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Classifications, applications, and design challenges of drones: A review

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ABSTRACT

Nowadays, there is a growing need for flying drones with diverse capabilities for both civilian and military applications. There is also a significant interest in the development of novel drones which can autonomously fly in different environments and locations and can perform various missions. In the past decade, the broad spectrum of applications of these drones has received most attention which led to the invention of various types of drones with different sizes and weights. In this review paper, we identify a novel classification of flying drones that ranges from unmanned air vehicles to smart dusts at both ends of this spectrum, with their new defined applications. Design and fabrication challenges of micro drones, existing methods for increasing their endurance, and various navigation and control approaches are discussed in details. Limitations of the existing drones, proposed solutions for the next generation of drones, and recommendations are also presented and discussed.

1. Introduction

Drones are flying robots which include unmanned air vehicles (UAVs) that fly thousands of kilometers and small drones that fly in confined spaces [1,2]. Aerial vehicles that do not carry a human operator, fly remotely or autonomously, and carry lethal or nonlethal payloads are considered as drones [3]. A ballistic or semi-ballistic vehicle, cruise missiles, artillery projectiles, torpedoes, mines, and satellites cannot be considered as drones [4]. Advances in fabrication, navigation, remote control capabilities, and power storage systems have made possible the development of a wide range of drones which can be utilized in various situations where the presence of humans is difficult, impossible, or dangerous [5,6]. Flying robots for military surveillance, planetary exploration, and search-and-rescue have received most attention in the past few years [7]. Depending on the flight missions of the drones, the size and type of installed equipment are different [6]. Considerable advantages of the drones have led to a myriad of studies to focus on the optimization and enhancement of the performances of these drones. According to the mentioned characteristics, drones benefit from the potential to carry out a variety of operations including reconnaissance, patrolling, protection, transportation of loads, and aerology [8–12].

Drones often vary widely in their configurations depending on the platform and mission. There are different classifications for the drones based on different parameters. Watts et al. [13] described a variety of platforms. They identified advantages of each as relevant to the demands of users in the scientific research sector. They classified the drones' platforms for civil scientific and military uses based upon characteristics, such as size, flight endurance, and capabilities. In their drones' classifications, they classified them as MAVs (Micro or Miniature Air Vehicles), NAVs (Nano Air Vehicles), VTOL (Vertical Take-Off & Landing), LASE (Low Altitude, Short-Endurance), LASE Close, LALE (Low Altitude, Long Endurance), MALE (Medium Altitude, Long Endurance), and HALE (High Altitude, Long Endurance). In an overview of military drones used by the UK armed forces, Brooke-Holland [14] classified drones into three classes. Class I is subdivided into four categories (a, b, c, and d). The categorization process is initially based on the minimum take-off weight combined with how the drones are intended to be used and where they are expected to be operated. This classification is shown in Table 1.

Arjomandi et al. [15] classified drones on the basis of weight, range and endurance, wing loading, maximum altitude, and engine type. They classified drones as super-heavy with weights more than 2000 kg, heavy with weights between 200 kg and 2000 kg, medium with weights between 50 kg and 200 kg, light/mini with weights between 5 kg and 50 kg, and finally micro drones with weights less than 5 kg [15]. This classification which is defined based on drones' weight is shown in Table 2.

Gupta et al. [3] classified drones as HALE, MALE, TUAV (medium range or tactical UAV), MUAV or Mini UAV, MAV, and NAV. Cavoukian [16] categorized drones as three main types, namely, micro and mini UAVs, tactical UAVs, and strategic UAVs. He divided the tactical UAVs into six subcategories: close range, short range, medium range, long range, endurance, and medium altitude long endurance

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Table 1
The proposed drones' categorization by Brooke-Holland based on their weight [14].

Class	Type	Weight range
Class I(a)	Nano drones	W≤200 g
Class I(b)	Micro drones	200 g < W≤2 kg
Class I(c)	Mini drones	2 kg < W≤20 kg
Class I(d)	Small drones	20 kg < W≤150 kg
Class II	Tactical drones	150 kg < W≤600 kg
Class III	MALE/HALE/Strike drones	W > 600 kg

Table 2
The proposed drones' categorization by Arjomandi et al. based on their weight [15].

Designation	Weight range
Super heavy	W > 2000 kg
Heavy	200 kg < W≤2000 kg
Medium	50 kg < W≤200 kg
Light	5 kg < W≤50 kg
Micro	W≤5 kg

Table 3
The proposed drones' categorization by Weibel and Hansman based on their weight [17].

Designation	Weight range
Micro	W < 2 lbs
Mini	2 lbs≤W≤30 lbs
Tactical	30 lbs≤W≤1000 lbs
Medium and high altitude	1000 lbs≤W≤30,000 lbs
Heavy	W > 30,000 lbs

(MALE) UAVs [16]. Weibel and Hansman [17] classified drones as micro, mini, tactical, medium and high altitude, and heavy types. In Table 3, the proposed classification is indicated.

