Unmanned Aerial Vehicles: An Overview

MARIA DE FÁTIMA BENTO

A Raven B Mini UAV, during system checks before its maiden flight over Kirkuk, Iraq

U.S. Air Force Photo/Senior Airman Jeremy McGuffin

Imagine yourself in the middle of a battlefield with only one truly compelling objective: to maneuver yourself from one point to another and execute your mission – with the reward of your own survival. One eye on the threat, one eye on the horizon! Tension perhaps a deep fear seizes you as you confront mortal danger. This is your last shot! Wouldn't you rather make it while seated behind a desk at a mission control station far from the raging conflict, directing an aerial vehicle without a human on board? A powered, aerial vehicle that can do more for than you could personally on the battlefield yourself?

Once we tried to Google "UAV" and got more than two million citations on the Internet.

Try to find *the* definition of unmanned aerial vehicle (UAV) and you'll uncover a welter of choices in the literature. So, let's just say that a UAV is an aerial vehicle capable of sustained flight without the need for a human operator onboard.

Although unmanned aerial vehicles (UAVs) are mostly used in military applications nowadays, the UAVs can also perform such scientific, public safety, and commercial tasks as data and image acquisition of disaster areas, map building, communication relays, search and rescue, traffic surveillance, and so on.

A UAV can be remotely controlled, semi-autonomous, autonomous, or a combination of these, capable of performing as many tasks as you can imagine, including saving your life. Nowadays, UAVs perform a variety of tasks in both military and civil/commercial markets. Indeed, many different types of UAVs exist with different capabilities responding to different user needs.

The purpose of this column is to give the reader an overview of the large number of existing UAV systems and R&D projects as well as the practical challenges facing UAV designers and applications.

UAV Classification

Several different groups have proposed creation of reference standards for the international UAV community. The European Association of Unmanned Vehicles Systems (EUROUVS) has drawn up a classification of UAV systems based on such parameters as flight altitude, endurance, speed, maximum take off weight (MTOW), size, and so forth. We should stress the fact that EUROUVS did not create this classification for certification purposes, but rather with the main purpose of compiling a universal catalog of UAVs categories as well as their associated acronyms.

Table 1, adapted from a EUROUVS publication, presents the various existing UAVs with examples of their usual missions.

Table 1 identifies four UAVs main categories: micro/mini UAVs (MAV/Mini), tactical UAVs (TUAVs), strategic UAVs, and the special task UAVs where only the Decoy and Lethal are currently flying. Let's take a closer look at each of these.

Micro and Mini UAVs. Micro and mini UAVs comprise the category of the smallest platforms that also fly at lower altitudes (under 300 meters). Designs for this class of device have focused on creating UAVs that can operate in urban canyons or even inside buildings, flying along hallways, carrying listening and recording devices, transmitters, or miniature TV cameras.

The U.S. Defense Advanced Research Projects Agency (DARPA) has developed a set of criteria with which to distinguish

