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Analysis of parametric and time-angle methods for determining the distance and positioning of unmanned aerial vehicles

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Abstract—**The paper considers modern approaches to determining the distance and positioning of unmanned aerial vehicles (UAVs) using radio signal parameters—RSSI, SNR, LQ—as well as ToF, TDoA, and AoA methods. The relevance of the research in the context of digital transformation and limitations of satellite technologies (GPS/GNSS) is justified. The accuracy, advantages, and disadvantages of each method are analyzed, and an integrated formula for distance estimation based on a combination of RSSI+SNR+LQ is presented. It is shown that the combination of parametric and time-angle methods increases the reliability and accuracy of UAV navigation. The prospects for the development of hybrid positioning systems using self-calibration algorithms, Kalman filters, and integration with 5G/6G and IoT technologies are noted.**

Keywords—UAV positioning; RSSI; SNR; ToF; TDoA; AoA; hybrid navigation systems.

I. Introduction

Digital transformation and the transition to Industry 4.0 necessitate the automation of technological processes with high precision, speed, and cost-effectiveness. One promising area is the use of unmanned aerial vehicles (UAVs), which, in combination with intelligent data processing systems, can optimize work processes, reduce costs, and increase the level of automation. Today, UAVs are widely used in agriculture, environmental monitoring, security, and defense, where their effectiveness largely depends on navigation accuracy.

Traditional satellite technologies (GPS/GNSS) have limitations due to interference and multipath effects, which makes the search for alternative and combined positioning methods relevant. The development of such solutions is aimed at increasing the autonomy and safety of UAVs, as well as contributing to the development of modern automation, telecommunications, and robotics technologies.

II. Formulation of Research Objectives

The aim of the work is to systematize approaches to positioning unmanned aerial vehicles using signals and technologies (RSSI, SNR, LQ, ToF, TDoA, AoA) with subsequent assessment of their suitability for improving the accuracy and reliability of navigation under restrictive conditions.

III. Statement of the Main Material

Measuring and determining the position of a UAV

The key accuracy parameters are positioning error, coordinate update frequency, and response speed. GPS provides an average accuracy of 5–10 m, DGPS — up to 1 m. INS (inertial systems) allow continuous tracking of movement, but accumulate error, so they are combined with GPS. The use of complementary filters (e.g., Kalman) allows data from different sources to be integrated and the shortcomings of each to be compensated for. In military and critical applications, an error of even a few meters may be unacceptable [1].

The importance of positioning accuracy

In civil applications: mapping, cargo delivery, and agricultural monitoring often require centimeter-level accuracy. In military applications: reconnaissance, targeting, attack, the margin of error must be minimal (up to tens of centimeters). From a flight safety perspective, accurate positioning allows obstacles to be avoided in real time (processing delay <100 ms) [2].

Modern methods of UAV positioning:

1. GPS/GNSS – the main method, sensitive to multipath, interference, and spoofing.

2. INS – an autonomous method that quickly accumulates errors.

3. Methods based on signal parameters:

- RSSI (signal strength),
- SNR (signal-to-noise ratio),
- LQ (channel quality).

These parameters allow you to estimate the distance to the signal source, but do not provide absolute coordinates on their own [3, 4].

4. ToF (Time of Flight) – measurement of signal transit time [5, 6].

5. TDoA (Time Difference of Arrival) – determination of the time difference between signals arriving from multiple sources [7, 8, 9].

6. AoA (Angle of Arrival) – estimation of the signal arrival angle to determine direction [1, 4].

Research on combining RSSI + SNR + LQ methods

- RSSI: reflects the level of the received signal (from –100 to 0 dBm). It is used to estimate distance, but depends on interference and the environment.
- SNR: a key indicator of signal quality; high (>20 dB) means a stable communication channel.
- LQ: reflects the integrity and reliability of the channel, measured as a percentage.

The integrated formula for determining distance takes all three parameters into account, which increases the reliability of calculations:

$$d_{final} = \left(10 \cdot \frac{A - RSSI}{10n}\right) \cdot \left(\frac{SNR}{SNR + k}\right) \cdot \left(\frac{LQ}{100}\right), \quad (1)$$

where A – is the reference RSSI at 1 meter; n – is the loss coefficient (n = 2 for open space, n = 3-4 for space with walls); k – is the adjustment coefficient (10–20 dB, selected experimentally).

It should be noted that in this case, the disadvantage is the need to calibrate the parameters (A, n, k) for each environment. However, the advantage is the possibility of using standard UAV telemetry channels [3].

ToF, TDoA, and AoA methods

ToF (time of flight). This method has the following characteristics:

- direct measurement of the time from signal transmission to reception;
- provides high accuracy (up to centimeters);
- vulnerable to multipath and noise [5, 6].

Examples of implementations are SS-TWR (single-shot two-way range) and DS-TWR (double two-way range with four messages)].

TDoA (time difference of arrival). This method has the following characteristics:

- requires at least three synchronized base stations;
- allows coordinates to be determined without the need for a return channel.

Used in UWB and LTE/5G systems [7, 8, 9].

AoA (angle of arrival). This method has the following characteristics:

- it is based on the use of antenna arrays to determine the direction of the signal source;
- it works well in combination with other methods (e.g., ToF + AoA).

The disadvantages of this method are its complexity and sensitivity to multipath [1, 4].

IV. Conclusions and prospects for further research

No positioning method is universal. GPS/GNSS remains the basic solution, but alternatives are needed in conditions of interference or inaccessibility. The integration of RSSI+SNR+LQ with ToF, TDoA, and AoA methods significantly improves positioning accuracy and reliability. The use of combined approaches (hybrid systems) is a promising direction for the development of navigation for UAVs.

Further research should focus on creating self-calibration algorithms, applying filters (Kalman, particle), and integrating with 5G/6G and IoT technologies.

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