A Challenge for Micro and Mini UAV: The Sensor Problem

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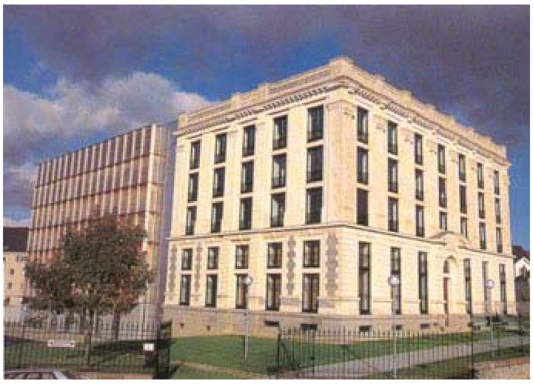
ABSTRACT

There is no doubt that so called tactical or short-range UAV played an important role in the military conflicts of the last 15 years. Such assets are expensive and very demanding regarding maintainability, operability and safety. Consequently they are operated at the levels of the brigade and higher. However, the commanders of the battalion and company, and even the platoon and squad leaders need also local situational awareness. This is the reason why in many countries, also outside NATO, Micro and Mini Aerial Vehicles (MAV), with dimensions not exceeding 15 cm respectively 150 cm, are presently under development. Typical missions are "Looking over the hill" or "Looking over the obstacle" (figure 1). Decreasing the size of such platforms is very challenging in all domains. Besides the platform complexity (aerodynamics at low Reynolds number, small but efficient and safe propulsion systems, high but compact and light weight energy storage devices, pre-programmed and fully automated flight), the sensor part of a MAV is extremely exigent. In addition to mission sensors (EO/ IR), MAVs need sensors to navigate, to provide stability and to allow manoeuvrability. This contribution will focus on micro-cameras, navigation sensors and attitude sensors. A large variety of micro-cameras are available off the shelf. During the last five years the UAV centre of the RMA gained a wide experience in this field and results in connection with military equipment are discussed in the paper.

Looking over the Hill (LoH)



Looking over the Obstacle (LoO)

Figure 1: Some Missions.

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INTRODUCTION

The Royal Military Academy (RMA) of Belgium is presently working on the development of several micro and mini UAV with a span varying from 25 cm to 1 m. These MAVs are in fact small platforms that can carry sensors of all kind. Some of these sensors are important for the in-flight behavior of the small airplanes, these are sensors developed to increase the platform's stability, to increase maneuverability or for navigation purposes. Other payloads include sensors for reconnaissance and surveillance (imaging sensors), target identification, sensing of nuclear, biological and chemical contaminants (NBC sensors), pilot recovery assistance and so on. Some of these sensors could also be used for civil operations, for example, detection of air pollutants, monitoring of bridges, power- and pipelines, police assistance and assistance in finding survivors after disasters like earthquakes, volcano eruptions, forest or bush fires, flooding etc...

The final goal of the research is to design and build a mini UAV with a range between 3 and 10 km allowing an autonomous flight lasting 20 to 60 minutes. The presence of onboard intelligence is of first importance. The plane is to be pre-programmed, using a laptop, to fly over a number of waypoints and send real-time video-images and other sensor information to the user. The airplane (including the ground station) should be easy to carry by one person. If the size of the plane is such that it needs to be dismantled for transport, the time needed for reassembling should be limited to a few minutes, without usage of any tool.

In this paper we will discuss four different platforms, all built at the RMA, with the emphasis on the sensors they carry. In our research we concentrate on those sensors that are necessary to attain the goals stated above. This means that besides aerodynamics at low Reynolds numbers, where some of the biggest challenges encountered in the design of micro and mini UAV are to be overcome [1-5], our interest mainly goes to imaging sensors, attitude sensors and sensors that can help to increase the MAV's stability.

MAV PAYLOADS [6]

As it is also the case for other subsystems, MAV payloads are constrained by weight, power consumption and integration limitations. The variety of possible payloads is very wide and will only increase due to technological progress.

Imaging Sensors

There is no doubt that the intelligence, surveillance, and reconnaissance function was the leading driver behind the first generation of MAVs of which the MIRADOR (figure 2) is one. Both tiny CCD and CMOS cameras and even infrared sensors can support applications for day/night imaging with a sufficient quality to meet mission needs today. Even in the early years of MAV development, imaging sensors had matured enough allowing to be integrated in light-weight micro UAVs. Of course, they have further improved over the years. Resolution and light sensitivity are much higher than ten years ago and power consumption has dropped tremendously.

