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Swarms of Unmanned Aerial Vehicles — A Survey

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ABSTRACT

The unmanned aerial vehicles or drones come in a great diversity depending upon the basic frameworks with their particular specifications. The purpose of this study is to analyse the core characteristics of the swarming drones and measure the public awareness levels with respect to these swarms. To achieve these goals, the functionality, problems, and importance of drones are highlighted. The results of an experimental survey from a bunch of academic population are also presented, which demonstrate that the swarms of drones are fundamental future agenda and will be adopted with the passage of time.

1. Introduction

A swarm or fleet of Unmanned Aerial Vehicles (UAVs) is a set of aerial robots i.e., drones that work together to achieve a specific goal. Each drone in a swarm is propelled by a specific number of rotors and has the ability to vertically hover, take-off, and land (VTOL). The flight of the drones is controlled either manually, i.e. by remote control operations, or autonomously by using processors deployed on the drones [1]. A common purpose for drones is a military one, but their civilian applications are attracting increased attention in the recent time. Indeed, low-cost drones and their swarms provide a promising platform for innovative research projects and future commercial applications that will help people in their work and everyday lives. Swarms of drones can be classified in different ways. For example, Fig. 1 illustrates fully and partly (semi) autonomous swarms. From another point of view, the classification can be envisioned in single-layered swarms with every drone being its own leader and multi-layered swarms with dedicated leader drones at every layer, which report to their leader drones at a higher layer; a ground-based server station is the highest layer in this hierarchy. In each swarm, every drone can have dedicated data collection and processing tasks with sufficient computing capability to execute these tasks in real-time. Its central processing takes place on the more performant server/base station or even in the cloud.

The paper is aimed to (1) study the characteristics of the drones and the swarm of drones, (2) discuss the existing technologies of linear and model-based nonlinear controllers, and (3) assess the public awareness levels regarding drones using an experimental query-based survey. To realize these contributions to the field of knowledge, this paper is structured as follows. Section 2 follows this introduction in which drone application fields are discussed. In Section 3, the classification of UAVs is presented. Section 4 lays out the description of the dynamics and flying mechanisms of drones. Section 5 studies key characteristics of autonomous drone swarms. An analysis of public awareness of drones is presented in Section 6. Lastly, conclusions are drawn in Section 7.

2. Application Areas

The advances in the capabilities of sensors deployed on UAVs enable the use of drones for different new purposes, facilitating the creation of a new breed of applications and services in the sector of unmanned operations. The prominent application areas of drones are briefly discussed in this section.

2.1. Security, Survey, Monitoring, and Surveillance

UAVs have traditionally been employed in military surveillance missions. Versatile and low-cost drones have been utilized in aerial surveys, for monitoring and surveillance, in numerous fields such as geophysics and agriculture [1,2]. For example, surveillance of a facility or environment might require updates of every movement detected after office hours. A large facility or environment would require a lot of manpower for thorough manual surveillance. Contrary to this, a swarm of drones can cover/monitor the region much more efficiently with a

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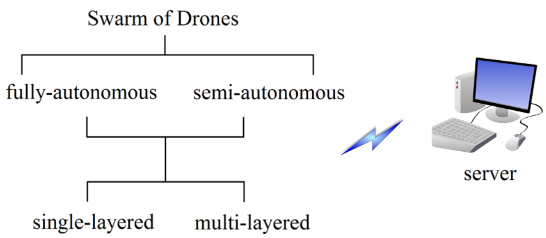

Fig. 1. Classification of swarms.

minimal manual effort, by automatically and quickly sending an alert to the base station upon detection of movement.

2.2. Leisure Pursuit

In our modern world, there is an increasing interest in using lightweight UAVs (weighing less than 55 pounds) as a hobby and/or for a recreational purpose [1].

2.3. Disaster Management

In the case of a natural disaster, UAVs can easily reach the disaster-struck locations that are dangerous and difficult to access otherwise. They can, therefore, provide disaster estimations and facilitate in putting effective countermeasures in place. For example, in the case of a wildfire, a swarm of drones, equipped with fire extinguishers or similar, can quickly examine and handle a large area without endangering human lives.

