drones

Editorial

Editorial of Special Issue "Advances in UAV Detection, Classification and Tracking"

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This is an editorial for a Special Issue of *Drones* titled "Advances in UAV Detection, Classification and Tracking". The main aim of this Special Issue is to promote global collaboration and knowledge transfer between researchers. This Special Issue also includes the top 17 out of 42 selected papers received from academicians, researchers, and students in the field. These papers mainly emphasize recent trends in drone research.

The first paper is titled "Research on Modeling and Fault-Tolerant Control of Distributed Electric Pro-pulsion Aircraft." This study proposes a very promising distributed electric propulsion (DEP) system with high propulsion efficiency and low fuel consumption. The redundant thrusters of DEP aircraft increase the risk of faults in the propulsion system, so it is necessary to study fault-tolerant controls to ensure flight safety. Little research has been performed on coordinated thrust control, and the research on fault-tolerant controls for DEP systems is also in the preliminary stage. In this study, a mathematical model of a DEP aircraft was built. Aimed at the lateral and longitudinal control of DEP aircraft, a coordinated thrust-control method based on the control of total energy and total heading was designed. Furthermore, a fault-tolerant control strategy and control method were developed for faults in the propulsion system. Simulation results showed that the controller could control the thrust at the pre-fault level. The correctness and effectiveness of the coordinated thrust-control method designed and the fault-tolerant control method for DEP aircraft were theoretically verified. This study provides a theoretical basis for the future engineering application and development of control systems for DEP aircraft [1].

The second paper in this Special Issue is titled, "Design and Implementation of Sensor Platform for UAV-Based Target Tracking and Obstacle Avoidance." Small-scale unmanned aerial vehicles are currently being deployed in urban areas for missions such as ground target tracking, crime scene monitoring, and traffic management. Aerial vehicles deployed in such cluttered environments are required to demonstrate robust, autonomous navigation and have both target-tracking and obstacle-avoidance capabilities. To this end, this work presents a simply designed but effective steerable sensor platform and implementation techniques for both obstacle avoidance and target tracking. The proposed platform is a two-axis gimbal system capable of roll and pitch/yaw. A mathematical model was developed to govern the dynamics of this platform. The performance of the platform was validated using a software-in-the-loop simulation. The simulation's results showed that the platform can be effectively steered to all regions of interest except in a backwards direction. Due to its design layout and mount location, the platform can engage sensors for obstacle avoidance and target tracking as per UAV requirements. Moreover, steering the platform in any direction does not induce aerodynamic instability with respect to the unmanned aerial vehicle [2].

The third paper Is titled "Mathematical Modeling and Stability Analysis of Tiltrotor Aircraft." Mathematical modeling is the key problem in developing a tiltrotor. Therefore,

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this paper proposes a dividing modeling method that divides a tiltrotor into five parts (rotor, wing, fuselage, horizontal tail, and vertical fin) and develops aerodynamic models for each of them. In this way, the force and moment generated by each part can be obtained. First, a dynamic model of the rotor and its flapping angle expression was developed using the blade element theory. Using the mature lifting line theory, dynamic models of the wings, fuselage, horizontal tail, and vertical fin were then built. The rotors' dynamic interference on the wings and the nacelle tilt variations against the center of gravity and moment of inertia were taken into account. A non-linear tiltrotor simulation model was built in a MATLAB/Simulink simulation environment, and the Trim command was then applied to trim the tiltrotor. Finally, the XV-15 tiltrotor was used as an example to validate the rationality of the developed model. In the end, the non-linear simulation model was linearized to obtain a state–space matrix, thus preforming a stability analysis of the tiltrotor [3].