Figure 2: The Mirador MAV.

Today we find a wide variety of tiny CMOS and CCD cameras on the market [7]. The challenge is to find a good balance between small size, low weight, low power and high image quality. A good example of such a camera is depicted in figure 3.

Figure 3: Miniature CCD Camera with High Power Audio/Video Transmitter.

Technical Specifications:

TX Power: 5v-8.4v 450mA Input
RF Output: 200mw
TX Frequencies: 2410, 2430, 2450, 2470
RX Power: 12v 350mA
TX/Camera Weight:(including antenna): 1.5ounces
Camera: Panasonic CX161 Color CCD: 350 lines of horizontal resolution, 330 lines of vertical resolution.

Nuclear, Biological and Chemical (NBC) Agent Sensors

It is commonly accepted that biological and chemical agent detectors will require further development before they can find application on micro-air vehicles. That a solution is on its way is proven by SANDIA's "*lab on a chip*", that is capable of collecting, concentrating, and analyzing chemical and biological agents. [8]

Attitude Sensors

These are sensors that can be used to improve the MAVs stability using feedback control, and also aid in navigating the MAV through the use of an autopilot or remote control. Very recently, the RMA developed in collaboration with a Belgian SME, an attitude sensor (figure 4). Based on three gyros, three accelerometers, three magnetometers and a computer chip, it allows viewing the motion of the MAV around its three axes (roll, pitch and yaw) on the screen of the ground station (basically a laptop).

Key Features:

- Heading / Roll / Pitch measurement
- Sinusoidal wave mapping
- Euler angles, quaternion, raw data
- Real Time
- Miniature with low power consumption

- Solid state inertial solution
- High precision
- High response and update rate
- Low Cost
- Zero maintenance

Figure 4: Attitude Sensor (left the prototype, right the commercial unit).

Technical Specifications:

Attitude data	Heading, roll, pitch Sinusoidal wave mapping
Accuracy	1° (depends on type of motion)
Repeatability	0.3°
Angular range	360° full scale all axes
Angular velocity range • Linear range • Maximum range	150°/s (z-axis), 300° (x/y-axis) 600°/s (z-axis), 900° (x/y-axis)
A/D Resolution	16 bits
Output format	RS232
Serial data rate	User selectable up to 115.2 kbauds
Output mode	On request / continuous mode
Output format	1) Raw data (hex) 2) Quaternion data (hex) 3) Euler angles (ascii)
Connector	Pin header with 0.1" pitch pin spacing
Power consumption	<160mA
Operating voltage	5V
Operating temperature	+5°C - +60°C (ambient)
Storage temperature	-5°C - +70°C
Weigth	52g
Dimensions	100 x 80 x 10 mm (L x W x H)

SENSOR PLATFORMS

The UAV center at the Royal Military Academy has so far developed 4 platforms that are able to carry sensors.

The Mirador (figure 2)

The first MAV that was build at the RMA was designed in cooperation with ONERA. It's a 25cm span Micro UAV weighing about 150g and able to carry a payload of up to 35g. The bi-plane concept was chosen in order to benefit from the vortex induced drag reduction, and obtain an acceptable lift-to-drag ratio. These 35g are enough to integrate a small wireless camera for navigation and a second one for observation purposes (figure 3).

The body of the MAV holds the batteries and all necessary electronics required to control the brushless motor. The camera in the middle is facing downward to be used for observation, a second camera in the vertical fin, connecting upper and lower wing, faces forward for navigation (figure 5). In this first version, no stabilizing electronics were used.

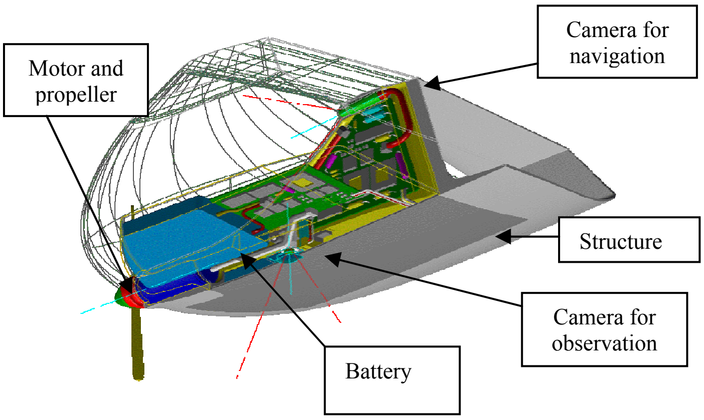

Figure 5: View of Internal Vehicle Organization.

