Unmanned Aerial Vehicle: Review of Onboard Sensors, Application Fields, Open Problems and Research Issues

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Abstract

Small Unmanned Aerial Vehicle (sUAV) platforms are becoming a potential source of data for many applications thanks to their onboard sensors. They can also provide more technical, environmental and economical advantages compared to classical manned aerial vehicle. This paper reports the state of the art of sUAV platforms and onboard sensors. It reviews their application fields, their open problems and their research issues.

Keywords: Unmanned Aerial Vehicles, Drone, Photogrammetry, Remote sensing, Aerial Images.

1. INTRODUCTION

The term sUAV (Small Unmanned Aerial Vehicle) refers specifically to small aerial vehicle that is controlled either with onboard flight computer or handheld remote control. Other names for sUAV are commonly used in the photogrammetric or computer vision communities such as Small Remotely Piloted Vehicle (RPVs), Small Unmanned Vehicle System (sUVS) or Drones.

Drone is defined in the oxford English dictionary as a remote-controlled pilotless aircraft or missile, which means that its development is firstly motivated by military applications. In recent decades, the development in the sUAV industry was impacted by the advancement of several technologies and the ability to use low-cost platforms, digital single-lens reflex (DSLR) cameras and GPS/INS integration systems. Consequently, a low-cost solution for non-military applications was proposed. We have also seen a growing number of sUAV that were designed to collect data in several fields such as photogrammetry, remote sensing, forestry and agriculture, environment and energy, civil engineering and surveillance.

Commonly, sUAV are composed of a small aerial vehicle, onboard sensors and a ground system (control system and image reception system). Their platforms are a very important alternative solution to measure rapidly and accurately in difficult indoor and outdoor environments and complex applications.

The miniaturisation of sensors and systems allows improving the performance and the reliability of unmanned aerial vehicle and reducing their costs as well as their dimensions. Currently, a wide range of sUAV is available and performs the same function as large manned aerial vehicles. In addition, their sizes allow performing complex manoeuvres and navigating more easily in several specific environments. However, sUAV are challenged by the way of application of a detection algorithm that allows to avoid obstacles and to achieve their full autonomy.

The paper reviews the most common sUAV model, platform and onboard sensors and describes their application fields, open problems and research issues related to obstacle avoidance.

The following section provides an overview of sUAV with a general arrangement of their components. Section 3 presents the most commonly sensors on board the sUAV. In Section 4, we review the use of sUAV for both military and civilian applications. In section 5, we outline some of the key challenges that currently exist in the context of obstacle avoiding. Section 6 describes the issues related to the use of sUAV. Finally, the conclusion and discussion are presented in Section 7.

2. UAV MODELS AND PLATFORM

Small UAV are commonly classified according to their weight and their normal operating altitude. However, the classification may be different from an organization to another. Table 1 illustrates the sUAV classification according to the United Kingdom Royal Air Force [1].

Category	Weight	Normal Operating Altitude	Normal Mission Radius	Civil category	Example platform for civil applications
Micro	< 2 kg	> 50 m	5 km	Weight Classification Group (WCG 1) Small Unmanned Aircraft (< 20 kg)	AR Drone DraganFlyer X6 The eBee senseFly DJI Phantom
Mini	2–20 kg	> 1 km	25 km		AeroVironment Puma of NOAA DJI Inspire
Small	> 20 kg <150 kg	> 1.5 km	50 km	WCG 2 Light Unmanned Aircraft (20> <150 kg)	Integrator System of INSTIU

TABLE 1: sUAV Classification.

Micro-UAV have wingspans of few centimeters and tend to operate at very low altitudes (<1 km). Generally, the degree of autonomy is between 5 and 30 min. The Mini-UAV has a small size of several tens of centimeters and a typical effective flight time of around 40 min. The small UAV have greater weights and sizes (on the order of one to three meters). Their aircraft commonly do require runways. They operate at up to 1500 m altitude and represent a long-endurance autonomous solution of multiple hours.

Designers develop refined and robust techniques to generate sUAV interface requirements. Many researchers have been conducted to recreate traits and ability of animals (birds or insects) in the so-called Biomimetic Unmanned Aerial Vehicles such as AeroVironment's Nano Hummingbird and Insect Spy Drone (Figure 1).