The fourth paper, which compiled research on motion-planning algorithms for UAVs, is titled "Optimization Methods Applied to Motion Planning of Unmanned Aerial Vehicles: A Review." A flying robot is a system that can fly off and touch down to execute specific tasks. These flying robots are currently capable of flying without human control and can make situation-appropriate decisions with the help of onboard sensors and controllers. Among flying robots, unmanned aerial vehicles (UAVs) are highly attractive and applicable for military and civilian purposes. These UAV applications require motion-planning and collision-avoidance protocols to achieve improved robustness and a faster convergence rate for meeting their targets. Furthermore, optimization algorithms improve the performance of the system and minimize convergence errors. In this survey, diverse scholarly articles were gathered to highlight motion planning for UAVs using bio-inspired algorithms. This study will assist researchers in understanding the latest research performed on UAV motion planning with various optimization techniques. Moreover, this review presents the contributions and limitations of every article to demonstrate the effectiveness of the proposed work [4].

In the fifth paper, the authors present a study titled "The Development of a Visual Tracking System for a Drone to Follow an Omnidirectional Mobile Robot." This research developed a UAV visual tracking system that guides a drone in tracking a mobile robot and accurately landing on it when it stops moving. Two different-color LEDs were installed on the bottom of the drone. The visual tracking system on the mobile robot can detect the heading angle and the distance between the drone and the mobile robot. The heading angle and flight velocity in the pitch and roll direction of the drone were modified by PID controls so that the flying speed and angle are more accurate and the drone can land quickly. The PID tuning parameters were also adjusted according to the height of the drone. The system embedded in the mobile robot, which is equipped with Linux Ubuntu and processes images with OpenCV, can send a control command (SDK 2.0) to the Tello EDU drone via WIFI by using the UDP Protocol. The drone can auto-track the mobile robot. After the mobile robot stops moving, the drone can land on top of the mobile robot. Experimental results indicate that the drone can take off from the top of the mobile robot, visually track the mobile robot, and finally land on the top of the mobile robot accurately [5].

The sixth paper, "A Multi-Colony Social Learning Approach for the Self-Organization of a Swarm of UAVs", offers an improved method for the self-organization of a swarm of UAVs based on a social learning approach. To begin, the authors used three different colonies and three best members, i.e., unmanned aerial vehicles (UAVs), that are randomly placed in the colonies. This study used max–min ant colony optimization (MMACO) in conjunction with a social learning mechanism to plan an optimized path for an individual colony. A multi-agent system (MAS) chooses the most optimal UAV as the leader of each colony and selects the remaining UAVs as agents, which helps organize the randomly positioned UAVs into three different formations. The algorithm then synchronizes and connects the three colonies into a swarm and controls it using dynamic leader selection. The major contribution of this study was to hybridize two different approaches to produce a more optimized, efficient, and effective strategy. The results verified that the proposed algorithm completed the given objectives. This study also compared the designed method with the non-dominated sorting genetic algorithm II (NSGA-II) to prove that the new method offers better convergence and reaches the target via a shorter route than NSGA-II [6].

The seventh paper, which proposes a triangular topological sequence for UAVs, is titled "Multi-Target Association for UAVs Based on Triangular Topological Sequence." Thanks to their wide coverage and multi-dimensional perception, multi-UAV cooperative systems are highly regarded in the field of cooperative multi-target localization and tracking. However, due to the similarity of target visual characteristics and the limitations of UAV sensor resolution, it is difficult for UAVs to correctly distinguish visually similar targets. Incorrect correlation matching between targets results in the incorrect localization and tracking of multiple targets by multiple UAVs. In order to solve the association problem of targets with similar visual characteristics and to reduce the localization and tracking errors caused by target association errors based on the relative positions of the targets, the paper proposes a globally consistent target association algorithm for multiple UAV vision sensors based on triangular topological sequences. In contrast to Siamese neural networks and trajectory correlations, this algorithm uses the relative position relationship between targets to distinguish and correlate targets with similar visual features and trajectories. The sequence of neighboring target triangles is constructed using the relative position relationship to produce a specific triangular network. Moreover, this paper proposes a method for calculating the similarity of topological sequences with similar transformation invariances and a two-step optimal association method that considers global objective association consistency. Experimental flight results indicated that the algorithm achieves an association accuracy of 84.63%, and the two-step association is 12.83% more accurate than a single-step association. By conducting this research, the multi-target association problem of similar or even identical visual characteristics can be solved via cooperative surveillance and using multiple UAVs to track suspicious vehicles on the ground [7].

