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Unmanned Aerial Vehicles: A Literature Review

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Abstract: In recent years, Unmanned Aerial Vehicles (UAVs) have grown and increased in applications because of computational simplicity and adaptive control capacity with strong support from both civilian and military sectors. The applications of UAVs in various military, commercial and civilian areas have led to sustainable results. The application areas include but are not limited to oil & gas, cargo transport, geographic mapping, aerial photography, health care, and disaster management. The success of the UAV application missions is completely dependent on the accuracy in control provided by the flight controllers. Thus, there is a need for accurate, robust, and adaptive flight controllers. UAV dynamics modeling and identification and control of these vehicles are still major active areas of research and development. They pose severe challenges due to the vehicle's complex design, inherently nonlinear, and time-varying dynamics. The main goal of this paper is to identify the past research trends and recent improvements in UAVs. Furthermore, this paper discusses a comprehensive literature review according to the optimized objectives, solution techniques, and applications of UAVs such as Cargo Transport, Disaster Management, etc. According to the literature review, aerial photography is one of the applications of smart UAVs. The reliability of image matching across multiple camera perspectives, angles, and positions encourages computer vision approaches for UAV navigation, opening the way for future researchers to develop vision applications. This article presents a comprehensive literature review discussing the importance of UAV applications related to cost-effectiveness and versatility. Furthermore, a detailed survey of system modeling identification and control techniques is presented.

Keywords: unmanned aerial vehicles, drones, applications, identification, modeling, control.

无人机：文献综述

摘要：近年来，无人机由于计算简单、自适应控制能力强，得到了民用和军用部门的大力支持，在应用领域不断发展壮大。无人机在各种军事、商业和民用领域的应用取得了可持续的成果。应用领域包括但不限于石油和天然气、货物运输、地理测绘、航空摄影、医疗保健和灾害管理。无人机应用任务的成功完全取决于飞行控制器提供的控制精度。因此，需要精确、稳健和自适应的飞行控制器。无人驾驶飞行器动力学建模以及这些飞行器的识别和控制仍然是研究和开发的主要活跃领域。由于车辆的复杂设计、固有的非线性和时变动力学，它们带来了严峻的挑战。本文的主要目标是确定无人驾驶飞行器过去的研究趋势和最近的改进。此外，本文根据无人飞行器的优化目标、解决方案技术和应用，如货运、灾害管理等进行了全面的文献综述。根据文献综述，航空摄影是智能无人机的应用之一。飞行器。跨多个相机视角、角度和位置的图像匹配的可靠性鼓励了无人机导航的计算机视觉方法，为未来研究人员开发视觉应用开辟了道路。本文提供了全面的文献综述，讨论了与成本效益和多功能性相关的无人机应用的重要性。此外，还详细介绍了系统建模识别和控制技术。

关键词：无人机、无人机、应用、识别、建模、控制。

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1. Introduction

Unmanned Aerial Vehicles (UAVs) have gained significant importance in the recent decade with their cost-effectiveness and versatility. They are increasingly employed in situations where the risks to human pilots are high. UAVs offer new and cost-effective solutions not previously attainable due to the advancement in the technical know-how of the different components like batteries, sensors, etc. However, due to the variety and importance of missions, sizes, and payloads that UAVs carry, the design of the flight control system (the brain of the UAV) still poses a significant challenge to the design experts. The success of the UAVs is entirely dependent on the accuracy in control provided by the flight controllers. The issues related to uncertainty, non-linearity, and complexity need to be appropriately addressed in the design of the flight controllers. Recently UAVs have proven to be one of the most useful tools for performing missions in hazardous environments, such as operations in nuclear power plants and Mars explorations. The use of UAVs is rapidly increasing day by day, ranging from civilian to military applications. This broad application range has become feasible due to the cost of high-power density batteries, wireless network devices, and miniaturized equipment has become cheaper. Hence considerable research is currently directed toward UAVs using suitable flight controllers, also known as autopilots.

2. UAV Applications

The literature survey focus of this paper is twofold. Firstly, to discuss the applications of UAVs centered on the following areas: Cargo Transport, Disaster Management, Aerial Photography, and Geographic Mapping. Secondly, to explain the identification control of UAVs.