	Category (acronym)	Maximum Take Off Weight (kg)	Maximum Flight Altitude (m)	Endurance (hours)	Data Link Range (Km)	Example	
						Missions	Systems
Micro/Mini UAVs	Micro (MAV)	0.10	250	1	< 10	Scouting, NBC sampling, surveillance inside buildings	Black Widow, MicroStar, Microbat, FanCopter, QuattroCopter, Mosquito, Hornet, Mite
	Mini	< 30	150-300	< 2	< 10	Film and broadcast industries, agriculture, pollution measurements, surveillance inside buildings, communications relay and EW	Mikado, Aladin, Tracker, DragonEye, Raven, Pointer II, Carolo C40/P50, Skorpio, R-Max and R-50, RoboCopter, YH-300SL
Tactical UAVs	Close Range (CR)	150	3.000	2-4	10-30	RSTA, mine detection, search & rescue, EW	Observer I, Phantom, Copter 4, Mikado, RoboCopter 300, Pointer, Camcopter, Aerial and Agricultural RMax
	Short Range (SR)	200	3.000	3-6	30-70	BDA, RSTA, EW, mine detection	Scorpi 6/30, Luna, SilverFox, EyeView, Firebird, R-Max Agri/Photo, Hornet, Raven, phantom, GoldenEye 100, Flyrt, Neptune
	Medium Range (MR)	150-500	3.000-5.000	6-10	70-200	BDA, RSTA, EW, mine detection, NBC sampling	Hunter B, Mücke, Aerostar, Sniper, Falco, Armor X7, Smart UAV, UCAR, Eagle Eye+, Alice, Extender, Shadow 200/400
	Long Range (LR)	-	5.000	6-13	200-500	RSTA, BDA, communications relay	Hunter, Vigilante 502
	Endurance (EN)	500-1.500	5.000-8.000	12-24	> 500	BDA, RSTA, EW, communications relay, NBC sampling	Aerosonde, Vulture II Exp, Shadow 600, Searcher II, Hermes 450S/450T/700
	Medium Altitude, Long Endurance (MALE)	1.000-1.500	5.000-8.000	24-48	> 500	BDA, RSTA, EW weapons delivery, communications relay, NBC sampling	Skyforce, Hermes 1500, Heron TP, MQ-1 Predator, Predator-IT, Eagle-1/2, Darkstar, E-Hunter, Dominator
Strategic UAVs	High Altitude, Long Endurance (HALE)	2.500-12.500	15.000-20.000	24-48	> 2.000	BDA, RSTA, EW, communications relay, boost phase intercept launch vehicle, airport security	Global Hawk, Raptor, Condor, Theseus, Helios, Predator B/C, Libellule, EuroHawk, Mercator, SensorCraft, Global Observer, Pathfinder Plus,
Special Task UAVs	Lethal (LET)	250	3.000-4.000	3-4	300	Anti-radar, anti-ship, anti-aircraft, anti-infrastructure	MALI, Harpy, Lark, Marula
	Decoys (DEC)	250	50-5.000	< 4	0-500	Aerial and naval deception	Flyrt, MALD, Nulka, ITALD, Chukar
	Stratospheric (Strato)	TBD	20.000-30.000	> 48	> 2.000	-	Pegasus
	Exo-stratospheric (EXO)	TBD	> 30.000	TBD	TBD	-	MarsFlyer, MAC-1

Source: Adapted from "UVS-International-"UAV System producers & Models: All UAV Systems Referenced," 2006

TABLE 1. UAV Classification

Micro UAVs Requirements:	
Specification	**Requirement**
Size	< 15 cm
Weight	100 g
Payload	20 g
Range	1-10 Km
Endurance	60 min
Altitude	< 150 m
Speed	15 m/s
Source: "Challenges facing future micro air vehicle development", D.J. Pines & F. Bohorquez AIAA Journal of Aircraft, April 2006	

TABLE 2. Mav requirements

micro UAV. These criteria are presented in Table 2.

With the DARPA requirements in mind and referring to some of the systems and performance specifications presented in Table 1, we can see that certain small UAVs systems identified in the literature don't actually satisfy all the DARPA requirements yet. These include the Black Widow and Microbat from Aerovironment, the FanCopter by EMT, and the MicroStar by BAESystems.

The ambitious performance goals represented in Table 2 are still unattained, perhaps due to the fact that not all technologies are scalable yet and also to UAV designers' inability to overcome environmental constraints with available technology.

The development of micro-electromechanical systems (MEMS) in recent years may help overcome these constraints by enabling the production of small, highly functional navigation hardware (MEMS accelerometers and piezoelectric rate gyros), room temperature infrared (IR) sensors and charge-coupled device (CCD) cameras arrays. (We will return to the subject of MEMS later.) Propulsion and energy storage technologies still remain critical research challenges for micro UAVs.

Turning to the category of Mini UAVs as described in Table 1, we can define these as any UAV under 30 kilograms flying at altitudes between 150 and 300 meters, with an endurance of about two hours of operation. Although mini UAVs are currently predominant — especially rotary wing mini UAVs with capabilities of vertical take off and landing (VTOL) — in the near future micro UAVs are expected to become more practical and prevalent. Thus, the prospects are good for micro and mini UAVs to become intelligent "aerial robots," that is, fully autonomous thinking machines.