The eighth paper is titled "Drones Classification by the Use of a Multifunctional Radar and Micro-Doppler Analysis." The use of radars to classify targets has received great interest in recent years, particularly for defense and military applications in which the development of sensor systems for identifying and classifying threatening targets is a mandatory requirement. In the specific case of drones, several classification techniques have already been proposed. Until recently, a micro-Doppler analysis in conjunction with machine learning tools was considered the most effective technique. The micro-Doppler signatures of targets are usually represented in the form of a spectrogram, which is a time–frequency diagram obtained by performing a short-time Fourier transform (STFT) on a radar return signal. Moreover, it is often possible to extract useful information from a target's spectrogram that can also be used in a classification task. The main aim of this paper is to compare different methods of exploiting a drone's micro-Doppler analysis on different stages of a multifunctional radar. Three different classification approaches were compared: a classic spectrogram-based classification; spectrum-based classification in which the received signal from the target is picked up after the moving target detector (MTD); and feature-based classification in which the received signal from the target undergoes a detection step after the MTD to extract and use discriminating features as input for the classifier. A theoretical model for the radar return signals of different types of drones and aerial targets was developed to compare the three approaches. This model was validated via a comparison with real recorded data, and it was used to simulate the targets. The results showed that the third approach (feature-based) demonstrated improved performance. Moreover, it also required less modification and less processing power when using a modern, multifunctional radar because it is capable of reusing most of the processing facilities that are already present [8].

The ninth paper is "Anti-Occlusion UAV Tracking Algorithm with a Low-Altitude Complex Background by Integrating Attention Mechanism." In recent years, the increasing number of unmanned aerial vehicles (UAVs) in low-altitude airspace has introduced not only convenience to work and life but also great threats and challenges. There are common problems in the process of UAV detection and tracking, such as target deformation, target occlusion, and the submersion of targets by complex background clutter. This paper proposes an anti-occlusion UAV tracking algorithm for low-altitude, complex backgrounds that integrates an attention mechanism to solve the problems of complex backgrounds and occlusions. The algorithm process is as follows: first, extracted features are enhanced using the SeNet attention mechanism. Second, an occlusion-sensing module is used to determine whether the target is occluded. If the target is not occluded, tracking continues. Otherwise, the LSTM trajectory-prediction network is used to predict the UAV position in subsequent frames from the UAV flight trajectory prior to occlusion. This study was verified using the OTB-100, GOT-10k, and integrated UAV datasets. The accuracy and success rates of the integrated UAV datasets were 79% and 50.5%, respectively, 10.6% and 4.9% higher than the rates of the SiamCAM algorithm. Experimental results showed that the algorithm could robustly track a small UAV in a low-altitude, complex background [9].

The tenth paper is titled, "A Modified YOLOv4 Deep Learning Network for Vision-Based UAV Recognition." The use of drones in various applications has increased, as has their popularity among the general public. As a result, the possibility of drone misuse and their unauthorized intrusion into important places, such as airports and power plants, are increasing. This threatens public safety. Therefore, the accurate and rapid recognition of drone types is important for preventing their misuse and security problems caused by unauthorized drone access. Performing this operation from visible images is always associated with challenges, such as the drone's small size, confusion with birds, the presence of hidden areas, and crowded backgrounds. In this paper, a novel and accurate technique with a change in the YOLOv4 network is presented to recognize four types of drones (multirotors, fixed-wing, helicopters, and VTOLs) and distinguish them from birds using a set of 26,000 visible images. In this network, more precise and detailed semantic features could be extracted by changing the number of convolutional layers. The performance of the basic YOLOv4 network was also evaluated on the same dataset, and the proposed model performed better than the basic network in solving the challenges. The proposed model also achieved automated, vision-based recognition with a loss of 0.58 in the training phase and an 83% F1-score, 83% accuracy, 83% mean average precision (mAP), and 84% intersection over union (IoU) in the testing phase. These results represent a slight improvement of 4% in these evaluation criteria over the basic YOLOv4 model [10].