2.1. Cargo Transport Level

The concept of cooperative load transportation using three quadrotors is clarified in [1]. This paper presents a method of carrying a heavy load suspended by cables utilizing a team of UAVs than a single vehicle. They described a nonlinear control strategy based on feedback linearization used to guide each aircraft in positioning and trajectory tracking tasks while keeping the formation stable, compensating for the disturbance caused by the load and the cross effect of cable tensions. The importance of delivery drones supporting the realization of industry 4.0, especially in the E-commerce industry, is emphasized in [2]. The paper presents a method of using a delivery drone with a single wire pulley mechanical system and detects landing and maximum phase without additional sensor requirements. The experimental results confirm that 9 out of 10 trials passed the test of dropping goods and proved the reliability and durability of a payload capacity of 3.8 kilograms. Workflow or algorithm flows incorporated with possible solutions during the implementation process and steps involved in automatic and safety workflows are clearly explained in this paper. Enabling an intelligent and adaptive multi-UAV system using a genetic-fuzzy control methodology to transport a load attached with cables to a given target location was described in detail by [3]. The economic and operational value of using drones to transport vaccines is discussed in detail by [4]. This paper focuses on the HERMES-generated simulation model to assess the impact of using an unmanned aerial system (UAS) for routine vaccine distribution under various circumstances reflecting variations in geography, population, road conditions, and vaccine schedules. The authors identified the UAV payload and UAS costs necessary for a UAS to be favorable over a traditional multi-tiered land transport system (TMLTS). In [5], the importance of UAVs to transport blood products in times of critical needs is shared. This paper aims to outline the demand, feasibility, and risks of using small UAVs to transport blood and pharmaceutical products to critical access hospitals, mass casualty scenes, and offshore vessels in critical demand. They concluded that unmanned airborne package delivery systems would soon be a financially and technically feasible mode of transport for the civilian sector. A helicopter unmanned aerial vehicle for stabilizing a range of objects in landed and hovering conditions is introduced and demonstrated [6]. This paper discusses the challenges in capturing the object due to aerodynamic disturbances encountered in low-altitude flights. The effect of dynamic load disturbances introduced by instantaneously increased payload mass and how those affect helicopters and quadrotors under Proportional-Integral-Derivative flight control was clearly explained by [7]. One of the factors that worsened the West Africa Ebola outbreak was the poor roads that delayed the transport of biological samples, and the solution for this problem was discussed in detail by [8] about the use of UAVs during the medical emergency period. This paper studies the timelines for drones and car-transported blood cultures. The results of this small study are consistent with the possibility of using UAVs to transport microbiological samples. However, the use of drones for medical sample transport is not yet settled, but the use of drones will impact the cost of vaccines.

In [9], a scalable hard- and software system for the flexible and automated in-house transportation of small load carriers with autonomous UAVs is developed. Besides, a tracking system is suitable for the basic tracking of a UAV during the flight and for the precise monitoring required to pick up and set down the cargo. The prescribed system is based on a newly developed cargo drone, including a lightweight and energy-efficient load-handling device. The challenges involved in the current loading device reduce the payload capacity, and the future scope of this project, focusing on optimal load handling clearly explained in this paper. James T. Hing et al. [10] suggested chase view methods to increase the situational awareness of UAV pilots and decrease the potential for crashes, thereby decreasing the chances of property damage or harm to civilians. The authors feel a more significant impact for a chase viewpoint can be found when using rotorcraft and for situations where accurate positioning and orienting the aircraft is essential. This paper stresses the importance of training UAE pilots and augmenting their performance to minimize accidents. Analysis of the current situation and development trend of the international cargo UAVs market has been explained in detail by [11]. This paper presents the transition from a stage of studying technologies to commercial operation and implementation of finished products. The impact of UAVs on air cargo transportation under various situations and comparing the advantages of UAVs with the present cargo transportation are studied [12]. The authors added that the importance of replacing current human-crewed aircraft with UAVs would be one of the solutions to reduce pollutant emissions in the future. Challenges of Transport with UAVs in Future Smart Cities were described in detail by [13], and the objective of this paper is twofold. First, list and discuss our key visions of aerial UAV transport in future smart cities. Second, outline the key challenges and research directions for agents: Design of fully autonomous UAVs, Explanation of the UAVs' behavior when they are part of a complex system, Security and authentication of UAVs, Verifying and validating the UAVs' behavior.