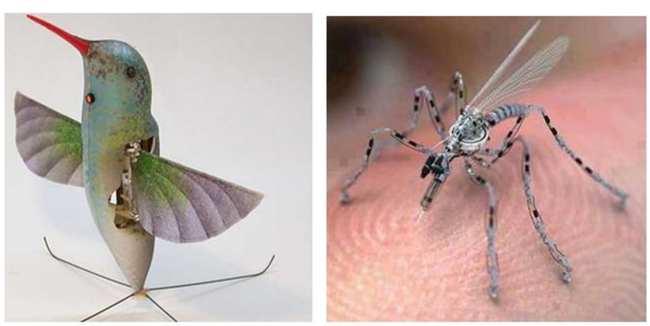


FIGURE 1: Examples of Biomimetic Unmanned Aerial Vehicles.

As shown in Figure 2, the Unmanned Aerial System is composed of three packages. The first package represents the flying vehicle that includes the UAV platform, sensors such as GPS, electrical and wireless communication systems and data acquisition systems such as camera or laser scanner. The second package corresponds to the ground control system and all of its associated support equipment to operate the sUAV and to receive a wide range of data. The third package includes platforms and software that allow processing incoming data.

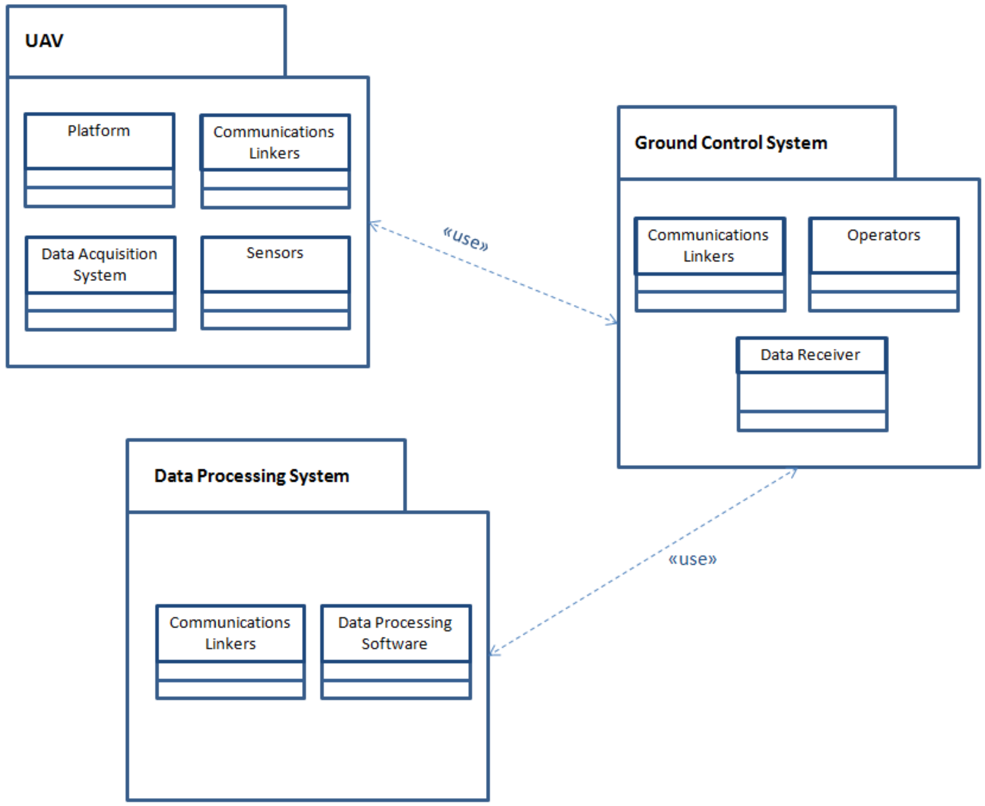


FIGURE 2: Package Diagram of sUAV.

