Design Considerations for Remote Sensing Payloads on Inexpensive Unmanned Autonomous Aerial Vehicles

Scot Smith, Zoltan Szantoi, John Perry, Franklin Percival, and Brandon Evers

ABSTRACT: This paper describes the latest version of the University of Florida (UF)'s unmanned autonomous vehicle (UAV), named the MAKO MAKO. The MAKO MAKO can operate in fully autonomous waypoint navigation mode, including autonomous takeoff and landing, allowing for repeatable, predictable ground coverage. Other features essential for the mission profile include hand-launch ability for takeoff, as well as a waterproof fuselage for aquatic landing. Low-altitude, high-resolution imaging is facilitated by a cruise speed of 15 m/s. The sensor payload on the MAKO is a digital single lens reflex (DSLR) camera operated at the shortest exposure to minimize the effect of motion blurring. The resulting images are capable of resolving objects on the ground as small as six cm. The MAKO has been used for a number of applications, including mapping wading bird nests in the Florida Everglades and elsewhere, monitoring the efficacy of defoliant spray programs in Lake Okeechobee, identification of invasive exotic vegetation, and mapping of bison.

KEYWORDS: Unmanned automous vehicle, remote sensing, digital single lens reflex

Introduction

The University of Florida (UF) Interdisciplinary UAV Research Group has completed development of the fifth generation (the MAKO) of small UAVs designed for natural resource and infrastructure applications (Watts et al. 2006; 2007; 2008). Over the past 10 years, UAVs have evolved to accommodate a robust set of operational capabilities. Chief among these is the ability to operate in autonomous waypoint navigation mode, allowing for repeatable, predictable ground coverage. Other features essential for the mission profile include hand-launching for takeoff from nearly any platform, as well as a waterproof fuselage for aquatic landing. Low-altitude, high-resolution imaging is facilitated by low-speed cruising (15 m/s), with a stall speed of 11 m/s and an efficient cruise speed (based on propeller selection) of up to 30 m/s. The all-electric drive system improves the reliability of the platform and minimizes airframe vibration. The total weight of the airframe, avionics, battery, and motor (excluding the remote sensing payload) is approximately 4.5 kg. A photograph of the MAKO is shown in Figure 1.

The weight specification for the remote sensing payload is 1 kg (kg), with a maximum payload of 2.25 kg. The dimension of the sensor suite payload bay is approximately 15 cm × 15 cm × 25 cm, a total of 6000 cm^3. In addition to physical constraints, it is important to consider the power required for the sensor payload that will reduce the available power for the avionics and motor. The standard payload specification of 1 kg drawing 1.5 A yields a specified flight duration of one hour.

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Payload Controller

The MAKO's primary mission is the collection of high-resolution, directly georeferenced, visible-spectrum imagery. The sensor suite and payload controller developed for this platform is a case study in the design of remote sensing payloads for small UAVs. The following constraints and features were identified during the planning phase and are used to anchor the design of the payload.

Figure 1. MAKO launching from an airboat.

- Physical constraints: The platform specifications given above limited the weight, size, and power consumption of the payload.
- Autonomy: The payload and avionics of the plane should be mutually independent. That is, it should be possible to fly the MAKO without the payload and operate the payload without the plane. This is particularly important during the design and testing phases, and also eliminates the need to engineer the payload to the level of reliability required for avionics.
- Consumer off-the-shelf hardware (COTS): Modularity, extensibility, ease of replacement, and minimization of development cost and sale price all deter the use of custom components.
- Remote (wireless) and direct (cabled) interfaces: It is an operational necessity to have remote access for command and communication with the payload, both for sensor control and status updates. The large data sets generated by the payload, however, preclude the sole use of wireless interfaces, so hardwired interfaces for data transfer and payload troubleshooting are necessary.
- Unified data bus: Limiting inter device communication to standards such as USB, Ethernet, and RS-232 simplifies the cabling and choice of connectors, an important consideration in the tight confines of the airframe.
- Unified data storage: Centralizing the data storage on one device eliminates the complexity and physical overhead of having redundant data storage devices.
- Unified sensor control: Command and communication with the payload in-flight must be aggregated for transmission over a single wireless data link. This implies the use of a device that has direct control over all sensors and subsystems.

The majority of these design considerations follow practically from the notion of a small, inexpensive UAV, such as the physical constraints. Not as obvious, however, is the use of COTS hardware. However, the development and operation of previous generations of small remote sensing UAVs informed many of the other constraints. For example, the proclivity to use COTS hardware came from the realities of implementing custom hardware, which required specialized knowledge and extensive redesign for even relatively minor changes in the sensor configuration, such as changing the camera model (Bowman 2008). Another pertinent example was the autonomy of the payload. In previous generations, the navigation system used by the avionics was exploited to provide direct georeferencing to the payload. However, the limitations of this became apparent once it was found that the navigation accuracy was insufficient for the payload purpose, yet, it was impractical (and even infeasible) to upgrade the navigation components of the autopilot (Wilkinson 2007).