2.4. Environmental Mapping

Mapping different environments via UAVs has been becoming an active research topic such as in the fields of cartography [3] and archaeology [1].

2.5. Search and Rescue (S&R)

UAVs can save a lot of time and manpower by providing real-time aerial images of targeted locations. As a result, S&R teams can easily determine where exactly the help is most urgently needed. For example, different UAVs in a swarm can be equipped with different basic first aid kits that can be redirected and delivered to a person in need of medical assistance even before the medical team reaches him/her, resulting in a much better chance to save someone's life.

3. Classification of UAVs

UAVs, in the market, come with diversity in the number of propellers/rotors as illustrated in Table 1 [4]. Drones can also be grouped based on their size, range, and equipment. The sizes can be either nano, mini, regular, or large while the range can be either very close, close, short, mid, or endurance. Drones can be equipped with cameras, stabilizers, sensors, Global Positioning System (GPS), and/or First Person View (FPV) accompanied by FPV goggles.

Table 1
Categorization of UAVs based on the number of propellers.

Drones	No. of propellers
Tricopter	3
Quadcopter	4
Hexacopter	6
Octocopter	8

Drones are classified into four major types; fixed-wing, fixed-wing hybrid, single rotor, and multirotor as shown in Table 2 [5]. Fixed-wing drones are mainly used for aerial mapping and inspection of pipelines/power lines. They are expensive and require skill training to operate. Though they require relatively more space for their launch and recovery, they are equipped to cover larger areas. This type of drones is not suitable for VTOL/hover and hence this makes them unfit for general aerial photography. However, they can stay in the air for up to 16 h by using gas engines as their power source.

Table 2
Types of UAVs determined by their basic structure.

Drones	Main features
Fixed-Wing	long endurance and fast flight speed
Fixed-Wing Hybrid	VTOL and long endurance flight
Single Rotor	VTOL, hover, and long endurance flight
Multirotor	VTOL, hover, and short endurance flight

In contrast, fixed-wing hybrid drones are a combination of manual gliding and automation. They are still in the development phase and not good at either hover or forward flight. They are commercially being used by Amazon for delivery purposes.

On the other hand, single rotor drones have more mechanical complexity and operational risks such as vibration and large rotating blades. Therefore, they also require skill training of the operator. They are costly and have the competency of the heavier payload such as LiDAR sensor to be steered. For even longer endurance, they can be powered by a gas motor.

Among the four types, the multirotor UAVs are the cheapest option available and easier to build. Such drones are commonly used for basic purposes such as photography and video surveillance. They can be tricopters, quadcopters, hexacopters, or octocopters (see Table 1). However, these types of drones are not appropriate for larger-scale aerial mapping and longer distance monitoring due to their limited speed, flight time and energy efficiency. Currently available multirotor drones can fly up to 30 min with a normal lightweight payload such as a camera. The most commonly used UAV type (considering the number of propellers) is a quadcopter, and therefore our discussion in the following sections will focus specifically on this type.

4. Dynamics and Flying Mechanisms

Consider an autonomous and adaptive quadcopter that is an under-actuated system having four input engines and propellers enabling roll, pitch, yaw, and thrust control as well as six degrees of freedom for movement and manoeuvre [2]. The propellers, also called the rotors, have fixed pitch mechanically moveable blades as shown in Fig. 2(a).

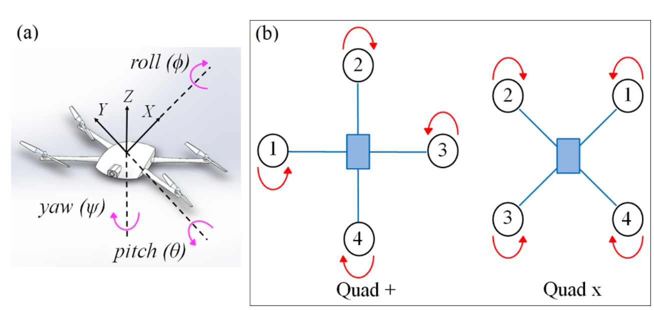

Fig. 2. (a) Movement about axes, (b) Configuration of a quadcopter.