Daniel Mellinger et al. [14] addressed the mechanics, design, estimation & control for aerial grasping and presented the design of several lightweights, low-complexity grippers that allow quadrotors to grasp and perch on branches or beams and pick up and transport payloads. The applications, deployment optimization, and security/privacy challenges for using UAVs in Intelligent Transport System (ITS) scenarios are presented and studied in [15]. Doppler-based navigation procedure that allows for automatic landing approaches is explained in detail in [16]. In the paper, the authors evaluated the impact of the UAV trajectory, the direction of the landing approach relative to radio beacons, and the temporal window of the signal analysis on the accuracy of the developed procedure. They indicated that the navigation error near the destination landing point is less than 1 m. In [17], an algorithm that combines optimal trajectory design and resource allocation scheme for multiple ground terminals with UAV arbitrary flight using the successive convex optimization and Lagrange duality is developed. The simulation results proved an increase in energy efficiency compared with the scheme without optimizing trajectory. Finally, the conceptual design of a fixed-wing battery-powered UAV, designed to carry an Automated External Defibrillator (AED) or any 1.5 kg of payload, was presented by [18].

2.2. Disaster Management

The evaluation of the forest fire detection model using video captured by UAVs is presented in [19]. This paper, to enhance the detection rate, includes forest fire-colored pixels' extraction using chromatic features; and foreground extraction using an optical flow algorithm to examine the motion characteristic of a forest fire. The results show that the forest fires are pointed out effectively using our particular model with a high detection rate of 96.09% and a low false alarm rate of 3.91%. Xing et al. [20] proposed a recursive least-squares estimator-based horizontal wind estimation approach for estimating the horizontal wind for forest fire monitoring using multiple UAVs and the airspeed measured without additional flow sensors. A distributed control framework designed for a team of UAVs that can closely monitor a wildfire in open space and precisely track its development is reported in detail by [21]. Saha et al. [22] proposed a low-cost, fully autonomous Global Positioning System-based Quadcopter for disaster management. Milan et al. [23] identified the main disaster management applications of UAV networks and discussed open research issues related to the use of UAVs. The authors supported that the UAV network, in conjunction with WSN and cellular network, was a promising future technology for applications in disaster management. Control of an _nscrewed vehicle with a synthetic vision system intended to search for people, machinery, and other objects in wildfire has been specified by [24] and proposed methods for selecting UAV trajectory and altitude when searching for ground objects. An overall architecture for drone hardware that enables fast exploration of GPS-denied environments and practical methods for victim detection is suggested [25]. They employed DJI Matrice 100 and utilized Hokuyo lidar for global mapping and Intel RealSense for local mapping. The final results show that fusing these sensors can assist rescuers in finding victims of natural disasters in unknown environments, and the detection system is insensitive to illumination change. Khaled et al. [26] reviewed the importance of using a team of UAVs-UGVs for cooperative forest monitoring and fire detection and avoiding the limited running time and limited payload of using UAVs alone. They added that the communication efforts between the UAVs and the ground station decreased due to pairing with UGVs and increased the efficiency of UAVs. A multi-UAV-based wildfire monitoring algorithm to estimate the spread rate and, therefore, further assess fire growth through fire front contour estimation is proposed in [27]. The recommended algorithm allows for convergent estimation with reasonable accuracy. The effectiveness of the algorithm was demonstrated in an independent fire simulation environment. Adams et al. [28] examined the use of _nscrewed aerial vehicles to capture imagery at the neighborhood and individual building level for use in post-disaster field studies. In this paper, the authors showed the sample post-tornado imagery of building damage and demonstrated the order of magnitude improvement in imagery resolution compared to typical post-disaster aerial photography. Lee et al. [29] employed DJI Matrice 100 and Hokuyo Lidar for global mapping and Intel RealSense for local mapping. The proposed method assists rescuers in finding victims of natural disasters in unknown environments, and the detection system is insensitive to illumination change. Syed et al. [30] proposed the Motion Estimation technique for obstacle detection problems for collision avoidance using a single camera. Rothman et al. [31] demonstrated some practical experiences of utilizing UAV-Based mapping in volcano eruption post-disaster for rapid assessment and reconstruction. Zhao et al. [32] established a unified framework of UAV-assisted emergency networks in disasters. Firstly, the trajectory and scheduling of UAVs are optimized to provide wireless connections for ground devices. Next transceiver design of UAV and ground multihop D2D establishment was studied to extend the UAV coverage scope, and also a multihop relaying scheme was examined to exchange the information. Yim et al. [33] proposed the low-power image stitching management (LPISM) that can reduce the power consumption of the UAVs that take images for image stitching in the disaster management system. Tanzi et al. [34] shared the potential of UAVs in assisting in different humanitarian relief scenarios and possible issues in such situations. They presented a typical use case based on the new detection and observation abilities that UAVs can bring to rescue teams. UAV-borne data used for supporting rapid mapping activities in combination with high-resolution airborne Interferometric Synthetic Aperture Radar (IFSAR) data is described in detail by [35]. A real disaster instance from 2013, in conjunction with the Mount Sinabung eruption, Northern Sumatra, Indonesia, is the benchmark test for the rapid mapping activities presented in this paper. De et al. [36] discussed the advantages of new UAV technology to current technology that employs fire retardant chemicals in terms of environmental protection and the cost-effectiveness of the present technology. Saeed et al. [37] explored a hybrid approach to mosaic an overview image of the area of interest given a set of individual images captured by UAVs flying at low altitudes and discussed its challenges. Hua et al. [38] researched a power-efficient unmanned aerial vehicle (UAV) based wireless sensor network (WSN), where the UAV is used as a flying base station to communicate with the sensor nodes (SNs) with a flexible movement path. The authors aimed to minimize the total power consumption of the UAV with a guarantee of the required transmission rate of SNs by jointly optimizing the SNs-UAV scheduling scheme, power allocation strategy, and flight trajectory of the UAV. Saikin et al. [39] analyzed an approach for accurately dropping a relatively large amount of fire retardant, water, or some other extinguishing agent onto a wildfire from an autonomous unmanned aerial vehicle (UAV) close to the epicenter of the fire. The proposed approach involves a risky maneuver outside the UAV's safe flight envelope. Ejaz et al. [40] showed an overview of different platforms (UAVs-based, IoT-based, and IoT, coupled with UAVs) for disaster management and demonstrated an energy-efficient task scheduling scheme for data collection by UAVs from the ground IoT network and thereby minimizing power consumption.