Tactical UAVs. This category includes heavier platforms flying at higher altitudes (from 3,000 to 8,000 meters). Unlike micro and mini UAVs, which are mostly used for civil/commercial applications, tactical UAVs primarily support military applications.

Referring again to Table 1 criteria, tactical UAVs can be divided in six subcategories: Close range (CR), Short Range (SR), Medium Range (MR), Long Range (LR), Endurance (EN), and, finally, Medium Altitude Long Range (MALE) UAVs.

The lack of satellite communications (Satcom) systems limits the distances over which close-, short-, and medium-range UAVs can operate. The absence of Satcom equipment is mainly due to the size, weight, and cost of antennas for this type of UAV.

Long-range UAVs, however, must use more advanced technology in order to achieve their missions. Usually, this means incorporating a satellite link or another platform acting as a relay, in order to overcome the communication problem between the ground station and a UAV caused by the earth's curvature.

Medium-range UAV platforms feature more advanced aerodynamical designs and control systems due to their high operational requirements, as exemplified by the AAI Corporation's Shadow 200 and 400 aircraft.

As for MALE UAVs, many readers have probably already heard about the MQ-1 Predator designed and built by U.S. General Atomics Aeronautical Systems. The Predator can operate for up to 40 hours at a maximum range of 3,704 kilometers and has seen extensive service in Kosovo, Afghanistan, and in other areas of conflict that puts human pilots at risk. Predators can carry and release precision guided missiles, however, endurance UAVs are considered the most sophisticated UAV systems for these purposes as a result of their large dimensions and high capabilities.

Strategic UAVs. As our discussion to this point suggests, at higher altitudes UAVs tend to be heavier platforms with longer range and endurance. Indeed, that makes sense, because big platforms can carry a larger payload and, in order to reach greater distances while flying for longer time, they require more energy. Thus, big platforms are usually used for high altitude, long endurance and long range purposes as is the case of the High Altitude Long Endurance (HALE) UAVs, which comprise the heaviest UAVs.

HALE platforms are strategic UAVs with a MTOW varying from 2.500 kilograms up to 12.000 kilograms and a maximum flight altitude of about 20,000 meters. They are highly automated, with takeoffs and landings being performed automatically. At any time during its mission the ground control station (GCS) can control the HALE UAV. Northrop Grumman's military UAV, the Global Hawk, with 35 hours of endurance is probably the most well-known HALE UAV and offers truly remarkable performance.

An example of a non-military HALE is the electric/solar-powered Helios from Aerovironment operated by NASA. The Helios uses solar panels to power electrically driven propellers and has set an altitude record of about 30.000 kilometers. This UAV's design offers many attractive features for civil tasks, such as Earth observation augmenting and complementing remote sensing satellites. Other HALE UAV applications include communications, mapping, and atmospheric monitoring.

VTOLs

A feature of particular interest in rotary wing UAVs is the capability for vertical take off and landing (VTOL). Although different in weight and configurations, the VTOL UAVs can be found in the mini, CR, SR, MR, and MALE categories. Indeed, the use of VTOL-capable UAVs is rapidly increasing due to their ability to hover over specific sites and fly at low altitudes in urban areas.

These capabilities make them favorites for civil and commercial applications such as surveillance and reconnaissance in urban canyons and indoors. Consequently, several institutes are working with this type of platform to aid their research projects, frequently presenting their results at events such as the International Aerial Robotics Competition organized by the Association for Unmanned Vehicle systems International (AUVSI).

Because VTOL platforms are mostly used by research institutes and agencies, tactical or strategic UAVs are unsuitable as test platforms for their experiments. Thus, an interest and need persists for designing micro and mini UAVs with the same degree of autonomy as their larger counterparts.

Technology and UAV Autonomy

The operational requirements of small UAVs — such as flying close to the ground and inside buildings with a lot of obstacles — introduces problems for a simplistic application of technologies used in larger UAVs. For instance, GNSS-based navigation is successfully used in tactical and strategic UAVs, but is less suitable for smaller UAVs operating close to the ground or around obstacles. This has helped stimulate the application of MEMS technology in highly integrated and light-weight navigation systems, as well as the development of miniature sensors such as microcontrollers and autopilots.