This means that when the blades rotate, their rotor pitch does not vary. In addition to a drone's direction of movement, its roll, pitch, and yaw movement depend on the difference between the throttle provided by the four motors operating the propellers. Stable flight requires high-precision control of the motors. The control algorithms continuously take feedback and adjust the throttle of the motors, thereby controlling roll, pitch, yaw, and thrust of the drone. Yaw movement is controlled to ensure the stability of rotation on the vertical or Z-axis. Pitch movement is controlled to ensure the stability of rotation on the Y-axis (also called lateral or transverse axis) that determines the degree of side-to-side tilting. Similarly, the roll is the measure of how high the nose or front of the drone is lifted. Its movement is controlled to ensure the stability on the X-axis (or longitudinal axis).

Fig. 2(b) illustrates the two basic flying mechanisms and rotor organizations known as the '+' and 'x' patterns. In each configuration of rotors, the two rotors on the opposite ends always rotate in the same direction while the other two rotate in the opposite directions. The 'x' design is a more stable structure, and it can produce more rotation acceleration than the '+' organization [6]. Generally, the '+' configuration provides easy manoeuvring and is well-suited for the purpose of sports flying. In contrast, aerial photography is much easier with the 'x' configuration that inherently keeps the propellers out of the screen.

Fig. 3 shows a hierarchical swarm of quadcopters in a leader-subordinate flying/operation model. It allows a single user to control the movement and formation of the whole swarm through the leader drone, using an intuitive remote control interface. This swarm is a self-organizing structure having the behaviour of a multi-agent control system. Its formation flying principle is associated with a remote user/operator and a wireless communication system between the operator and the swarm.

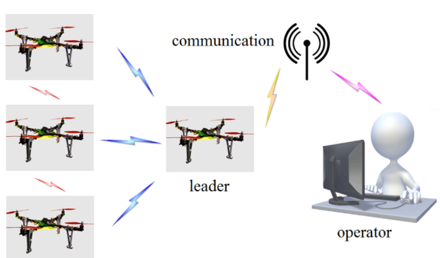

Fig. 3. Example of a hierarchical swarm of drones.

Refer to a simple example in Fig. 3, there is only a single leader drone leading a cluster of subordinate worker drones. Generally, the hierarchy can be much more complex such as consisting of multiple clusters each having its own leader(s) and multiple layers of leaders forming "superclusters" of different sizes. Each drone in the swarm can directly communicate with its peers at the same level of the hierarchy and with its immediate leader drone(s). Leader drones at the highest level of hierarchy communicate with the ground-based server, sharing the data collected and pre-processed by the swarm and distributing downwards mission objectives provided by the server.

4.1. Mechanical Design

For the controlled movement of the quadcopter in the presence of disturbance and uncertainties, the initial step is to construct a balanced drone with an adaptive computing platform. The targeted control system is designed by building a dynamic model of the drone, consisting of a set of mathematical equations dealing with all the acting forces on the system at a given time interval.

Fig. 4 shows a basic battery-powered quadcopter consisting of a mainframe that serves as its base, Electronic Speed Control (ESC), Inertial Measurement Unit (IMU), programmable microcontrollers mounted at the centre, electric motors, radio transmitters and receivers, batteries, a set of sensors, and four rotors at the ends of the four arms of the drone [7].

Fig. 4. Basic quadcopter.

4.2. Description of Sensors

In order to maintain a stable and controllable flight, the two crucial types of sensor and control units essential for any quadcopter are ESC [8–11] and IMU [3,8,10–21].

The velocity control can be set up using ESCs with most of the commercially available brushless DC motors. An ESC consists of a three-phase inverter accompanied by rotor position feedback. By providing a suitable level of electric power, an ESC runs the brushless motor while converting the Pulse Width Modulation (PWM) signal from radio receivers or flight controllers. In the x-y plane, a position drift of the quadcopter is present because of a slight variation in the speeds of the four motors when concurrently applying a constant input signal to the four separate ESCs. This drift is normally overcome by implementing versatile feedback control systems [22].

An IMU is an electromechanical device that consists of an accelerometer and a gyroscope. It helps in determining the angular position and altitude of the quadcopter. The accelerometer is in charge of measuring the acceleration forces such as gravity (being applied to each axis) with respect to the Earth while the gyroscope is capable of measuring the rate of angular rotation for every axis.