2.3. Aerial Photography

Gurtner et al. [41] investigated the use of fish-eye lenses to overcome field-of-view (FOV) issues for highly agile UAV platforms susceptible to turbulence and explained the benefits of a FOV in terms of the large observation area and less aircraft weight. The effectiveness of the image matching algorithms, Scale-Invariant Feature Transform (SIFT) and Speeded Up Robust Features (SURF) over a set of aerial images from an Unmanned Aerial Vehicle (UAV) is evaluated and compared [42]. Experimental results show the robustness of image matching over different camera perspectives, angles, and positions, encouraging the use of computer vision methods for UAV navigation. Sebastian et al. [43] presented the application of an Unmanned Aerial Vehicle (UAV) for monitoring soil erosion in Morocco. The authors successfully performed the data acquisition at multiple scales, closing the gap between field and satellite image scales with the chosen fixed-wing UAV. Cheng et al. [44] analyzed the key technology of low-altitude UAV aerial photographic systems in island topographic mapping, including exposure control of auto excursion angle rectification and exposure point calculated by differential GPS and the flight plan considering the characteristic of the island. Ahmad [45] investigated the capability of UAVs in producing a digital map and assessed the accuracy of mapping using UAVs. This paper uses a lightweight fixed-wing UAV as a platform and a high-resolution digital camera to acquire aerial digital images at low altitudes. Braga et al. [46] proposed an image matching system using aerial images captured in flight time and geo-referenced aerial photographs to estimate the Unmanned Aerial Vehicle (UAV) position in a situation of Global Navigation Satellite System (GNSS) failure. An Artificial Neural Network (ANN) performs the edge detection process with an optimal architecture. The image matching system was tested on real flight-test data, and promising results were obtained. Yang [47] designed a UAV intelligent aerial photography system to improve the system stability and reliability of UAV aerial photography and to capture high-quality aerial images. Siyuan et al. [48] presented the geometric and kinematic features of a landslide in Mabian, Sichuan, China, which occurred on 5 May 2018, derived from data from UAV photography and concluded that the UAV-based aerial photography technology provided well-characterized landslides rapidly in a quantitative manner. In [49], the possibility of building an aerial photography system with autonomous capabilities based on the open-source hardware (autopilot flight controller) and software initiative (ground control station software, camera controlling software) is presented. The experimental result shows that the hardware and software presented in this paper are configured to build an unmanned aerial vehicle for the primary platform of autonomous aerial photography. T. Koch et al. [50] investigated the performance of SIFT-based image matching regarding significant differences in image scaling and rotation, as this is usually the case when trying to match images captured from UAVs and airplanes.