Neither inertial nor GNSS navigation systems can provide guidance or collision avoidance for autonomous close-proximity flight, however. These operations require an accurate position estimation of the UAV relative to surrounding objects. For their part, radar technologies are too large and heavy to use for in smaller UAVs. However, the development of CMOS cameras and improved digital imaging has promoted the development and application of "camera images" for these purposes in small, autonomous UAVs.

Visual sensing can provide a source of data for relative position estimation, situation awareness, and a UAV's interaction with the physical world and probably represents a more preferable technology for these purposes than either GPS or INS.

On the other hand, however, data from sensors such as the GPS, IMU, and magnetometer, when combined with the information obtained from sequences of images, can significantly increase the situation awareness of the vehicle and its operator. So, visual techniques are used for positioning in several UAV projects, and computer vision plays the most important role in the environmental sensing accomplished by UAVs.

Inertial Sensors

Inertial navigation systems — or, more precisely, inertial measurement units (IMUs) — are widely used as sensors for position estimation. Current IMU technologies come in many shapes, sizes, and costs, depending on the application and performance required. Small, lightweight, power-efficient, and low-cost MEMS inertial sensors and microcontrollers available in the market today help reduce the instability of such platforms making them easier to fly.

Although MEMS inertial sensors offer affordable, appropriately scaled units, they are not currently capable of meeting UAV requirements for accurate and precise and navigation due to their inherent measurement noise. If MEMS inertial accuracy can be improved by integrating them with other sensors while simultaneously developing improved estimation algorithms, however, adequate solutions may be found.

Although external sensors, such as vision/radar, are widely used in autonomous UAVs, the GPS/INS integration is still the most commonly used option in such applications. The best estimate is obtained by combining both INS and GPS measurements using one of the existing GPS/INS integration methods. Typically, these techniques rely upon filtering techniques to achieve accurate state estimation.

Aerovironment's Helios strategic UAV modified for use by NASA in environmental monitoring

NASA Tom Tschida

State Estimation Methods

One of the most important capabilities of an autonomous UAV is its state estimation or localization. In fact, reliable localization is an essential component of every autonomous land, underwater, and air vehicle.

The most common algorithm used for state estimation is based on theoretical estimation algorithms such as the Kalman filter (KF) and the extended Kalman filter (EKF). Indeed, the KF offers an efficient, iterative means of combining information from several sensors in order to provide the best estimate of the state of the vehicle.

Currently, two methods are most commonly used to estimate the VTOL UAV state. The first is to use a state-space helicopter model from which a KF-based estimator can be built. Typically, the dynamics of the helicopter is described using a conventional six-degrees-of-freedom (6 DOF) rigid body model: three degrees for translational motion (along the three body axes) and three degrees for rotational motion. Thus, the equations that describe the translational and rotational movement of the helicopter can be derived (from the Newton-Euler equations for a rigid body) and then expressed by a state-space model.

The second approach is to use a sensor model and forget the complex helicopter model, which is the preferred option.

A survey regarding the estimation methods for integrated navigation systems has identified three common approaches: the linearized Kalman filter (LKF) or the extended Kalman filter (EKF); sampling based filters, such as particle filters and the unscented Kalman filter (UKF); and artificial intelligence–or AI-based methods. The latter category include such techniques as artificial neural networks (ANN) or adaptive neural fuzzy information systems (ANFIS).

The LKF or EKF has seen extensive use in the design of navigation software. Given the simplicity and low computational demand of LK filters, they have been very attractive for low-cost UAV applications. The EKF can provide a more accurate solution but is more complex than the LKF. It also requires a higher computational overhead.

Both of them have been used in a variety of applications and have distinct advantages and disadvantages; so, the choice of which one to use will depend on the particular situation at hand.