3. CAMERA AND SENSORS INSTALLED IN THE sUAV

Nowadays, sUAV can be equipped with extensive range of sensors and cameras. The miniaturization and the cost-effectiveness of sUAV on one side, and the smart sensors and the high resolution cameras on board on the other, make them flexible and adaptive for several high-performance applications.

The technology used depends on the size of the sUAV and the type and detail of data to be collected. The range of advanced imaging and sensor technologies that can be mounted on sUAV commonly includes GPS, INS, Standard cameras, hyperspectral and multispectral cameras, thermal sensors, LiDAR and Radar sensors and several other specialized sensors.

3.1 GPS (Global Position System) and INS (Inertial Navigation System)

The autonomous navigation of sUAV is commonly realised using GPS device and inertial sensor. The GPS/INS data allow measuring the position and the orientation of the sUAV at all times and especially when the data is acquired.

3.2 Visible-range or Standard Cameras

Several configurations of the sUAV enable carrying onboard digital camera. Visible-range cameras used in many applications have low weights and high resolution such as Sony NEX-7.2 This kind of cameras that includes small and wide angle cameras provides fast images and real time videos of the target. In some case, especially in indoor environment where GPS data are not available, a vision navigation system based on this camera could be a good alternative [3].

3.3 Zoom Lens
Several cameras on board of sUAV are equipped with a zoom lens. It allows to magnify any part of the scene and to capture small details from greater distances without being perceived.

3.4 Hyperspectral and Multispectral Cameras
Hyperspectral sensors contain bands with narrow wavelengths while multispectral sensors contain bands with broad wavelengths [4]. Multispectral imagery generally refers to 3 to 10 bands that range from the visible to NIR. Hyperspectral sensors consist of much narrower bands and generate more than 200 spectral bands that range from the visible to short wave infrared.

An example of low cost multispectral sensor is Tetracam Mini MCA-6 that weighs 0.7 kg and includes 6 bands. It is used to extract vegetation and soil information such as plant stress factors, soil types and vegetation indices [5].

Many companies have produced hyperspectral sensors that can be mounted on sUAV and consist of tens to hundreds of narrow wavelength intervals like Micro-Hyperspec sensor by Headwall. Hyperspectral sensors provide high spectral resolution imagery that can be used to characterize biophysical properties and chemical composition of vegetation, water and soil.

3.5 Infrared or Thermal Sensors
Thermal sensors can be integrated to the sUAV and used to detect targets using their thermal signatures. FLIR T620 thermal digital camera is an example of these onboard devices [6] thanks to its small size (57.4 x 44.4 mm) and low weight (around 100 g).

3.6 Stabilized Camera Platform
It is a system that compensates the roll, pitch and yaw angles of the drone to keep the camera stable and pointed at the target. Likewise, it allows stabilizing the camera as well as moving it and reducing the camera shake and the motion blur.

3.7 Radar Sensors
Several miniature radar sensors are developed to be carried by any sUAV platform and to perform both target detection and identification. They are used to collect a data of several objects such as crops, forests, ice flows, and oil spills [7]. IMSAR's NanoSAR C is an example of these miniatures that has a weight of less than 1.3 Kg and a resolution of 0.3 m resolution at 2000 m height.

3.8 Laser Scanners
Laser scanners or LiDAR systems offer the opportunity to collect reliable and dense 3D point data over objects under consideration. They have become a cost solution for quickly and accurately capturing spatial data in complex urban, forest and agricultural areas. An UAV-LiDAR System is developed in [8] for forest applications. The sensor on board is an Ibeo LUX laser scanner which has a maximum range of 200 m. It scans in 4 parallel layers with a transversal beam divergence of 0.8°.

3.9 Special Sensors
Many other sensors may be used in sUAV platform depending on the type of the data to be collected or the parameters to be measured such as sonar, acoustic, chemical or radiation sensors [9].

4. sUAV APPLICATION FIELDS
The technological development in control command systems, passive and active sensors, digital cameras and communication systems offers a major improvement potential for sUAV applications. In the last two decades, many applications proposed sUAVs equipped with high resolution camera and satellite positioning system. They allow to acquire images from greater distances with greater resolution and to provide low-cost and accurate solution for several

applications. Consequently, there has been great interest expressed by public and private sectors in exploiting the advantages of sUAV (Figure 3).