2.4. Aerial Photography (Continuation)

The feasibility and advantages of mini-UAV-borne LIDAR have been demonstrated by [51], obtained promising results based on the real-measured data, and mentioned the benefits of the mini-UAV-borne Sensei LIDAR. Aside from low cost and high mobility, the system can supply local reference data with a high spatial resolution to revise or calibrate traditional airborne LIDAR data or investigate the plots of interest thoroughly as a means of in-field measurement. Moreover, collecting the high-temporal resolution data efficiently for, e.g., tree foliation monitoring is appropriate. Francesco and Remondino [52] reported the state of the art of UAV for geomatics applications, giving an overview of different UAV platforms, applications, and case studies and showing the latest developments & new perspectives of UAV image processing. Fornace et al. [53] discussed UAVs providing spatially and temporally accurate data critical to understanding the linkages between disease transmission and environmental factors and shared the numerous benefits of UAVs related to public health. A Lucieer et al. [54] studied the first to use an Unmanned Aerial Vehicle (UAV) for mapping moss beds in Antarctica. They used Structure from Motion (SfM) techniques to generate a detailed 3D point cloud of the terrain from overlapping UAV photography Hackney. Clayton [55] outlined the considerations and regulations which must be adhered to when operating UAVs in many situations and showed the example of an aerial survey of pro-glacial push moraines in Iceland to detail a suggested best practice when operating UAVs in challenging and remote locations. F. Remondino et al. [56] discussed UAV photogrammetry's current and future perspectives for mapping and 3D modeling. The authors explained the great advantage of existing UAV systems to quickly deliver high temporal and spatial resolution image information and to allow a rapid response in several critical situations where immediate access to 3D geoformation is crucial. Rokhmana [57] revealed some practical experiences using the Unmanned Aerial Vehicles (UAV) platform based on remote sensing in supporting cos-effective precision agriculture mapping. The UAV platform utilizes the R/C aeromodelling plane as the aerial platform carrying a digital pocket camera as sensor imagery. Yin et al. [58] explained the path planning for unmanned aerial vehicles (UAVs) flying through low-altitude urban environments. They proposed a multi-objective path planning (MOPP) framework to explore a suitable path for a UAV operating in a dynamic urban environment, where safety level is considered in the proposed framework to guarantee the safety of the UAV in addition to travel time. Hodgson et al. [59] conducted a UAV trial that showed that dugongs could be readily detected within images captured using the *ScanEagle* with a digital SLR imaging system and explained the potential advantages of using the UAV to conduct surveys rather than a human-crewed aircraft. An unexpected outcome was that the dugong sighting rate using the imaging system was not affected by sea state, while high sea states are known to decrease sighting rates during manned surveys. The authors concluded that UAV surveys could potentially be conducted in a broader range of wind conditions than manned surveys. Mah and Cryderman [60] described the factors considered when building a UAV mapping system and supported the UAV technology as a better alternative for mapping than full-scale manned aircraft.

5. UAV System Identification

Identification is defined as a tool or an algorithm that builds a mathematical model of a dynamical system from measured data. It is the first stage in the adaptive control design. The system identification problem includes structural and parameter identification. The structure identification stage concerns the order of the system, the degree of coupling, non-linearity, etc. When there is no prior knowledge about a system, the structure identification will be challenging, and the system's structure can be selected by trial and error. When the structure of the model of the system is known, the system identification problem becomes a parameter identification problem. For the system identification of a UAV, the state, output, and measurements equations can be written in a state-space form as

$$\dot{x}(t) = f[x(t), u(t), \theta], x(0) = x_0$$

$$y(t) = h(x(t), u(t)] \tag{1}$$

where the state vector, x is comprised of the linear and angular velocities and Euler angles. The vector, u is the control surface deflections and θ is a vector of parameters that specify the aerodynamic characteristics of the aircraft. The outputs, y are the variables defining the UAV responses. In many practical applications, the structures of and are assumed to be known, and the UAV identification problem is reduced to parameter estimation. Many papers have been published on state-space identification and control of aircraft.