The EKF has been successfully applied to helicopter-state estimation problems. However, a 2004 comparison analysis discussed in the paper by M. St-Pierre and D. Gingras, cited in the Additional Resources section at the end of this article) showed that the EKF exhibited some weakness in comparison to the UKF. In fact, because the sensor model used in the filter is strongly nonlinear, the UKF's estimation performance is better. Moreover, implementation of this sampling-based filter is simpler than that of the EKF due to the fact that no derivatives of the state equations need to be calculated. For application in small UAVs, this point is very important given the limitations of on-board computer power.

Wan Van der Merwe has proposed an interesting approach to state estimation involving the possibility of implementing the UKF in its square root form, which has been demonstrated to present improved numerical stability along with reduced computational complexity. (See his paper cited in Additional Resources for further details.)

A research group from Stanford University has also presented a method for navigating a small UAV through an unsurveyed environment. (See the paper by J. Langelaan and S. Rock in Additional Resources.) The authors address the problem of estimating the state of an air vehicle in its environment given the used of limited sensors. The results of the simulations conducted in two dimensions show that while an EKF implementation diverges, the UKF implementation generates consistent estimates of the state of the vehicle.

Another sampling-based filter is the particle filter, also known as sequential Monte Carlo filter, which has been widely developed for nonlinear/non-Gaussian processes based on the Bayesian filtering theory. These methods have been put aside mainly due to the lack of computing power. However, recent work has sought to apply these methods in some practical problems such as communications, computer vision, and target tracking for radar.

Finally, we have AI-based estimation methods that are well differentiated from the other types presented previously. AI-based estimation differs from other methods in its lack of any mathematical models in the system dynamics and measurements. Although these methods are considered to be simpler to implement in terms of design, they present some limitations such as the fact that no statistical information is used as input. As a result, they do not present statistics associated with the solution as output, which plays an important role in post-processing applications.

Other AI-based approaches for dealing with the navigation and control of the UAVs include non-linear adaptive control and fuzzy logic.

UAVs Challenges

With this background, we can now identify the main issues facing the development of improved UAV capability which are autonomous micro and mini UAVs, autonomous VTOL applications, and vision-based systems for navigation and control of autonomous vehicles. In addition to that, collision avoidance, the development of simultaneous localization and mapping algorithms (SLAM) and multi-vehicle systems are also challenges that need to be overcome.

UAV Autonomy. Some of the intended applications proposed for small UAVs — such as flying close to the ground, inside buildings, or around a lot of obstacles — introduces problems for a simplistic application of technologies used in larger UAVs. For instance, GNSS-based navigation is successfully used in tactical and strategic UAVs, but is less suitable for smaller UAVs.

Most micro UAVs are too small for remote control instrumentation, such as traditional stability-and-control or navigation aids. Thus, the autonomy of flight of such vehicles is an issue of great importance.

Neither inertial nor GNSS navigation systems can provide guidance or collision avoidance for autonomous close-proximity flight, which requires an accurate position estimation of the UAV relative to surrounding objects. For their part, radar technologies are too large and heavy to use in smaller UAVs. The application of MEMS technology in highly integrated and light-weight navigation systems will help the situation, along with the development of miniature sensors such as microcontrollers and autopilots.

Other factors that need to be addressed to achieve autonomy for small UAVs, as reflected in the DARPA criteria in Table 2, include: aerodynamics at low Reynolds numbers; miniaturization of the airframe, components, and payload; collaborative control; new concepts in inertial and remote sensing, propulsion, and energy storage; integration of air traffic management, and robust communications (secure and unjammable).

Vision-Based Systems. Visual sensing can provide a source of data for relative position estimation, situation awareness, and a UAV's interaction with the physical world and probably represents a preferable technology for these purposes than either GPS or INS.

At the same time, data from sensors such as GNSS, IMUs, and magnetometers — when combined with the information obtained from sequences of images — can significantly increase the situation awareness of the vehicle and its operator. So, visual techniques are used for positioning in several UAV projects, and computer vision plays the most important role in the environmental sensing accomplished by UAVs.

The development of CMOS cameras and improved digital imaging has promoted the development and application of "camera images" for these purposes in small, autonomous UAVs. Another area of considerable interest involves emulating the optic-flow vision of flying insects, which employ it to maneuver through regions with dense obstacles fields. Flying insects don't have GPS or IMUs to perform tasks such as collision avoidance, altitude control, take off and landing. Thus, in the last few years, new navigation and collision-avoidance techniques have been developed modeled on flying insects.