To further facilitate high-precision control of a drone, additional modules such as barometer [10,23], magnetometer [3,10,18,20,23], and altitude [13,17] sensors can be used to get highly accurate real-time measurements on altitude and direction of movement.

For low altitude operation, ultrasonic sensors (or sonar/radar) are commonly used in quadcopters to detect and avoid obstacles [9,11,19,24–26]. This type of sensor system assesses the characteristics of a target by identifying how the target impacts the transmitted sound or radio waves. For the detection of flat objects, the distance of an obstacle is determined by evaluating the time interval between the signal sent and the echo received. Other sensors such as infrared rangefinders [19,20,24] and LiDAR (or laser scanner/rangefinders – for map building) [13,21,27] are also used for the same purpose.

Moreover, a camera is often mounted on a quadcopter for sensing purposes [9,13,25,27]. It can provide visual feedback, image recognition and processing, 3D obstacle identification, and avoidance of indoor/outdoor facilities.

The Global Positioning System (GPS) is also commonly found on quadcopters [3,9,10,13,15,17–20,23,27]. The fundamental purpose of such a navigation module is to provide means for path planning, tracking, and drone localization. This technology is utilized in outdoor operations such as in surveillance missions.

A detailed literature review on multi-sensor integration and fusion is presented in [72]. Furthermore, multi-sensor fusion approaches for object detection are discussed in [73,74].

4.3. Existing Control Approaches

There are many proficient techniques to control UAVs, e.g., Proportional Integral Derivative (PID) control, adaptive control, Boltzmann-Hamel equations of motion, localization and mapping methods [21,28–30], marker recognition algorithms [31,32], vision-based schemes [33,34], wireless communication methods [35–38], memory-based controllers [43], brain emotional learning-based intelligent controllers [44], and learning-based control methods such as fuzzy logic [39], artificial neural networks [40], iterative and reinforcement learning [41,42]. Here, the focus is to discuss the existing technologies of linear and model-based nonlinear controllers from the control engineering perspective.

Authors in [8] simulated classical control techniques of P, PI, PD, and PID on a quadcopter and concluded that the P and PI controllers did not provide a sufficiently good response. On the other hand, the PD and PID controllers were found to perform adequately well in the case of steady-state stabilization. Additionally, authors in [45] demonstrated indoor and outdoor flight tests using gravity compensated PID approach for altitude control and attitude stabilization of a tilt-wing UAV. In both tests of the proposed vertical flight control, good performance was obtained with small altitude and attitude errors. Furthermore, authors in [46] designed and simulated a PID cascade control architecture in a 3D environment to resolve the problem of trajectory tracking for a quadcopter while the author in [2] demonstrated a PD control design for stabilizing the attitude of a quadcopter. In the case of disturbances, to get a better flight performance and to control the trajectory, an approach integrating the PD controller with a heuristic method was developed.

For a quadrotor micro aerial vehicle, authors in [12] implemented a nonlinear control approach of backstepping to control its position and attitude. In an attempt to generate a specified trajectory, Model Predictive Control (MPC) method was used. In their experiments, the quadrotor was kept hovering for 25 s, and the robustness of the proposed controllers was compared with the results of a geometric tracking algorithm. The method proposed by the authors in [12] proved itself to be more efficient in comparison to the geometric tracking algorithm.

In addition to the above mentioned, authors in [47] have presented two different nonlinear control techniques, i.e. Backstepping and Sliding Mode Control (SMC), for an indoor micro quadrotor. They validated the control approaches and concluded that the SMC controller provided average results due to its switching nature whereas in the presence of high perturbations, the backstepping controller was capable of controlling the orientation angles.

On a stationary platform, authors in [13] used a nonlinear Backstepping control approach for autonomous take-off and landing of a quadcopter. The focus of the paper was to improve the altitude measurement with a LiDAR, an inertial unit, and a Kalman filter. The proposed method was demonstrated in real conditions of outside tests. Moreover, authors in [19], in order to control the altitude of a quadrotor, implemented an enhanced Kalman filter to fuse the data of different sensors such as signals of the sonar and accelerometer. Furthermore, authors in [25], using a pole placement technique with a Kalman filter, simulated a dynamic feedback linear controller of a quadrotor.