5.1. Classical Identification

Zuniga et al. [61] showed the results of traditional aerodynamic analysis and flexible flight dynamics modeling, including the effects of structural motion for an adjustable wing unmanned aerial vehicle. In addition, they investigated the influence of some design parameters such as wing flexibility, horizontal/vertical tail aerodynamics for aero-elasticity, and flight dynamics of flexible aircraft. A system identification approach for UAVs based on Dependent Gaussian Processes has been presented in detail by [62]. Venkataraman and Seiler [63] presented a system identification procedure for a class of small, rudderless, fixed-wing unmanned aircraft. The procedure was demonstrated on an aircraft with only two aerodynamic control surfaces (called elevons) and one electric motor. A physics-based, first-principles approach is used to obtain the initial model parameters and to design flight tests wherein the longitudinal, and lateral-directional dynamics are exciting. The aircraft is rudderless and introduced a key challenge in model identification. Specifically, the lateral-directional model has more free parameters than can be identified using the elevon excitations alone. This paper uses black-box methods to identify sensitive modes whose damping ratios and natural frequencies change significantly compared with their initial values. Gray-box methods update the stability and control derivatives related to these sensitive modes while retaining the remaining derivatives at their respective initial values. Flight tests were conducted to validate the updated model parameters. Saad et al. [64] assessed ruts and potholes on the road surface using a UAV. The methodology consists of four phases: site reconnaissance and planning, data acquisition, data processing, and result and data analysis. The authors found that low altitude gave a better result than high altitude and demonstrated the capability of multirotor UAV images for rut and pothole extraction. This system provides a detailed and accurate measurement of road ruts and potholes and thus improves the efficiency of road condition monitoring. Araar et al. [65] presented a simple yet efficient approach for identifying a multirotor UAV’s aerodynamic and inertial parameters.

The proposed solution was tested on one of the most popular platforms –the F450 quadrotor from DJI. K.S. Hatamleh and R.Paz [66] presented the results of a simulation-based study of an in-flight model parameter identification method, and the technique can identify unknown inertia parameters of the UAV. They discussed a scheme of estimating an upper bound of the identification error in the input data (or sensor errors). Sadovskis et al. [67] presented the results of a series of experiments devoted to determining the modulation of control signals used by several commercially available UAVs using software-defined radio (SDR). Bauer et al. [68] presented the airbrake’s modeling, system identification, simulation, and flight testing (consisting of a servo motor, a nonlinear mechanism, and the airbrake flap itself) of an unmanned experimental aircraft in the frame of the FLEXOP H2020 EU project. Mario G et al. [69] presented a Matlab/Simulink simulation environment developed at West Virginia University to facilitate the design, testing, and analysis of fault-tolerant control laws for the autonomous operation of unmanned aerial vehicles. They illustrated the versatility and utility of the simulation environment through example simulation results at normal and abnormal flight conditions. Zhou et al. [70] proposed a new nonlinear system identification method in the time domain for a small-scale flybarless unmanned helicopter based on an adaptive differential evolution algorithm. The validity of the identified model was confirmed by comparing the output of the mathematical model with the actual flight response under the same control input.

Koehl et al. [71] explained the nonlinear modeling of a new Gun Launched MAV concept using two-bladed coaxial contra-rotating rotors for the hover-flight case.

5.2. Intelligent Identification

Jiang et al. [72] proposed a behavior-based intelligent UAV identification and security supervision. In this paper, the authors explained the concept based on location tracking and flying data acquisition provided by the airborne black box, the UAV’s behavioral data collected in real-time. Yang et al. [73] proposed a system identification method based on a genetic algorithm for the quadrotor model parameter identification. The authors used the real flight input and output information, and the genetic algorithm identified the model parameters. The results proved that the identified parameters with the genetic algorithm have acceptable accuracy.

