

A SYSTEMATIZATION OF MODERN METHODS FOR POSITIONING UNMANNED AERIAL VEHICLES BASED ON SIGNAL PARAMETERS AND TOF, TDOA, AND AOA TECHNOLOGIES

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The current development of unmanned aerial vehicles (UAVs) is accompanied by increasing demands on the accuracy, reliability, and autonomy of their navigation systems. This is particularly relevant in situations where satellite navigation signals are limited or intentionally jammed. In such situations, there is a need for alternative or combined positioning methods capable of ensuring stable UAV operation under challenging operating conditions.

In practice, UAV positioning approaches based on radio signal parameters (RSSI, SNR, LQ) are used, as well as methods based on temporal (ToF, TDoA) and angular (AoA) signal characteristics.

Methods based on signal parameter analysis are simple to implement and allow for the use of existing communication channels without additional hardware. They enable rapid estimation of the distance to a target; however, their accuracy depends significantly on external factors, particularly multipath propagation, interference, and environmental changes. Using a combination of RSSI, SNR, and LQ allows these shortcomings to be partially compensated for and improves the stability of the estimation. Methods based on signal timing characteristics provide significantly higher positioning accuracy. Time-of-Flight (ToF) technology determines distance based on the time it takes for a signal to travel and is effective at short distances, where centimeter-level accuracy can be achieved. However, its effectiveness decreases in the presence of interference. The Time Difference of Arrival (TDoA) method determines an object's coordinates based on the time difference in signal arrival at multiple receivers and is suitable for covering large areas. Its main limitation is the need for high-precision synchronization of base stations. The Angle of Arrival (AoA) method complements these approaches by enabling the determination of the direction of the signal source through the use of antenna arrays. This is particularly effective in urban environments or indoors, where traditional satellite systems perform poorly. However, implementing AoA requires complex signal processing algorithms and appropriate hardware.

A comparative analysis shows that none of the methods considered is a one-size-fits-all solution. Simpler approaches are characterized by low cost and rapid implementation, but they are less accurate. More accurate methods, in turn, require more complex infrastructure and greater computational resources. In this regard, the most promising direction is the use of hybrid positioning systems, which combine the advantages of various methods and allow for adaptation to changing environmental conditions.

The practical application of such approaches encompasses tasks related to territorial monitoring, autonomous navigation, logistics, as well as security and defense systems. Particular attention should be paid to integration with inertial navigation systems and satellite technologies, which helps to improve the overall reliability of the system.

References

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