Obstacle Avoidance. Sensing technologies such as laser range finders or radar are available, but only for medium and large UAVs. These technologies are unrealistic for micro and mini UAVs due to their heavy weight and excessive power requirements. Because most UAVs carry cameras on board, however, it makes sense to use those as an alternative.


AAI's Aerosonde, an endurance UAV

AAI Corporation

Now, with cameras available the real challenge becomes one of creating a simple, efficient, robust, and computer vision algorithm that can convert images into a real-time guidance and obstacle-avoidance system practical for use in small UAVs.

Simultaneous Localization and Mapping (SLAM). SLAM algorithms are used to develop landmark-based, terrain-aided navigation systems, with the capability for online map building. Such systems simultaneously use the generated map to bind the errors in the inertial navigation system.

● SLAM techniques have been widely used for ground robot navigation but only a few are based on vision sensors. Usually these techniques are associated with GPS/INS sensors. A 2002 paper by S. Lacroix *et alia* (see Additional Resources) presents a new concept of autonomous UAV navigation based on a SLAM algorithm and applied on a 6 DOF airborne platform that the group's work demonstrated the potential for applying SLAM-augmented, low-cost GPS/INS systems to UAVs in GPS-denied situations, such as urban canyons, indoors, or even underwater.

Another example is the perception system designed for the Karma airship that applies stereo vision, interest point matching, and Kalman filtering techniques for simultaneous localization and mapping using only visual data. (See the referenced paper by J. Langelaan.) Other Stanford researchers (see K. Jonghyuk *et alia*) have developed a passive GPS-free navigation for small UAVs operating in areas where GPS signals are jammed or obscured by natural or man-made features. The navigation method is based on only an IMU and a monocular camera, with SLAM providing the cornerstone of this work.

Multi-Vehicle Systems. In many applications, the active cooperation of several different vehicles such as UAVs, unmanned ground vehicles (UGVs), and airships, has important advantages. Indeed, over the last few years, research on the coordination and cooperation of multiples vehicles not only research but competitive activities such as DARPA's Urban Challenge for UGVs have focused on coordination of multiple vehicles.

Recently, research supported by the Office of Naval Research and the University of California, Berkeley, led to a collaborative UAV design based on in-the-air task allocation and conflict resolution. Each UAV used in that project has onboard software that provides low-altitude, vision-based control, task selection and negotiation, and aircraft-to-aircraft communication.

This combination allows for a high degree of autonomy at both the individual and group level, requiring a mini-

Hunter MQ-5B, medium altitude endurance tactical unmanned aerial system

Northrop Grumman photo

mum of human intervention. Future work will include the development of a similar platform based on a larger airframe in order to provide greater weight and power allowances to allow longer flights and support a variety of sensing and communication devices. For more information, see the article by A. Ryan *et alia* cited in Additional Resources.

Another example is the BEAR (BErkeley AeRobot) project, which was presented at the 2002 International Conference on Intelligent Robots and Systems. BEAR uses a hierarchical multiagent system architecture for coordinated team efforts (helicopters and ground vehicles), including vision-based pose estimation of multiple UAVs and UGVs. Pursuit-evasion games and learning have also been presented in that research effort. The main goal of these games is to put a team of UAVs and ground vehicles in pursuit of a second team while concurrently building a map in an unknown environment.

Another good example of multi-vehicle systems is the COMETS project, funded by the Information Society Technologies (IST) Program of the European Commission. The main objective of COMETS is to design and implement a distributed control system for cooperative detection and monitoring using heterogeneous UAVs, particularly helicopters and airships.

The UAVs used in the experiments are the helicopters Marvin (TU Berlin), the Heliv (Robotics, Vision and Control group at the University of Seville, Spain), and the airship Karma developed by LAAS (Laboratoire d'Architecture et d'Analyse des Systèmes at Toulouse, France). The COMETS UAVs exploit the complementarities of distributed sensors on different platforms when they work together in the same mission, employing a vision-based, real-time image processing method for multi-UAV (VMUAV) motion estimation.

