Artificial Intelligence Application for Unmanned Aerial Vehicle Navigation

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Abstract—**This paper analyzes the use of artificial intelligence technology for autonomous control of an unmanned aerial vehicle. The remote control in difficult conditions limits the capabilities of the unmanned aerial vehicle and reduces the efficiency of the entire system. Therefore, an urgent task is the autonomous navigation of an unmanned aerial vehicle using artificial intelligence technology. In this case, the aircraft can perform tasks depending on the variability of external factors. Artificial intelligence in the autonomous control of an unmanned aerial vehicle plays an important role in ensuring the characteristics of human control. The paper explores several artificial intelligence approaches for autonomous navigation of an unmanned aerial vehicle: mathematical optimization, learning programs. Various characteristics, types, models of navigation are analyzed. The equation for the errors of the inertial navigation system in the normal earth's coordinate system is analyzed.**

Keywords—Unmanned Aerial Vehicle; autonomous navigation; artificial intelligence; navigation models.

I. Introduction

It is known that unmanned aerial vehicles (UAVs) cannot perform their tasks optimally due to reliance on human control and limitations of radio communications. Therefore, autonomous UAV navigation plays an important role in achieving an optimal result. Various methods of localization, mapping and detection methods are used to achieve autonomous navigation. Many works [1-5] are devoted to these methods.

Up to now, the various navigation methods have been proposed: inertial navigation, satellite navigation and observation-based navigation. However, depending on the task, it is necessary to choose the optimal technology for UAV autonomous navigation. One of the effective ways is the Artificial Intelligence (AI) technology, which is widely used in the field of engineering research. AI can detect anomalies and predict the potential of scenarios, respond to changing situations, study complex problems associated with huge amounts of data, and find regularities that a human might ignore. It can analyze and use external factors to improve the maneuvering of the UAV.

AI control technologies are used to increase the autonomy of the UAV to the level of self-management. While there is no universal consensus on how to define or measure an intelligent system, there are several characteristics that an intelligent controller possesses: adaptability, learning ability, non-linearity, autonomous character interpretation, and goal-directedness. In the case of AI-assisted UAV flight, the controller output is determined using an input sensor to create an internal representation (recognition) of the environment. In this they differ from UAVs, where pre-established mathematical models are used [6].

II. UAV Navigation Model

There are many different types of UAVs for military and civilian applications. UAVs are often classified according to characteristics related to shape, flight range, maximum takeoff weight and payload. The payload may include cameras, sensors, mobile phones and bases, cellular assistance stations. The larger the payload, the more equipment, and accessories can be carried.

UAV navigation can be divided into four categories according to application: outdoor navigation, indoor navigation, search and rescue navigation, and wireless network navigation, as shown in fig. 1. External navigation includes surveillance, delivery of goods, target tracking, and crowd monitoring. Indoor navigation includes indoor mapping, production automation, and indoor surveillance. In addition, UAV navigation can be categorized by navigation parameters: inertia navigation, signal navigation, and surveillance navigation. For the inertial navigation, UAVs use gyroscopes, accelerometers, and altimeters to control the onboard flight controller. UAVs use GPS modules and a remote radio head in the case of cellular communications for signal-based navigation, and cameras for visual navigation.

At first, the altitude and horizon controllers receive signals from these sensors and the pitch and yaw controllers depending on the trajectory. Then the pitch and yaw controllers control the elevators and maneuvering ailerons of the UAV depending on the signals from these sensors, as shown in Fig. 2 [7].

The planned path of the UAV during autonomous flight is carried out using various methods of artificial intelligence: optimization-based approaches or learning-based approaches. The UAV flies autonomously [7] using various artificial intelligence methods: optimization-based approaches or learning-based approaches.

Optimization-based approaches include:

- particle swarm optimization;

- ant colony optimization;
- genetic algorithm;
- simulated annealing;
- pigeon-inspired optimization;
- cuckoo search algorithm;
- dijkstra and A* algorithm;
- differential evolution;
- grey-wolf optimizer;
- miscellaneous algorithms.