To stabilize the position of a quadrotor by using visual feedback, authors in [48] implemented and compared three control strategies; namely nested saturations, backstepping, and SMC. Through real-time experiments, they concluded that the technique of nested saturations control provided better and smooth vehicle performance and energy consumption than the other two control designs.

Authors in [3] used control algorithms based on PI, Linear Quadratic Gaussian (LQG), and State-Dependent Riccati Equation (SDRE) in development of a “Remotely operated Aerial Model Autopilot”. They simulated the stabilization of angular rates, attitude, and velocity in their work.

Authors, in [16], used a Lyapunov function that defines the stability of the equilibrium, to control the angular rotation of an indoor micro quadcopter. Additionally, Lasalle invariance theorem and pole placement methods were used to ensure the asymptotic stability and to stabilize the altitude respectively. Authors performed an experiment in a real system to analyze the control of a vehicle's orientation (roll, pitch, and yaw) with a fixed altitude.

In [49], the author investigated the longitudinal flight dynamics of a UAV using the Linear Quadratic Regulator (LQR) technique for the short period mode (pitch control) only. In addition, the longitudinal dynamics included the UAV's response along the pitch axis and velocity to thrust. Furthermore, authors in [50] simulated a model of a quadcopter using an Integral Time-weighted Absolute Error (ITAE) tuned PID approach, a classic LQR method, and a PID approach tuned with LQR loop controlling techniques. Satisfactory results were achieved for the vertical attitude only. A small radio-controlled UAV was used in [51], where authors studied its longitudinal motion (short period and phugoid/long period) with and without disturbances (Gaussian white noise characteristics) by means of LQR and Kalman Filter.

Authors in [52] presented a comparative study analysis among PID, LQR, LQG, and SMC techniques for pitch control of a UAV. They concluded that the system behaviour with SMC design has no overshoot and steady-state error with respect to other simulated control methods.

In order to acquire robustness against the signal noise as well as to attain a consistent behaviour for the altitude control of a self-designed miniature quadcopter, authors in [53] proposed a model reference adaptive control scheme. The weight of the quadcopter was 2.25 kg without a payload, and based on the experimentations, the maximum take-off weight was up to 4.7 kg. The results of the implemented control approach were compared with a benchmark PID control. The analysis showed that the proposed method provided consistent performance before and after the payload added or dropped.

Authors in [54] presented the modelling of flight dynamics of a UAV in terms of numerical simulation of Boltzmann-Hamel equations with non-holonomic constraints. Additionally, authors in [55] designed a state feedback controller using the H_∞ continuous-time control method to control the translational position and yaw angle of the quadrotor. In [56], the authors examined the same technique on the UAV model in the presence of atmospheric turbulence whereas in [57], authors applied a mixed robust feedback linearization with linear GH_∞ control technique to a nonlinear quadrotor in the presence of external disturbances, uncertainties, and measurement noise.

Authors in [58] implemented a robust controller in a two-stage structure including an attitude and a position controller to attain a motion control of a quadcopter. These designs were based on the nominal controller to get its desired tracking performance and robust compensator to control its influence of uncertainties.

5. Autonomous Swarms

A swarm of UAVs with smart monitoring system can rapidly and reliably cover a given target area by utilizing several parallel operating drones. In this section, some important characteristics of autonomous swarms of drones are discussed.

5.1. Battery Swapping/Recharging

An automatic battery exchanging system for a single drone or a cluster of drones is very crucial in missions that require long flight durations. In order to prevent data loss during the swapping process, authors in [59] proposed an autonomous refilling system that used hot battery swapping by providing external power to a drone on the base charging station. This external power source was used for processing onboard data and communication between the drone and the base station while the drone stayed at the charging station. This design was based on a portable rocker arm and a revolving carousel that supplied four charging batteries. The whole duration of battery swapping was about 60 s from landing to takeoff. The proposed prototype only served a single quadcopter that has 15 min of flying time, and it could fully charge an exhausted battery in about 45 min. Considering a swarm of drones, the approach proposed in [59] can be improved by enabling the charging station to deal with several drones (e.g., a full cluster with a leader drone and its worker/slave drones) in parallel.