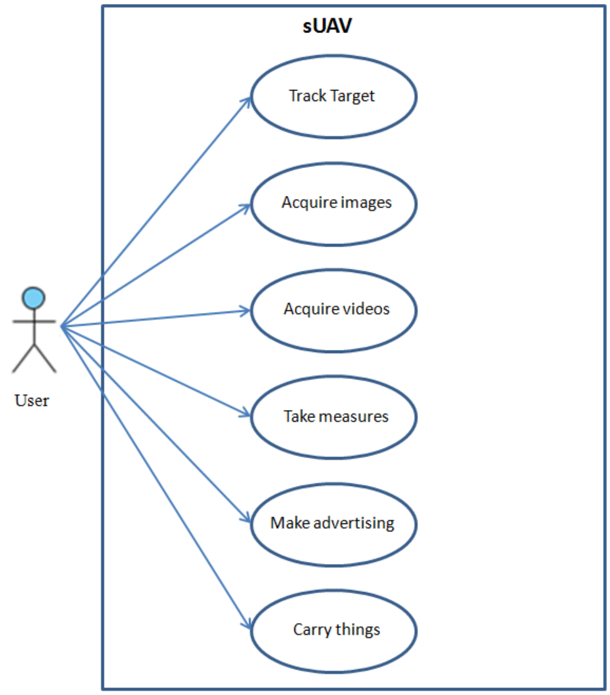
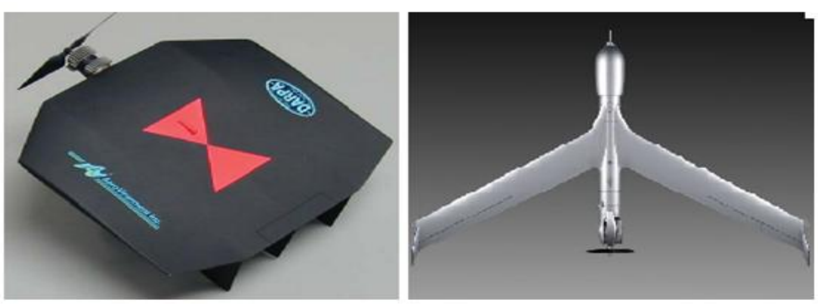


FIGURE 3: Use Case diagram of sUAV.

4.1 sUAV FOR MILITARY AND SECURITY APPLICATIONS

The success of the sUAV in several operations increases their use in military force. Commonly, the sUAV were not used in the attack missions because of their low-altitude flying. However, the advantageous characteristics of sUAV such as low radar cross section, low infrared signature and low acoustic signature make their use possible for tactical and strategic missions. ScanEagle (Figure 4(b)) for example is a micro unmanned aerial vehicle that combines low-cost, long endurance and the ability to carry out security operations for US Navy and Marine Corps [10]. It is operated via LOS data links and employs EO/ IR sensors. It aids to provide situational awareness for Marines in certain cases where it is physically impossible to use some other way.

Many sUAV are also developed for military application such as the Black Widow (Figure 4(a)). It is a 6-inch span, fixed-wing aircraft. It operates at 30 mph, with an endurance of 30 minutes and a maximum communications range of 2 km. It is developed for military surveillance and law enforcement [11].



(a) Black Widow *(b) ScanEagle*

FIGURE 4: Example of sUAV for military applications.

4.2 sUAV for Photogrammetry and Remote Sensing

Remote sensing data acquired from earth observation satellites and piloted aircraft provide valuable tools for measuring in many applications. Recently, the miniaturization and the cost-effectiveness of inertial sensors, GPS devices, multispectral sensor and cameras have enabled the use of sUAV.

The ability to use sUAV forms a rapidly developing area of research in remote sensings in the last decade. Many hyperspectral sensors were developed for sUAV applications [12]. UAV-HYPER sensor is an example of sensor developed by Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences. It is a pushbroom scanner that utilizes linear CCD arrays and contains 128 bands (cover the spectral range from 350 to 1030 nm). The SNR estimation and the radiometric evaluation of this sensor were performed in [13].