The initial design was altered to increase lateral stability, which led to Birdy (figure 6). With a single gyro and some adaptations on the aerodynamics and the position of the center of gravity, this version is much easier to handle.

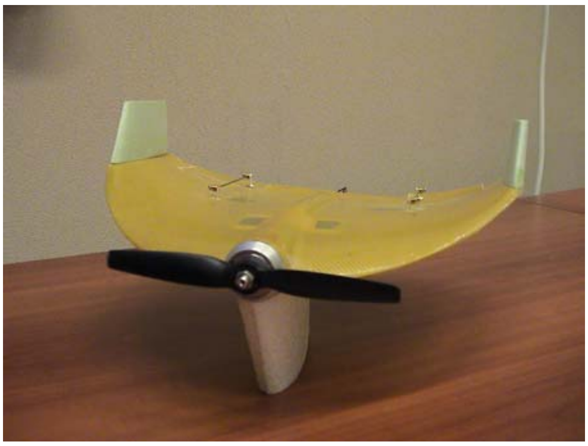

Figure 6: Birdy MAV.

The Sparrow (figure 7)

The third platform is a mini UAV with a 1m wing span and a payload of 500g, enabling the integration of a high quality camera with zoom lens and an auto pilot system which enables multiple waypoint programming, autonomous take-off and landing. It could also carry the attitude sensor and in the near future, possibly sensors for NBC detection.

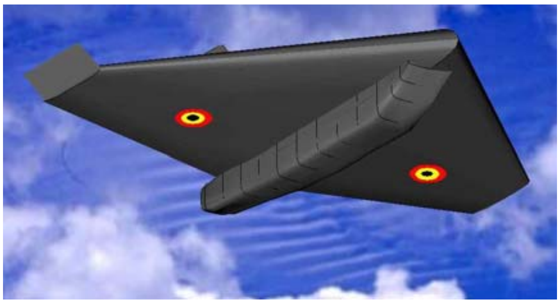

Figure 7: Sparrow MAV.

The integrated autopilot is an off the shelf electronic device from *Micropilot* called the MP2000. It features GPS waypoint navigation with altitude and airspeed hold, completely independent operation including autonomous takeoff, bungee launch, hand launch and landing. It is fully integrated with 3-axis gyros/accelerometers, GPS, pressure altimeter, pressure airspeed sensors on one single circuit board (Figure 8).

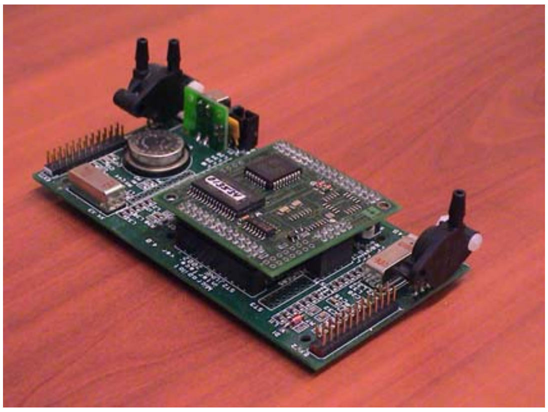

Figure 8: Autopilot.

The Quadcopter

The fourth and final MAV is a quad-copter with 2X2 counter rotating propellers (Figure 9). For the stabilization of this system, a stabilization unit is being built in cooperation with the university of Leuven (Figure 10). The central part of the unit is an Inertial Measurement Unit (IMU), the MICRO-ISU BP3010, weighing less than 30 grams (Figure 11). The total weight of the MAV is estimated to be around 200g, with a possible payload of at least 50g. Its hovering capabilities permit flying between and even inside buildings.