The 11th paper is titled "Using Classify-While-Scan (CWS) Technology to Enhance Unmanned Air Traffic Management (UTM)." Drone detection radar systems have been verified to support unmanned air traffic management (UTM). In this paper, the authors propose the use of classify-while-scan (CWS) technology to improve the detection performance of drone-detection radar systems and to enhance UTM applications. The CWS recognizes radar data from each radar cell in the radar beam using an advanced automatic target recognition (ATR) algorithm. It then integrates the recognized results into the tracking unit to obtain real-time situational-awareness results for the entire surveillance area. Real X-band radar data, collected in a coastal environment, demonstrated a significant advancement in a powerful situational-awareness scenario in which birds were chasing a ship to feed on fish. The CWS technology turns drone-detection radars into a sense-and-alert platform that revolutionizes UTM systems by reducing the detection unit's detection response time (DRT) [11].

The 12th paper, "ARSD: An Adaptive Region Selection Object Detection Framework for UAV Images", proposes an object detection framework for UAVs. The performance of object detection has greatly improved due to the rapid development of deep learning. However, object detection in high-resolution images from unmanned aerial vehicles images remains a challenging problem for three main reasons: (1) the objects in aerial images have different scales and are usually small; (2) the images are high-resolution, but state-of-the-art object-detection networks are of a fixed size; (3) the objects are not evenly distributed in aerial images. To solve these problems, the authors proposed a two-stage adaptive region selection detection framework. An overall region detection network was first applied to coarsely localize the object. A fixed-point, density-based target-clustering algorithm and an adaptive selection algorithm were then designed to select object-dense sub-regions. The object-dense sub-regions were sent to a key region detection network where the results were fused with the results from the first stage. Extensive experiments and comprehensive evaluations on the VisDrone2021-DET benchmark datasets demonstrated the effectiveness and adaptiveness of the proposed framework. Experimental results showed that the proposed framework outperformed the existing baseline methods by 2.1% without additional time consumption in terms of the mean average precision (mAP) [12].

The 13th paper is titled "Comprehensive Review of UAV Detection, Security, and Communication Advancements to Prevent Threats." Over time, unmanned aerial vehicles (UAVs), also known as drones, have been used in very different ways. Advancements in key UAV areas include detection (including radio frequency and radar), classification (including micro-, mini-, close-, short-, and medium-range; medium-range endurance; low-altitude, deep-penetration; low-altitude, long-endurance; and medium-altitude, long-endurance), tracking (including lateral tracking, vertical tracking, a moving aerial pan with a moving target, and a moving aerial tilt with a moving target), and so forth. Even with these improvements and advantages, security and privacy can still be ensured by researching a number of key aspects of unmanned aerial vehicles, such as jamming a UAV's control signals and redirecting them for a high-assault activity. This review article examined the privacy issues related to drone standards and regulations. The manuscript provides a comprehensive answer to these limitations. In addition to updated information on current legislation and the many classes that can be used to establish communication between a ground control room and an unmanned aerial vehicle, this article provides a basic overview of unmanned aerial vehicles. This review provides readers with an understanding of UAV shortcomings, recent advancements, and strategies for addressing security issues, assaults, and limitations. The open research areas described in this manuscript can be utilized to create novel methods for strengthening the security and privacy of unmanned aerial vehicles [13].

The 14th paper is "Detection of Micro-Doppler Signals of Drones Using Radar Systems with Different Radar Dwell Times." Not all drone radar dwell times are suitable for detecting the micro-Doppler signals (or jet engine modulation, JEM) produced by rotating blades in the radar signals of drones. Theoretically, any X-band drone radar system can detect the micro-Doppler effects of blades due to the micro-Doppler effect and the partial resonance effect. However, the authors of this paper analyzed radar data from three radar systems with different radar dwell times and similar resolutions for frequency and velocity. These systems, Radar$-\alpha$, Radar$-\beta$, and Radar$-\gamma$, had radar dwell times of 2.7 ms, 20 ms, and 89 ms, respectively. The results indicated that Radar$-\beta$ is the best radar for detecting the micro-Doppler signals (i.e., JEM signals) produced by the rotating blades of DJI Phantom 4, a quadrotor drone. Radar$-\beta$ achieved the best results because the detection probability for JEM signals was almost 100% with approximately two peaks that had similar magnitudes to the body Doppler. In contrast, Radar$-\alpha$ could barely detect any micro-Doppler effects, and Radar$-\gamma$ detected only weak micro-Doppler signals at a magnitude of only 10% of the body Doppler's magnitude. A proper radar dwell time is the key to micro-Doppler detection. This research provides an idea for designing a cognitive micro-Doppler radar by changing the radar dwell time to detect and track the micro-Doppler signals of drones [14].