Smart energy management and automated maintenance have become increasingly important with the emergence of UAV swarms and their applications. In [60], the authors developed an efficient autonomous Ground Recharge Station (GRS) by reducing the charging phase of single UAV using better and safer electrical contacts. They used a balancer to improve charging efficiency, ensuring proper contact between the circuits on the drone and the recharging station. Furthermore, in the case of a swarm of UAVs, the proposed system can employ a prioritization algorithm which guarantees that a drone with a higher priority is recharged before a drone with a lower priority.

5.2. Robustness against Collisions

Authors in [61] designed an 11 cm pico quadcopter with 25 g mass, 12 g maximum payload sufficient for carrying a small RF camera, and a 2 g carbon fibre cage that protected the device in the event of a collision, enabling its recovery. A custom-designed autopilot board provided smart control for the device. To test the copter's capabilities in tight/dense formations, delta leader-follower and square formation flight experiments were conducted with promising results. The drones were also demonstrated to be robust to collisions at velocities of 4 m/s.

In [27], authors developed a collision avoidance algorithm based on MPC to obtain reliable trajectory prediction for autonomous control of emergency evasive manoeuvring. This approach was simulated in various collision conditions such as one-on-one and one-to-many patterns. Using two helicopters, a flight test was executed demonstrating the algorithm's efficiency in the case of a face-to-face collision course.

Authors in [62] used inexpensive ultrasound localization method to develop a collision-avoidance system (avoiding impact with obstacles and other copters) for commodity hardware quadcopters in Global Navigation Satellite Systems (GNSS) denied regions. Experimentation was done in two dimensions with three quadcopters and at least two stationary anchors. The testing platform had a size limitation because the maximum allowable distance between the anchors and the copters was 12 m.

5.3. Surveillance Systems

Quadcopter-based surveillance systems are gaining more attention among researchers due to recent advances in manoeuvrability and payload capacity of this type of drones. Authors in [63] experimented and demonstrated a set of algorithms on a quadcopter swarm-based surveillance system for tracking the detected targets. The swarm was modelled as a multi-agent system, and the goal was to facilitate optimal cooperation of the agents and to ensure their safety during the execution of a mission. The developed path tracking approach was found to enable smooth and safe navigation in a dense environment.

Authors in [64] developed, based on the concept of a scalable dynamic grid of cooperative quadcopters, an autonomous path planning approach for covering a given environment in an efficient and reliable manner. The method kept track of the space that had been surveyed and directed drones to areas that had not recently been monitored. A non-linear optimization approach determined the flying altitude for each drone, Furthermore, in [65,66], authors demonstrated the capabilities of quadcopter swarms in object localization and tracking tasks.

5.4. Swarm Design, Management, and Optimization

In [67], authors used the principles of Organic Computing (OC) to develop a comprehensive framework for designing and controlling swarms of autonomous collaborative robots, with a special focus on quadcopters that collaborate with each other in order to complete spatial tasks. The proposed approach facilitated self-optimization of individual drones, optimization of joint efforts between drones, and efficient control of the swarm by the human user at multiple abstraction levels.

Authors in [68] developed a distributed relative localization framework for 3D quadcopter swarms, allowing each drone to autonomously localize itself with respect to the other drones in the swarm and enabling fast propagation or dissemination of this localization information everywhere in the swarm. The framework consisted of an Internet of Things (IoT) enabled hardware platform mounted on each drone, its operating system, and middleware software running on this platform. The goal of the proposed work was to support the design of performant 3D swarming applications and eventually facilitate the efficient interaction between the human operator at the base station and the swarm.

5.5. Hovering Performance

The hovering stability and synchronization of flight mechanisms cannot be ignored when considering the mission execution of a swarm of quadcopters. Authors in [69] used a two-stage controller for generating appropriate control feedback to successfully maintain the stability of individual drones and flight formation synchronization within the fleet, even in the case of a single quadcopter failure.