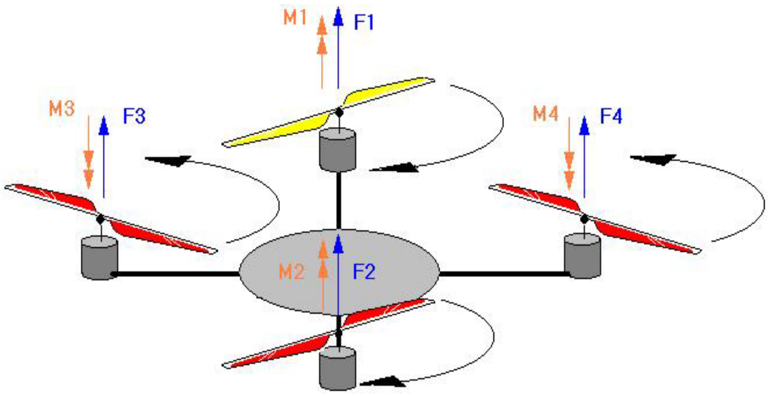

Figure 9: Quadcopter MAV.

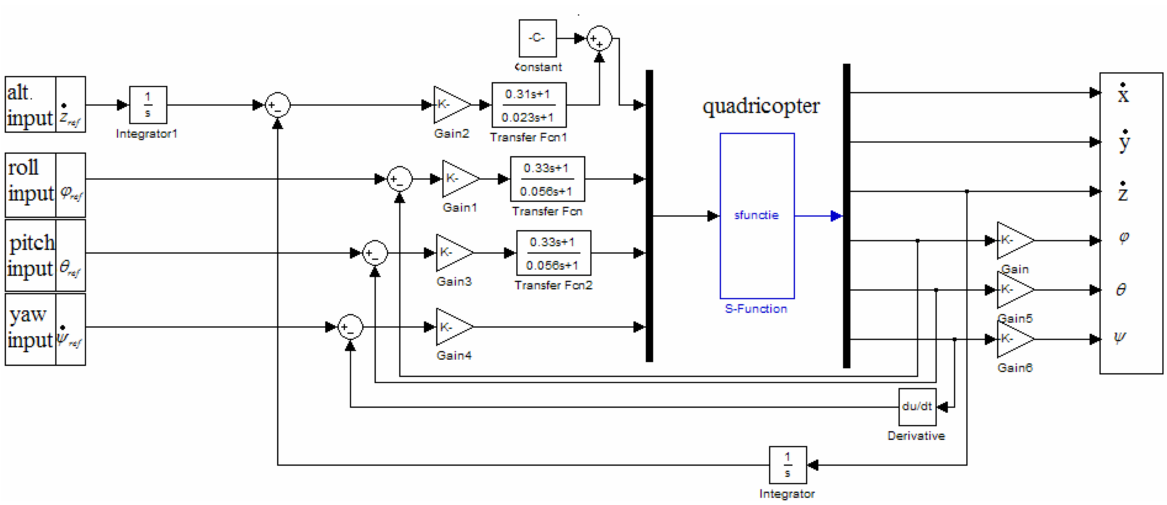

Figure 10: Loopshaping Diagram.

The IMU contains 3 MEMS gyros. These form the rotational sensors Gx, Gy and Gz. The linear acceleration sensors Ax and Ay are contained in one dual accelerometer. A second dual accelerometer provides the linear acceleration sensor Az. Six integrated circuits provide the interfaces to the 3 micro-controllers for reading and re-balancing the integrated sensor output signals. One of the micro-controllers also measures and filters the temperature of the gyro Gz and transmits this temperature along with sensor data in a serial-chain to the other two micro-controllers.

Figure 11: IMU and Test Board.

CONCLUSION

Today, MAVs are in full development. Surprisingly it is the territory of excellence of the universities. So far the industry, in particular in Europe, showed only very little interest in MAVs. Small attitude sensors help stabilizing the MAVs and small autopilots provide fully autonomous flight. Optical sensors are getting more precise every day and already permit to distinct between a soldier and a civilian, a dozer and a tank from a distance of 200 m.

As sensors get smaller the range of applications extends further. Nano-MAVs are already envisioned for the horizon 2020-2030. These tiny air vehicles will imitate the flying techniques used by small birds (flapping wings) and even by insects (vibrating wings). Once in operation, they will be extremely discrete, making it very difficult to distinct them from their living counterparts.

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