Peng et al. [74] used the differential evolution (DE) intelligent algorithm for a state-space model identification for an Extra-atmospheric vehicle. The DE method has the advantage of choosing the initial point randomly. They showed that the new guidance law significantly improves performance over the commonly used classical proportional navigation law. The simulation results proved that the system achieves a top-level control performance. Rimal et al. [75] considered the simulation of identification of a nonlinear system dynamic using an artificial neural networks approach. They developed a neural network model of the plant that needs control. Dynamical model identification of a small-scale unmanned helicopter based on an integrated approach was discussed in detail by [76]. The integrated approach has two parts: the parameter identification process and the wind tunnel test. The parameter identification uses a hybrid algorithm Prediction Error Minimization-Improved Artificial Bee Colony (PEM-IABC) to optimize the unknown dynamical parameters of the Trex-600 small-scale unmanned helicopter and the wind tunnel test conducted to modify the main rotor time constant of the identified model. The proposed PEM-IABC has higher identified accuracy when compared with the Genetic Algorithm, Artificial Bee Colony, and Chaotic Artificial Bee Colony. With the three improved strategies, the robustness and search efficiency of the hybrid algorithm Prediction Error Minimization-Improved Artificial Bee Colony were enhanced. Yue et al. [77] designed an intelligent acquisition system for UAVs based on edge computing used in the transmission line inspection. The system includes the front-end edge computing detection module based on the SSD (Single Shot Multibox Detector) algorithm and a PTZ camera control module.

Kim et al. [78] presented a crack identification strategy that combines hybrid image processing with UAV technology. The proposed system has successfully measured cracks thicker than 0.1 mm with a maximum length estimation error of 7.3%.

6. UAV Control Techniques

To control a dynamic system means to regulate its physical variables to specific values. There are two approaches to UAV controller design. The first method is based on the idea that an acceptable mathematical model of the dynamic system is available. The other method is based on the fact that the dynamic system model is uncertain or unavailable. This latter approach is termed intelligent control.

6.1. Classical Control

Mustapa [79] discussed real-time application altitude control of a quadcopter unmanned aerial vehicle: the Newton-Euler equation was used to derive the model of the system, and the model characteristic was analyzed. Saengphet et al. [80] presented a methodology to implement a flight control system based on PID control design for the PX4 autopilot system. The method's objective is to find the optimal controller gains on the same control structure of PX4 flight stack software without iterative controller tuning. Abdul Sattar et al. [81] investigated the identification of multi-segment unmanned aerial vehicle (SUAV) via aileron (two segments) instead of the conventional control. Only the roll axis is considered in this paper. It represents the most sensitive axis to atmospheric disturbances. The multi-segment aileron is configured as a multi-input and single-output system, and each segment is regarded as a control input.

The frequency response of the system and the corresponding transfer functions are determined by conducting experiments in a wind tunnel. The experimental results and the mathematical models indicated nonlinear property for the interaction between various aileron surfaces. They proposed a model that alleviates the labor-intensive mathematical modeling process and has the inherent capability to handle system noise and deal with biases in in-flight data. Neamtu et al. [82] presented a paper on an Unmanned Aerial Vehicle (UAV) based on a miniature helicopter. The UAV platform consists of sensors that sense the helicopter's movement, wireless communication, and a PC-based controller. The authors described the model identification for the yaw movement based on the identified model. An incremental PID controller was designed and implemented with very good results. AI-Radaideh et al. [83] illustrated the development and building of a fully functioning test-bed UAV platform. The test-bed includes enhanced hardware in the loop simulation “HILS” system to facilitate the development of the flight control system (FCS), and finally, trajectory following results demonstrated. Abdulrahman [84] concentrated on the optimal control and state estimation for the unmanned aerial vehicle under the combination of random vibration noise and uncertainty collected by the sensors. The author discussed the effects of random vibrations at various stages of a large-scale flight that are a priori uncertain and require the inclusion of identification algorithms in the optimal control loop. The results showed that the method used in the analysis had been able to provide accurate estimations. Ahmed and Pota [85] presented the attitude control of a Rotary wing Unmanned Aerial Vehicle (RUAV), including a dynamic compensation method. The proposed controller takes advantage of the two-level hierarchal control schemes while mitigating the presence of the fly bar. Alkowatly et al. [86] presented the mathematical development of a body-centric nonlinear dynamic model of a quadrotor UAV suitable for developing biologically inspired navigation strategies. In this paper, the nonlinear model parameters are initially approximated by analytical methods and then further refined using system identification methods. Grymin et al. [87] presented an approach for obtaining dynamically feasible reference trajectories and feedback controllers for a small unmanned aerial vehicle (UAV) based on an aerodynamic model derived from flight tests.