5.6. Communication Reliability

Authors in [15] designed and implemented a motion-driven packet forwarding algorithm for multi-hop micro aerial vehicle networks to set up connectivity in larger regions. However, the communication linkage among agents of a quadcopter swarm must be reliable to enable successful completion of missions. The Takahashi Self Deployment (TSD) movement algorithm, a network expansion algorithm, was used by authors in [70] to form quadcopter swarm agents for connecting two wireless nodes by creating an ad-hoc network. A bandwidth-efficient multi-robot coordination algorithm utilizing 3G/4G wireless networks was used by authors in [71] to overcome the challenges of real-time coordination of UAV based swarms in a wide area setting.

6. Public Awareness

To get an idea about public awareness of the swarm technology, six very basic questions were asked targeting the academic audience. The questions are as follows:

1) *What is the area of your expertise/which sector do you work in?*
2) *Are you familiar with the drone technology and do you understand the term swarm of drones?*
3) *Have you used drones yourself?*
4) *If a swarm of drones is used to monitor the area (e.g., cities, forests, farming fields, public events) and for gathering aerial images, would you be in the favour of it or would you have any concerns?*
5) *Do you think any kind of surveillance done by drones is faster, safer, and more cost-effective than relatively traditional surveillance activities based on manual effort/helicopters/satellites?*
6) *How do you think you would utilize drone technology in your activities/business? Please also specify the target field.*

To summarize, altogether 187 people participated (mainly from Finland and Pakistan) in this online survey that was conducted using Google Forms. Table 3 illustrates the no. of participants with respect to their disciplines. (Please note that each participant is either working in

Table 3
No. of participants w.r.t. their disciplines.

Disciplines	No. of participants
Engineering	47
IT related	36
Health and allied	31
Social science	24
Business (development/administration/marketing)	21
Management related	17
Natural science	5
Art and design	4
Military	2

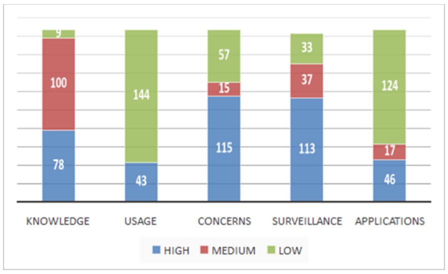

Fig. 5. Survey results.

his/her respective field, studying, or has completed studies). The survey produced the following results as shown in Fig. 5.

- 78 participants had knowledge about a drone and swarm of drones whereas 100 of them understood what a drone is but did not know about the swarm of drones. However, 9 of the participants had never even heard about drone technology.
- Only 43 participants had used drones as a hobby, work, building inspection, counting of cows, research, First-person view (FPV), photography, filming, and/or leisure activities.
- 115 participants mentioned having security concerns whereas 6 of them had privacy concerns, and 8 had security as well as privacy concerns. Only 1 participant added that any type of concerns was dependent on the functional capabilities of drones. On the other hand, 57 participants had no concerns at all in case of the use of a swarm of drones for surveillance.
- 113 participants were of the view that the use of drones was better for surveillance, 37 did not see any difference in either way, and 33 of the participants preferred to use traditional surveillance ways. 4 answers were discarded due to lack of information given.
- Table 4 shows the participants categorized as per the field in which they used or intended to use the drone technology.

Table 4
Interested no. of participants in specific activities.

Applications	No. of participants
Mobile defibrillation for emergencies, monitoring patients and other health-related activities	9
Surveillance	12
Marketing	3
Mapping	5
Business and Management	5
Security	2
Hobby	1
Military	1
Research	1
Delivery (distribution/transportation) of supplies/goods/mails	7
Aerial images/footage	17

7. Conclusion

This paper presented a survey-type study on UAVs (drones) and swarms of UAVs, with a special focus on quadcopters. The mechanics, functionality, organization, modelling, applications, and autonomy aspects of such drones and drone swarms were discussed. Additionally, the paper included the result of an online survey in order to get a picture of public awareness regarding the use of drone technology. The participants of this survey were from different countries and associated with several professional fields. The results showed that though a large proportion of the sample was concerned about a swarm of drones and its usage, it was still considered as a crucial future figure of merit.

Declaration of Competing Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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