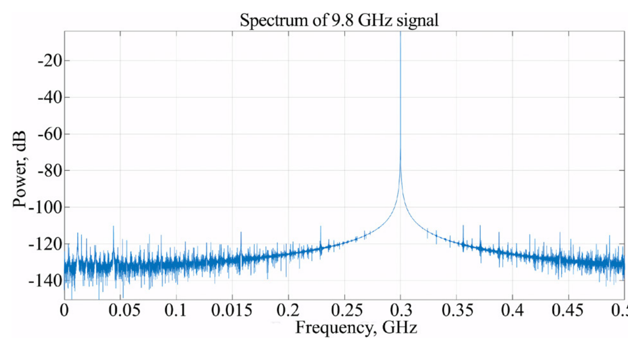
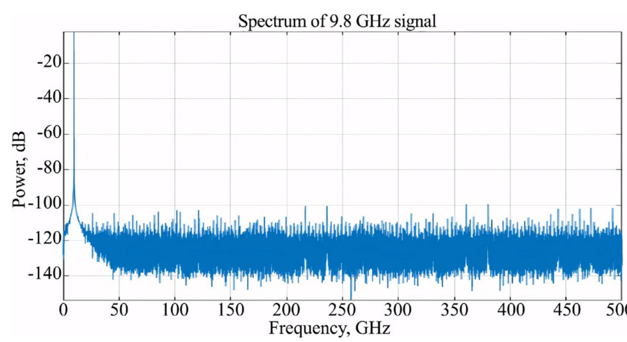


Fig. 14. Spectrum analyzer bouncing interference simulation



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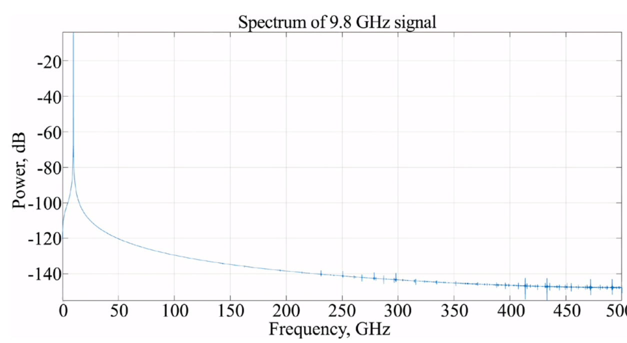

b

Fig. 15. Simulation results:
a – signal with noise; *b* – signal with noise reduction

6. Discussion of the proposed UAV prototype design with applied changes

A technical model has been developed that makes it possible to deliver medications up to 2 kg with a flight range of 5 km, under conditions of exposure to interference from a moving source, taking into account the time variation of the interference/signal ratio at the input of the UAV receiver for given trajectories and speeds of movement of objects and the source of interference. The experiments conducted confirm the applicability of such copters in real-life scenarios where precise delivery of medicines to the designated destination is required. The result of the experiment can be called a UAV-copter, which requires taking into account the variable noise intensity and the complexity of signal filtering.

Injection testing for sensor and antenna components was conducted in the environment as shown in Fig. 4. The measurements of the signals captured by the Wi-Fi block at the engine start is shown in Fig. 5, 6. The measurements show a severely noisy channel, that demands mean for noise cancellation. The measurement results in Fig. 7–9 show an improvement in receiver signal clarity after the application of Kalman filter.

The inclusion of Kalman filter in junctions between antennas/sensors and microprocessors ensures precise calculation during flight and navigation, which is explained by enhanced clarity of received signals. The incremental nature of Kalman filter success rate provides long-term efficiency of the method.

Fig. 10–15 provide measurements of Wi-Fi block receiver signals before and after Kalman filter application, that show a major improvement in signal decoding clarity.

[17] provides fundamental insights into the endurance and range capabilities of multiple-rotor unmanned aerial vehicles (UAVs) and a qualitative discussion on the safety and acceptability features of each configuration implemented in an advanced air mobility context. As a result, the side-by-side helicopter configuration was identified as the best solution to be introduced within urban environments, fulfilling all the performance and mission requirements.