Frequently, remote sensing data derived from multispectral, hyperspectral and thermal sensors, digital cameras, laser scanners, radars, and GPS. The authors in [14] have developed a sUAV capable of collecting hyper resolution visible, multispectral and thermal imagery for application in precision viticulture. A digital SLR camera was adapted to carry out multispectral camera that operates in six bands set by fitting specific filters. The images were used to estimate vegetation reflectance and indices.

For many situations, sUAV equipped with imagers and other kinds of sensors provide a multi-scale remote sensing to collect spatial and temporal information of Earth’s surface [15] and to obtain a wide variety of environmental observations [16].

LiDAR offers the opportunity to collect reliable and dense 3D point data over objects under consideration. The authors in [17] have presented a remote sensing system composed of a small T-Rex 600E helicopter and an Ibeo Laser Scanner for fine-scale mapping (tree height estimation, road extraction, and digital terrain model refinement). Another integration includes a multirotor UAV (OktoKopter Droidworx/Mikrokopter AD-8) and an Ibeo LUX automotive scanner [18]. This system was validated for forest structure mapping.

Photogrammetry is the process whereby geometric, physical, semantic or/and temporal information are determined through the use of images, especially aerial images. The use of sUAV in photogrammetry gives various and new applications mainly in difficult indoor and outdoor environment and introduces also low-cost alternatives to the classical manned aerial vehicle. Many unmanned aerial sensor platform have been developed in the literature for photogrammetric applications such as micro-drone md4-200 with attached PENTAX Optio A40 camera [19] or Gatewing X100 and Ricoch GR Digital camera [21]. The GPS/INS data allows the measurement of the position and the orientation of the camera frame when the image is acquired. High resolution images and data collected by sensors mounted on the sUAV can be used to produce high quality aerial orthophoto (orthoimage) and digital surface models (DSM).

An essential step for remote sensing and photogrammetric applications is the mission or the flight planning. Several software solutions were developed to cover the whole territory and to plan and control autonomous flights. The main inputs of the software are sensors characteristics, camera characteristics, target characteristics, the flight spend and the desired overlap.

4.3 Surveillance and Safety Applications

Several works in the literature have proposed sUAV as a potentially useful tool for indoor and outdoor surveillance applications. Indeed, sUAV platforms allow to monitor a target at different altitudes or from different viewpoints. They provide cost-effective options for several surveillance applications. Commonly, monitoring system should be capable to perform target acquisition, localization, and surveillance [21].

The sUAV can be applied into forest fire damage assessment and mapping. Casbeer et al. have presented an approach for forest fire surveillance using a single sUAV equipped with an infrared camera [22].

The combination of micro-sensors and sUAV represent a good alternative to support public safety. In fact, a special sUAV and micro-radar can be used to obtain advanced warning and damage assessments of severe storm or especially of the manifestation of a tornado event [23].

In some cases, the data generated by small and micro unmanned systems is processed in real time and can be useful in building situational awareness. In fact, a sUAV equipped with video cameras provides the users with required data to facilitate their critical decision-making. For instance, it provides fast images as well as real time videos of a range of locations around the jobsite in order to explore potential benefits for safety managers [24].

One of the recent uses of sUAV is in safety applications. When a tsunami struck the Fukushima nuclear power plant in Japan on the 11 March 2011, Japanese company developed a drone (TEPCO) that is able to fly inside the reactor buildings and is equipped with a camera, a dust collector and devices to measure radiation levels.

Surveillance operations include also inspecting and monitoring boundaries and coastal lines. A sUAV can be deployed along an area to provide useful data for Maritime interception/interdiction operations [25].

4.4 Forestry and Agriculture

Forestry and agriculture applications often require images with a high spatial and temporal resolution. The low operating altitude of sUAV compared to piloted aircraft, allows the acquisition of high spatial-resolution imagery. The low-cost platforms of sUAV offers a good solution to acquire imagery more frequently and then provides higher temporal resolution when compared to the use of satellite or piloted aircraft imagery.

In forestry applications, sUAV may be used to:

- Detect forest fire [22].
- Monitor illegal forest exploitation using real time or time-series images [26].
- Access to inaccessible or challenging areas as in many tropical countries [26].