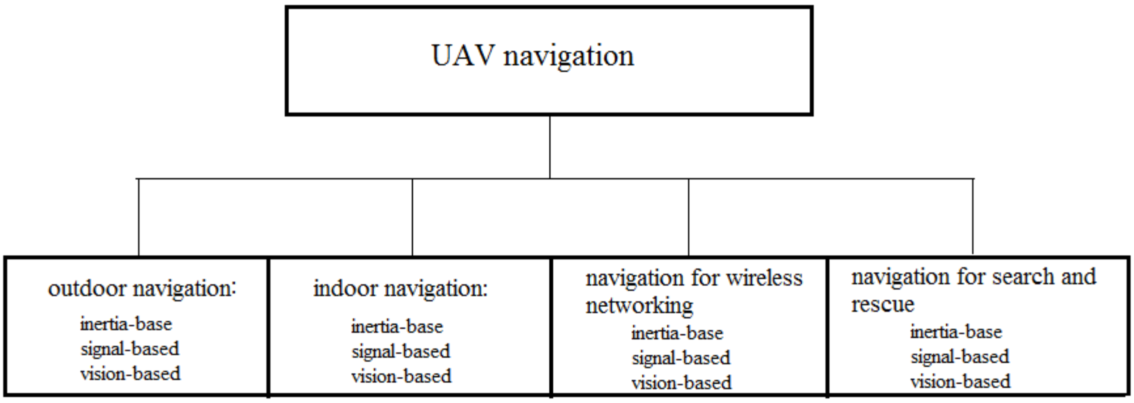

Figure 1. UAV navigation architecture

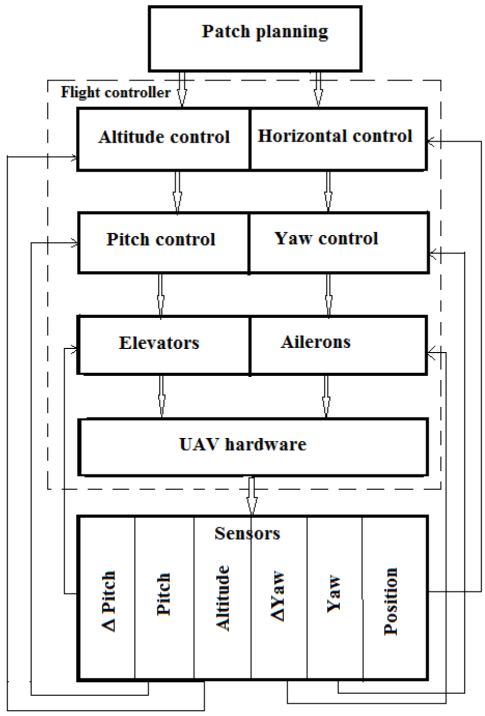

Figure 2. UAV navigation system model

Methods and technologies based on mathematical optimization cover traditional mathematical algorithms for solving AI problems. These algorithms make it possible to achieve near-optimal solutions for any given non-deterministic polynomial complex problem. However, these algorithms are quite difficult in terms of characteristics such as time and coordinates [8]. Let considered some of these approaches.

Particle swarm optimization determines the movement of a particle depending on its current position and speed. Particle speed continues to update based on the optimal position vector. The swarm optimization reaches its optimum position when it reaches its target or at the lowest possible error. In navigation, the swarm optimization treats the UAV as particles and controls their movement in 3D space.

Regarding autonomous UAV navigation, an ant colony optimization based solution for multiple colonies has been proposed, avoiding the complexities of 3D space. The multiplicity of ant colony optimization particles overcomes the problem of premature convergence caused by a single colony. Initially, the UAV navigation problem was formulated as a traveling salesman problem, and then as a multi-part problem when a group of UAVs were looking for the best routes to their destination.

Genetic algorithm is a stochastic optimization algorithm that starts with a population of randomly generated chromosomes known as a start population. Each gene on a chromosome is a series of numerical numbers. Each chromosome in this study reflects the trajectory of the UAV, which is constrained by the dynamics of the UAV. Genetic operations such as crossbreeding, mutation, selection, insertion and deletion will periodically change the population in each generation. The goal of this procedure is to decrease the fitness function as much as possible by identifying a chromosome with a near minimum fitness value.

Simulated annealing is an approximation approach describing a continuous process that converges to a global minimum. For example, let consider a continuous process of heating and cooling metals. When a metal is heated, the atoms vibrate and change configuration with minimal energy. After that, the metal is slowly cooled to provide the minimum configuration energy. The simulated annealing algorithm imitates the same process to obtain a global minimum for complex problems with a polynomial estimate of the time spent in running the algorithm.

III. UAV INTEGRATED NAVIGATION SYSTEM

An integrated navigation system should carry out joint processing of information from a strapdown inertial navigation system, a satellite navigation device and a radio engineering system for measuring altitude and velocity components. At the same time, the main task solved by the integrated navigation system is the development of reliable navigation information for the UAV control system with the required errors and dynamic characteristics.

Inertial sensors for primary information, which are part of the block of sensitive elements of the strapdown inertial navigation system:

- a three-axis accelerometer unit that measures the parameters of the linear motion of an object relative to inertial space (apparent acceleration $\vec{a}_{k1}$);
- three uniaxial laser gyroscopes that measure the parameters of the angular motion of an object relative to inertial space (angular velocity $\vec{\omega}_1$).

The most significant components that determine instrumental errors are:

- offset of the zero signal;
- error of the scale conversion factor;
- non-orthogonality of the measuring axes of the sensors;
- casual care.