Another example of related academic research in this field is the University of Sydney, Australia, Autonomous Navigation and Sensing Experimental Research or ANSER project. ANSER demonstrates decentralized data fusion and SLAM methods on multiple UAVs.

UAV Research in Portugal

Considerable expertise in the coordination and control of ground, underwater, and surface autonomous vehicles has developed over the years in Portugal with which this author is familiar. Last year, two teams from the Faculty of Engineering of the University of Porto (FEUP) designed and built two airplanes for the Portuguese Air Cargo Challenge. The teams developed extensive knowledge in such areas as coordination and control, task planning and execution control of multiple vehicles, and for fleets of UAVs.

Led by FEUP, the so-called Asasf program seeks to gather the expertise acquired in airplane design with the existing expertise on the coordination and control of multiple vehicles in order to develop an innovative program on cooperative air vehicles. The main goal is the development of a system where air, ground, and aquatic vehicles perform coordinated actions in order to achieve a common goal.

FEUP is also one of the national institutes that participates in the "Projecto de I&T em veículos aéreos nao-tripulados" undertaken by the Portuguese Air Force Academy (PAFA) and Porto University (UP) with the support of the Ministério da Defesa Nacional. The main objective of this project is to promote PAFA R&D activities in several aeronautics-related areas of interest for the Portuguese Air Force (FAP), especially UAVs.

The PAFA UAV is designated ANTEX-M ((from the Portuguese acronym for "Aeronave Não-Tripulada Experimental – Militar").) This platform has to be able to demonstrate control systems, development of intelligent structures for detection of defects in aircraft, GNSS navigation system, and control of autonomous team vehicles.

Other partners in the ANTEX-M project are the Observatório Astronómico da Faculdade de Ciências da Universidade do Porto (OAFCUP) and Instituto de Engenharia Mecânica e Gestão Industrial (INEGI). The international partners in this project are the Institute of Geodesy and Navigation (IGN), University FAF Munich, Germany; the University of California at Berkeley (UCB), Center for Collaborative Control of unmanned Vehicles (C3UV) ;Swedish Defense Research Agency (FOI); Embraer, Empresas Brasileiras de Aeronáutica S.A (EMB), and Honeywell.

The main focus of IGN's portion of the project is to develop an accurate INS/GPS/Galileo navigation system as a source for feedback control in UAVs. Ultimately, the ANTEX-M flight tests

ANTEX-M, Portuguese Air Force Academy UAV

will take place at the GATE (Galileo Test and Development Environment) facility in Berchtesgaden, Germany, within the next two years.

Conclusions

A surprising and seemingly vast number of different types of UAVs exist in the literature, with different capabilities responding to different user needs. We have reviewed the four main categories: MAV/Mini UAVs; Tactical UAVs; Strategic and special task UAVS. MAV/mini UAVs represent the smallest class of UAVs and are mostly used for civil applications. Strategic UAVs are the largest and mostly used in military applications. Although the tactical and strategic UAVs are the more used, in the mean time MAVs and Mini UAVs will become more practical and prevalent.

Different kinds of UAV platforms have different mission and applications. For instance, most research institute prefers rotary wing UAVs with vertical take off and landing capacities as test platforms for demonstrating their research subjects. International competitions such as the Aerial Robotic competition organized by AUVSI are very important, not only as a good way to promote and share research results but also to understand what is going on in the field of UAVs.

As we said before, it is unreasonable to know all the ins and outs of UAVs. That is why one can say: Once we tried to "Google" UAV, we are still Googling UAV," and . . . we haven't found the end yet!

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Author

Maria de Fátima Bento received her degree in Avionics Engineering, from the Portuguese Air Force Academy (PAFA), Sintra, Portugal, and the Master of Science degree in Satellite Positioning and Navigation from the Faculty of Sciences, Porto University. She has been a lecturer at the PAFA since 2006 and is a Ph.D. student at the Institute of Geodesy and Navigation of the University FAF Munich. Her main subject is sensor fusion for applications in UAVs. IG