In precision agriculture, the sUAV and the imaging sensors on board have been applied to collect different kinds of data about soil and crop. Commonly, they may be used to:

- Manage agricultural production and material protection [27]
- Estimate crop growth and food quality [28]
- Perform aerial pesticide delivery in order to reduce human intervention [29]
- Quantify the loss due to an accidental damage caused by insect, inundation, severe storm.

4.5 Urban Planning, Architecture, Civil Engineering and Mining

sUAV, with precise sensors (such as GPS and IMU), high resolution camera and image stabilizers on board, becomes an accurate and reliable measuring instrument.

Recently, sUAV appears to be a valuable topographic surveying technique in architecture and civil engineering applications. Its great advantages are as follows:

- It is easy to use and allows the collection of data without having to rely on heavy equipment or deploying a team.
- It allows a quick access to precise data and simplifies the various steps of on-site operations.
- It is a cost-effective solution. In fact, it surveys a territory using only few vols. Therefore, the technique is more cost-effective than using ground surveys.
- It is able to manage large datasets and to access complex urban sites.

- It is sometimes able to self-orientate and navigate without a permanent GPS signal using altitude and heading reference system and inertial system.

In the architecture applications, sUAV can be applied to optimize the design by allowing pre-project surveys and environment 3D models. For example, an effective method to detect and extract architectural buildings under rural environment from sUAV video sequences was presented in [30]. sUAV is used to capture stereo images. Then, the matching targets (stereo correspondence) are extracted between them and the estimated 3D model is estimated through stereo triangulation.

The sUAV has also great potentials in terms of infrastructure inspection and traffic management by providing both static data acquisition and dynamic data streaming. In fact, sUAV can fly sufficiently close to the target and capture the smallest weaknesses or defects [31]. sUAV can move at higher speeds than ground vehicles (without road problems or restrictions). Consequently, it is an important alternative solution to rapidly monitor freeway conditions and track vehicle movements [32].

sUAV platforms is an important tool also for a precise modeling of a challenging environment such as mines and carries. They are able to operate inside small and confined areas and to quantify the volume of production and the progress of deposits using high resolution aerial imagery.

4.6 Energy and Power Industry Applications

sUAV can generate more specific and accurate data than manned system using special tool such as differential thermal imaging. This advantage allows the use of sUAV to monitor oil and gas pipeline. An example of this platform was developed by Barnard Microsystems to achieve pipeline monitoring and oil and gas security using both thermal and visual imaging systems on board of sUAV.

The authors in [33] have proposed two different scenarios for unmanned aerial vehicle based pipeline monitoring systems. The first platform had a weight of less than 20 Kg (sUAV) and an endurance of 5 to 6 hours. The second platform weights more than 200 Kg (Medium) and the degree of autonomy is up 30 hours. Experimental investigations have been performed using an optical/infrared multispectral scanner.

The use of sUAV has specific benefits in power industry applications. Indeed, sUAV can fly over and around the power lines and structure and can closely examine the element of danger for the pilot and the inspector. Using GPS and high resolution camera, it is possible to acquire reliable data that includes position, some related images, and possible defects or warnings for overhead power line [34].

4.7 Delivery Applications

Recently many companies such as Amazon and Dominos had explored the potential benefits of drones in the field of delivering products. Amazon announced a drone delivery called Prime Air and designed to safely get packages to customers. The Federal Aviation Administration (FAA) gave approval to test the drone's ability to deliver an order under certain conditions [35]. Domino's Pizza is also testing“Domicopter” drones to deliver pizzas in the United Kingdom [36].

The main challenge to use sUAV for delivery applications and for several other applications is how to ensure the individual privacy and to respect government regulations.

In all of these sUAVs applications in literature, a combination of factors affects accuracy of the proposed solution or product. Indeed, several factors can directly influence the expected results of these techniques such as the sensors potential accuracy (both navigation and measuring sensors), the stability of flight, the number and the quality of the measures and the type and the quality of the data processing.

The effect of these factors has not been evaluated in most proposed studies in literature.

A sufficient number of well-distributed ground control points are required to perform accurate product mainly in photogrammetric and remote sensing applications. This has not been fully explored in many research works.