Australian Civil Aviation Safety Authority (CASA) [18] categorized drones into three classes, namely, micro UAVs with weights less than 0.1 kg, small UAVs with weights between 0.1 kg and 150 kg, and large UAVs with weights more than 150 kg for fixed wing models and more than 100 kg for rotorcrafts [18]. United Kingdom – Civil Aviation Authority (CAA) [19,20] classified drones into three types consisting of small unmanned aircraft (weight≤20 kg), light UAV (20 kg < weight≤150 kg), and UAV (weight > 150 kg). Zakora and Molodchik [21] classified drones based on their weight and range as follows: micro and mini UAV close range, lightweight UAVs small range, lightweight UAVs medium range, average UAVs, medium heavy drones, heavy medium range UAVs, heavy drone large endurance, and unmanned combat aircraft. They also categorized drones based on their missions, namely, (1) attack UAV multiple applications, (2) attack UAV expendable, (3) strategic UAV, (4) tactical UAV, and (5) miniature UAV [22]. In Table 4, the presented drones' classification by Zakora and Molodchik is shown.

Nowadays different types of drones evolved from the advancement

Table 4
The proposed drones' categorization by Zakora and Molodchik based on their weight and flight range [21].

Designation	Weight range	Flight range
Micro and mini UAVs close range	W≤5 kg	25 km≤R≤40 km
Lightweight UAVs small range	5 kg < W≤50 kg	10 km≤R≤70 km
Lightweight UAVs medium range	50 kg < W≤100 kg	70 km≤R≤250 km
Average UAVs	100 kg < W≤300 kg	150 km≤R≤1000 km
Medium heavy UAVs	300 kg < W≤500 kg	70 km≤R≤300 km
Heavy medium range UAVs	500 kg≤W	70 km≤R≤300 km
Heavy UAVs large endurance	1500 kg≤W	R≤1500 km
Unmanned combat aircraft	500 kg < W	R≤1500 km

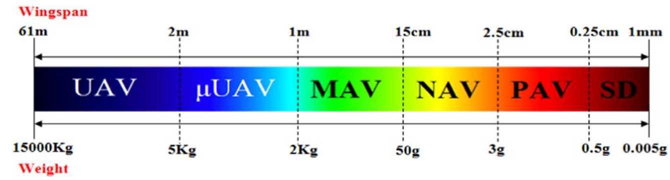

Fig. 1. Spectrum of drones from UAV to SD.

in miniaturization of electronic components, such as sensors, microprocessors, batteries, and navigation systems [23]. A wide variety of drones were used for military and civilian purposes. Drones range in size from vast fixed-wing unmanned air vehicle (UAV) to smart dust (SD) which consists of many tiny micro-electro-mechanical systems including sensors or robots. In Fig. 1, the spectrum of different types of drones is presented.

As shown in Fig. 1, there is a spread spectrum of drones from UAV class with maximum wing span of 61 m and weight of 15,000 kg [24] to smart dust (SD) with minimum size of 1 mm and weight of 0.005 g [25]. Between UAV and SD at both ends of the defined spectrum, there are various types of drones, which are called micro drones, such as micro unmanned air vehicle (µUAV), micro air vehicle (MAV), nano air vehicle (NAV), and pico air vehicle (PAV) [7]. In this study, we offer a new classification for drones which covers other types of classifications with better and more comprehensive categorization. The rest of this study is organized as follows: the unconventional classification of drones is presented in Section 2. In Section 3, the various applications of these drones are investigated and discussed. Design and manufacturing methods and their challenges are, respectively, studied in Sections 4 and 5. Different propulsion systems and actuators for drones, and their power supply and endurance are shown in Sections 6 and 7, respectively. Control and navigation, and swarm flight of drones and conclusions are, respectively, presented in Sections 8–10.

2. Classification of drones

In the recent decades, due to the development of a smaller air drone called micro air vehicle, the demands for intelligence missions have been increased [26]. Therefore, nowadays, there is a serious effort to design and fabricate air drones that are very small for special missions. These efforts have resulted in the development of different types of small drones with various shapes and flight modes. In Fig. 2, a comprehensive classification of all of the existing drones is shown, where HTOL is the abbreviation of Horizontal Take-Off and Landing.

Generally, drones can be categorized by their performance characteristics. Features including weight, wing span, wing loading, range, maximum altitude, speed, endurance, and production costs, are important design parameters that distinguish different types of drones and provide beneficial classification systems. Furthermore, drones can be classified based on their engine types [15]. For example, UAVs often apply fuel engines and MAVs use electrical motors. The types of propulsion systems which are used in drones are different based on their models. The offered classification of drones in Fig. 2 shows different models of drones as a function of their configuration. The indicated flowchart in Fig. 2 also considers the bio models of micro and nano air vehicles, which are defined as live controllable birds or insects and flying taxidermy birds.

2.1. Classification of UAVs

The main aspects that distinguish UAVs from other types of small drones (such as MAVs and NAVs) include the operational purpose of the vehicle, the materials used in its fabrication, and the complexity and cost of the control system [27]. UAVs vary widely in size and configuration. For example, they may have a wing span as broad as a Boeing 737 or smaller than a radio-controlled drone [2]. Different