The 15th paper is titled, "Elliptical Multi-Orbit Circumnavigation Control of UAVS in Three-Dimensional Space Depending on Angle Information Only." In order to analyze the circumnavigation tracking problem in a complex, three-dimensional space, this paper proposes a UAV group circumnavigation control strategy in which the UAV circumnavigation orbit is an ellipse for which its size can be adjusted arbitrarily. At the same time, the UAV group can be assigned to multiple orbits for tracking. The UAVs only have the target's angle information, and the target's position information can be obtained by using the angle information and the proposed three-dimensional estimator, thereby establishing an ideal relative velocity equation. By constructing the error dynamic equation between the actual relative velocity and the ideal relative velocity, the three-dimensional circumnavigation problem is transformed into a velocity-tracking problem. Since UAVs are easily disturbed by external factors during flight, a sliding mode control was used to improve the system's robustness. Finally, the effectiveness of the control law and its robustness to unexpected situations were verified via simulations [15].

The 16th paper is titled, "Small-Object Detection for UAV-Based Images Using a Distance Metric Method." Object detection is important in unmanned aerial vehicle (UAV) reconnaissance missions. However, since UAVs fly at a high altitude to obtain a large reconnaissance view, the objects captured often have a small pixel size and their categories have high uncertainties. Given the limited computing capability of UAVs, large detectors based on convolutional neural networks (CNNs) have difficulty achieving real-time detection performance. To address these problems, the authors designed a small-object detector for UAV-based images in this paper. They modified the backbone of YOLOv4 according to the characteristics of small-object detection and improved the performance of small-object positioning by modifying the positioning loss function. Using the distance metric method, the proposed detector can classify trained and untrained objects by using the objects' features. Furthermore, the authors designed two data-augmentation strategies to enhance the diversity of the training set. The method was evaluated on a small-object dataset and obtained 61.00% on trained objects and 41.00% on untrained objects with 77 frames per second (FPS). Flight experiments confirmed the utility of the approach on small UAVs, which demonstrated a satisfying detection performance and real-time inference speed [16].

The 17th paper is "Simultaneous Astronaut Accompanying and Visual Navigation in Semi-Structured and Dynamic Intravehicular Environment." The application of intravehicular robotic assistants (IRA) can save valuable working hours for astronauts in space stations. There are various types of IRAs, such as those that accompany drones working in microgravity and a dexterous humanoid robot for collaborative operations. In either case, the ability to navigate and work alongside human astronauts lays the foundation for IRA deployment. To address this problem, this paper proposes a framework of simultaneous astronaut accompaniment and visual navigation. The framework contains a customized astronaut detector, an intravehicular navigation system, and a probabilistic model for astronaut visual tracking and motion prediction. The customized detector was designed to be lightweight. It achieved superior performance (AP@0.5 of 99.36%) for astronaut detection in diverse postures and orientations during intravehicular activities. A map-based visual navigation method was proposed for accurate localization with 6 DoF (1~2 cm, 0.5°) in semi-structured environments. To ensure navigation robustness in dynamic scenes, the feature points within the detected bounding boxes were filtered out. A probabilistic model was formulated based on the map-based navigation system and the customized astronaut detector. Both trajectory correlation and geometric similarity clues were incorporated into the model for stable visual tracking and the trajectory estimation of the astronaut. The overall framework enables the robotic assistant to track and identify the astronaut efficiently during intravehicular activities and can provide foresighted services while moving. The overall performance and superiority of the proposed framework were verified by conducting extensive ground experiments in a space station mockup [17].

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