A set of sensors has been integrated with sUAV. Some of them have the ability to provide high quality solution. Some others are distinguished by their relative low cost. Additional researches are clearly required to evaluate the price-quality relationship of several sensors combinations in order to select the most advantageous or appropriate solution.

5. OBSTACLE AVOIDANCE

The sUAV are challenged by a variety of static and dynamic obstacles on one hand, and by the weather conditions that reduce the visibility and complicate the real-time detection and the collision avoidance on the other hand.

UAV-based photogrammetric systems with obstacle detection algorithm were proposed in previous works [37]. Their accuracy is mainly influenced by the accuracy of the navigation sensors and the platform calibration.

sUAV operates in 3D space which is a challenging environment compared to 2D space for a ground robots for example. Several algorithms are proposed to avoid obstacles, depending on characteristics of the environment in which the vehicle flies. Generally, there are three steps involved in the obstacle avoidance operation:

1. Detect the obstacle and its characteristics such as its size, its height and if it is dynamic or static.
2. Evaluate the collision situations and estimate the distance to the possible collision site.
3. Re-plan an optimal path to avoid it.

There are several techniques that allow the detection of the obstacle position and the estimation of the relative distance from the UAV's camera to it. The most known technique is performed using geometric constraints in multi-view images taken at different moments. It is the stereovision technique that allows the 3D reconstruction of an obstacle observed from two or several viewpoints. Indeed, one [38] or two cameras [39] are used to capture multiple images, extract the matching targets (stereo correspondence of the target) between them and compute the 3D localisation through stereo triangulation. This allows to estimate the distance to the possible collision site through establishing a distance threshold for the 3D stereo data and to recompute a collision free trajectory by a path planning algorithm.

A low coast laser ranger can be also mounted on a sUAV to detect obstacles directly in front of it and to generate new waypoint paths around them [40].

Otherwise, LiDAR becomes a promising technology to achieve accurate results for obstacle avoidance. The challenges associated with the use of this technology are the extent of its Field-of-View (FOV) and its detection performance at various incidence angles [41].

Obstacle avoidance is a challenging research problem with a wide array of sensors including cameras, radars, and laser scanners. Recent years have seen a growing number of sUAV specialized hardware and software developed to react to obstacles and to avoid them.

Several developed techniques achieve accurate results mainly in outdoor applications, but can’t be relied upon when navigating indoors, particularly when GPS data are used. Some used sensors have very limited range and/or require good lighting. When Cameras are used, various image sequences are provided and detection algorithms are generally complex and require higher processing power and memory.”

Further research using combinations of small size and low weight sensors may provide real-time localisation and insure the avoidance of obstacles in both indoor and outdoor environments.

6. ISSUES RELATED TO THE USE OF sUAV

A number of questions arise from the use of sUAV technology such as safety, security, privacy and regulatory [42]. The operation of sUAV in dangerous territories could cause serious injuries. Their uses in populated areas can also involve privacy violations.

Several governments regulate their use to keep the public and the airspace safe. In Canada for example, the use of sUAV for any form of work or research requires the user to apply for a special flight operations certificate. Indeed, Transport Canada, as many government agencies in other countries, introduces rules to ensure air, marine, rail and road safety regarding the use of these new technologies.

The operator should provide the procedures/rules that are utilized to manage physical and technical security of the sUAV system such as the take-off and landing performance in normal and emergency situations and collision avoidance especially in a populated area.
He should also specify how sUAV regulation ensures the privacy right of individuals.

7. CONCLUSION DISCUSSION

Due to its attractive price and its small dimensions, sUAV is now a competitive solution for rapidly and accurately measurement in difficult indoor and environment and complex applications. The objective of many works in progress is to develop a sUAV that produces on-time and accurate reliable sensor trajectory and spatial measurement and senses and avoids obstacles. A new integration approach between LiDAR, sonar, IR data and panoramic image could be developed in the future to achieve accurate results in quite large variety of indoor and outdoor applications and to increase the autonomy level of sUAV. Several research projects, such as that carried out in [43], could be achieved to compromise between the increase of sUAV use on one side and the respect of the privacy and the preservation of human and material security on the other.

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