6.2. Intelligent Control

Rosales et al. [88] proposed a novel adaptive PID controller for trajectory-tracking tasks, and the developed PID controller follows an adaptive neural technique. The Lyapunov discrete theory verifies its stability. Abbaspour et al. [89] developed a new online strategy to detect faults in sensors and actuators in UAV systems. In this design, the Neural Network (NN) weighing parameters were updated using the Extended Kalman Filter (KPF) and tested on the model of a small UAV named WVU YF-22 via MATLAB SIMULINK. Ferdaus et al. [90] considered the realistic outdoor perturbations and uncertainties related to the controllability of a quadcopter. The authors discussed the solution using model-free data-driven system identification, and the accuracy was high using the fuzzy clustering model. Kuroki et al. [91] discussed the UAV navigation by an expert system for contaminant mapping with a genetic algorithm approach. Muliadi et al. [92] propose a comparative method to assess the performance of an artificial neural network’s direct inverse control (DICANN) with the PID control system. The comparison served as an analysis tool to evaluate the advantages of DIC-ANN over conventional control methods for a UAV attitude controller. Liu et al. [93] jointly designed the trajectory design and power control of multiple UAVs for maintaining a high quality of downlink service. Sarotama et al. [94] derived the System Identification and Control of Dynamic MIMO UAV nonlinear system based on the collection of input-output data sampled from test flights using an artificial neural network and discussed its advantages compared to physics and mathematics methods. Abbaspour et al. [95] introduced a new algorithm to detect UAV fault data injection attacks. In this paper, an adaptive neural network is used to detect the injected faults in sensors of a UAV, and an embedded Kalman filter (EKF) is used for online tuning of neural network weights; this online tuning makes the attack detection faster and more accurate. Chen et al. [96] investigated the problem of joint caching and resourced allocation for a network of cache-enabled unmanned aerial vehicles (UAVs) that service wireless ground users over the LTE licensed and unlicensed bands. Ozgur Koray Sahingoz [97] presented a paper on how a flyable trajectory can be constructed for multi-UAV systems using a Genetic Algorithm (GA) in a known environment and at a constant altitude. In this paper, firstly, a feasible path is calculated using a parallel GA, and then the path is smoothed by using Bezier curves to convert it to flyable. Dierks and Jagannathan [98] developed a novel framework for leader-follower formation control for controlling multiple quadrotors unmanned aerial vehicles (UAVs) based on spherical coordinates. In this paper, the control objective for the follower UAV tracks its leader at a desired- separation, angle of incidence, and bearing by using an auxiliary velocity control. Then, a novel neural network (NN) control law for the dynamical system is introduced to learn the full dynamics of the UAV, including unmodeled dynamics like aerodynamic friction. Lee et al. [99] presented an unmanned quadrotor flight controller with advantages in robust structure and versatile missions by implementing the dynamic model inversion technique with an adaptive neural network. Razmi et al. [100] suggested a novel method for the position and attitude tracking control of a quadrotor UAV in the presence of parametric uncertainties and external disturbance. The proposed method combines a neural network adaptive scheme with sliding mode control.

7. Conclusion

Unmanned aerial vehicles are currently being developed with incredibly versatile technology, always exploring innovative methods to deliver good service. This paper presents a detailed systematic literature review on context classification, past research trends, and recent Unmanned Aerial Vehicles (UAVs) advancements. The study also covers many aspects of optimum objectives, possible solutions, and applications of UAVs. UAVs are now widely used in aerial photography to capture images on a camera from various angles and positions. Computer vision & AI pollinators are a wonder in Aerial precision photography. UAVs will play a significant role in computer vision and artificial intelligence in the future by combining vision techniques such as geo-referencing, mosaicking, classification algorithms, and collecting high-resolution images. The key research challenges in Aerial precision photography raise the opportunities and further pave the way for researchers to develop future UAV applications.

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