The assembly of paddle holders and auto-tilters for medium- to large-sized multi-rotor UAVs is examined in [6]. The multi-rotor UAV is intended to mount an auto-tilter. Its component strength checks are analyzed. Additionally, the blade requirements are chosen, along with strength tests of the individual components, and the structural design of the UAV rotor system is provided. The mechanical viability of the UAV is then confirmed using a motion simulation of its mechanical design.

The prototype design was a simple hexacopter with statically placed motors, as opposed to variable paddle provided in [6], for the sake of simplicity and production cost. Same conclusion to be made in comparison to two-mode flight prototypes, such as in [7–10].

Advantages of the developed copter:

1. Increased payload: larger drones can carry more complex equipment and more sensors, resulting in more useful data.
2. Longer flight time: larger drones have larger battery capacity, allowing them to conduct long-term missions and collect data over longer distances.
3. High stability: larger drones are more resistant to wind conditions and can fly in more varied weather conditions.

Limitations for the developed hexacopter:

1. Less maneuverable: larger drones are less maneuverable and less suitable for flying in confined spaces.
2. Larger size: their size may not be convenient enough for some missions, especially in dense urban areas.

To dwell on the strengths and weaknesses of the object under study, the strengths include:

1. Mobility.
2. Customer safety.
3. Convenience for users.
4. Clear schedule.

The weaknesses include the following:

1. Limitations of the UAV's payload capacity, which may limit the amount of medicine that can be delivered at one time.
2. Expensive equipment, the cost of specialists.
3. Weather. Due to both the design of UAVs and the nature of aircraft in general, weather conditions are a large factor in risk calculations.
4. Navigation and communication. Due to the design of the UAV, all energy-consuming elements are located in close proximity to each other, and also require a large supply of electricity, but also limiting the size of batteries or generators;
5. Legal restrictions. The use of UAVs in urban environments poses risks, since malfunctions and breakdowns of flying vehicles can result in damage to human life and health or damage to property.
6. Possibility of terrorist attacks.
7. Abuse of legal use.

Basically, it is better to use helicopter-type UAVs for delivering medicines. Helicopter-type UAVs are similar in design to a manned helicopter. Rotating wing UAV has a wide range of applications. According to the laws of aerodynamics, drones of this design are much more efficient than the multi-rotor version. According to the characteristics, the flight time is higher, as well as the carrying capacity and high maneuverability. The obvious advantage of helicopter-type UAVs is the ability to hover at a point and operate in a small space [7–10]. Among these configurations, Quadrotor, a multi-rotor rotorcraft, deserves special attention due to its simple architecture, small size, great flexibility and safety for indoor and outdoor flights, which is what we are developing for research. A hexacopter is a six-motor device, and an octacopter, accordingly, is an eight-motor device.

7. Conclusions

1. EMC considerations to improve reliability of electronic components in high EMI density urban and suburban locations. Measurement results from the test flight demonstrated that sensitive components like antennas and sensors require signal filtering. During the test usage of the prototype UAV, such problems as shaking and unstable fixation of the lock mechanism holding the delivered cargo are observed and noted. This study proposes the use of a Kalman filter for noise cancellation. Kalman filter is put between sensors/antennas and processing units. The filter makes an assumption for the next measurement, by calculating the difference between current and previous measurements. The error between the assumption and next iteration measurement is minimized over time. As a result, there is a clear signal decoding from Wi-Fi block of the UAV, which allows for faster data transfer between UAV and ground station, and therefore more control and clarity during flight.

2. After thorough testing of Kalman filter application for noise cancellation in Matlab/Simulink model, the same result was derived. The decision for inclusion of Kalman filter for antennas and sensors was made. Measurements before and after Kalman filter application, show decisive progress in noise cancellation.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The study was performed financial support of Ministry of Education of the Republic of Kazakhstan.

Data availability

Manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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