The inertial navigation system is the main meter of trajectory motion and orientation parameters in the integrated navigation system and provides continuous calculation and output to the user (in the UAV control system) of the required navigation information.

The fundamental strategy for implementing simulated annealing algorithm is to select random points in the vicinity of the current best point and quantify the cost functions. Then, the UAVs move from one point to another, comparing the values of the current and next point. Note, that simulated annealing optimization is a time-consuming process.

<u>Learning-based approaches</u> cover traditional models based on AI algorithms. These algorithms can achieve near-optimal results for any given non-deterministic polynomial-time hard problem with very low complexity.

The following are the most widely used learning-based AI approaches for UAV navigation:

- reinforcement learning;
- deep reinforcement learning: Markov decision process and partially observable Markov decision process;
- asynchronous advantage actor-critic;
- deep learning;
- miscellaneous learning algorithms.

When complexing an inertial navigation system, a satellite navigation device and a radio engineering system for measuring altitude and velocity components, an error model of the integrated navigation system is adopted, including the errors of these systems, as the equations of state of the filter for joint information processing. Taking into account the equations of inertial navigation, there are the following equations (1) for the errors of the inertial navigation system in the normal terrestrial coordinate system (without taking into account nonlinear components and insignificant components).

The satellite navigation device outputs according to a standard protocol with a frequency of 1 Hz, transmits transport information about object's coordinates and speed, parameters for linking information to the time of their calculation (time marker), the estimated value of the standard deviation, coordinate errors, signs and reliability of data.

Studies of the characteristics of a satellite navigation device as part of a ground testing complex make it possible to form the following error model of navigation information:

- systematic component of coordinate error $2\sigma \leq 2$ m;
- systematic component of the height error $2\sigma \leq 12$ m;
- random component of coordinate error $2\sigma \leq 1$ m;
- systematic component of the speed error $2\sigma \leq 0{,}05$ m/sec;
- random component of speed error $2\sigma \leq 0{,}03$ m/sec.

The random component of the satellite navigation device according to the projections of the velocity vector has the character of "white" noise with a sampling period of 1 sec. The random component of the satellite navigation device in terms of location coordinates corresponds to the output of 2nd order shaping filter with a time constant ≈ 30 sec.

$$\begin{cases} \Delta(d\vec{R}_g / dt) = \Delta\vec{V} \\ \Delta(d\vec{V}_g / dt) = -\vec{\Psi} \times A_{g1}\vec{a}_{k1} + A_{g1}\Delta\vec{a}_{k1} + \Delta\vec{g}_g - 2\Omega_g \times \Delta\vec{V}_g \\ d\vec{\Psi} / dt = -\vec{\Omega}_g \times \vec{\Psi} + A_{g1}\Delta\vec{\omega}_1 \end{cases} \quad (1)$$

Here:

$\Delta\vec{R}_g$, $\Delta\vec{V}_g$, $\vec{\Psi}$ are the position, speed and orientation error vectors;

Ag1 is the orientation matrix of the normal earth coordinate system with respect to the bound;

$\Delta\vec{g}_g$ is the gravity error;

Ωg is the angular velocity of the Earth's rotation;

$\vec{a}_{k1}$, $\Delta\vec{\omega}_1$ are the instrumental errors of accelerometers and gyroscopes.

In addition to the above statistical characteristics, the satellite navigation device has a delay in issuing navigation information about the speed of movement, which is about 1.1 sec.

IV. Conclusion

This paper analyzes the use of artificial intelligence technology for autonomous control of an UAV. Artificial intelligence in the autonomous control of UAV plays an important role in ensuring the characteristics of human control. The paper explores several artificial intelligence approaches for autonomous navigation of UAV: mathematical optimization and learning programs. Various characteristics, types, models of navigation are analyzed. The equation for the errors of the inertial navigation system in the normal earth's coordinate system is investigated. The UAV autonomous AI navigation has provided greater flexibility and improved performance in complex dynamic environments.

This review summarizes the UAV navigation system and application-based classification. In terms of methods based on optimization and learning, the fundamentals, operating principles and critical features of numerous artificial intelligence algorithms used for autonomous UAV navigation have been described. Various optimization-based algorithms have been analyzed. These methods have been modified according to their requirements in order to achieve optimal results. The training algorithms were classified and analyzed.

Various neural networks, learning parameters, and decision processes were used to complete their tasks. After analyzing all approaches to artificial intelligence, the comparative studies were presented comparing all methods from the same point of view.

Thus, various resources and data related to UAV autonomous navigation and artificial intelligence are available for further research and development. AI can be computationally expensive, but it improves the overall performance of the UAV in terms of important parameters such as power consumption, flight time and communication latency in a complex dynamic environment for any tasks.

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