Several of the design considerations were met simultaneously with the decision to use a Microsoft Windows XP-compatible computer. Pairing the VIA Technologies, Inc.® Pico-ITX form factor motherboard, the EPIA™ P700-10L, with an Intel® X18-M solid state drive provided U.S.B, GigE, and RS-232 interfaces; a single data storage device; a centralized sensor controller; and the ability to rapidly develop extensible sensor control software. The use of the Windows XP™ operating system had the disadvantage of not providing low-level real-time access to the hardware layer, but greatly simplified the ability to connect COTS sensors that often have proprietary SDKs available only for Windows XP™.

The wireless interface is provided by connecting a wireless modem to the payload computer. In a compromise of the fully autonomous design consideration, this connection was provided by "piggy-backing" the payload communications on the wireless data link used by the autopilot. (Procerus Technologies®, Kestrel Autopilot™). However, this was a standard service provided by the autopilot and the eliminated the need for redundant wireless data links on the plane.

The navigation sensors are of paramount importance to the mapping accuracy of the direct georeferencing solution. The navigation sensors provide the EOPs and hence the absolute orientation of the photogrammetric solution. The two canonical components of the navigation system are the Inertial Mapping System (IMU) and GPS (Global Positioning System) sensors, which are further integrated using a state estimation filter

(Chatfield 1997). Additional sensors such as magnetometers and air pressure sensors are often used to augment the navigation performance.

Size, weight, and cost restrictions severely limit the selection of the navigation sensors. In general, the selection for small UAV platforms is limited to the two lowest-accuracy classes of these devices; a MEMS-based IMU and a code-solution single-frequency GPS. As a result, the primary factors in selecting the INS/GPS were the relative accuracy, robust design, and ease of integration. The Xsens, Inc.® MTi-G™ was chosen for implementation. Key features of the MTi-G™ include a built-in Kalman filter for a real-time orientation parameter solution, a raw data output mode for postprocessing refinement, a high update rate, and a simple serial data communication protocol [Xsens MTi-G]. Importantly, an interface is also provided for device synchronization based on the GPS 1PPS signal.

A final hardware component common to many sensor suite implementations is a device that provides sensor synchronization facilities. This is particularly true where the desired remote sensing products are dependent on the fusion of the data from multiple sensors, as is the case for direct georeferencing. Often, this facility is integrated into the navigation sensors due to their dependency on accurate timekeeping, but the appearance of this feature is less frequent in the class of navigation sensors compatible with a small UAV. Because a reasonable off-the-shelf solution has not been identified, this was the sole hardware component on the sensor suite that was custom-designed. A detailed description of the device and its method of operation is available (Perry and Childs 2009).

Optical Sensors

Given the flexibility of the payload controller, the increased options for the sensor suite were limited only by the practicalities of size and weight. There are three practical options for optical sensors on the MAKO:

1. High definition aerial video camera
2. Compact rangefinder digital camera
3. Digital single lens reflex camera

High-definition video (HDV) refers to any video system of a higher resolution than that of a standard-definition (SD) video and most commonly involves display resolutions of 1280 × 720 pixels. An example of a relatively lightweight HDV camera is shown in Figure 2. With a weight

Figure 2. High definition aerial video camera (Panasonic HDC-SD9).

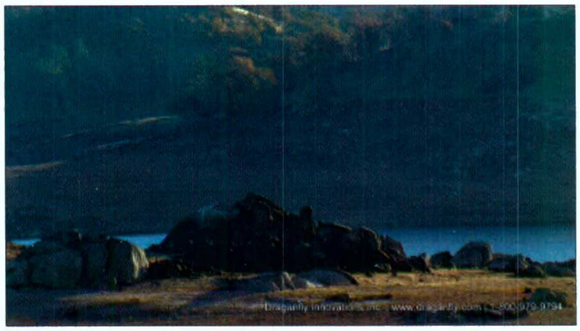

Figure 3. Image from an HDV mounted on a UAV. Source: Draganfly Intions (www.draganfly.com).

of 275 g (gr), the camera can be flown in the MAKO platform (for results, see Figure 3).

One of the most important performance parameters of an optical sensor is resolution as defined by the smallest object on the ground that can be detected. One means of indirectly measuring this is the array of pixels for a system. Larger arrays yield higher resolution. The best HDV cameras have a resolution of 1920 × 1080 pixels.[1]

At a flying height of 100 m, a 3 mm focal length HDV system has the ability to detect targets on the ground that are approximately 3 m × 3 m if the target to background contrast is high. For some applications, this resolution might be adequate. For example, if the purpose of the mission were to assess the extent of a wildfire, a resolution greater than 5 m would be sufficient to be useful. However, if the mission were to calculate the amount of potential fuel for the fire in adjacent areas, this resolution would probably be too coarse.

[1] For comparison, a typical 12 mega pixel, mp, compact rangefinder camera has a pixel array of approximately 4000 × 3000 pixels.

Compact or rangefinder cameras are cameras designed primarily for simple operation. An example of a typical compact digital camera is shown in Figure 4. Most rangefinder cameras use focus-free lenses or autofocus for focusing and automatic systems for setting the exposure. Compact cameras are distinguished from single-lens reflex cameras (DSLRs) in several respects, but the two most significant differences for UAV applications are (1) size and weight and (2) sensor size. Compact or rangefinder cameras are smaller and lighter than any DSLR on the market. The MAKO aircraft can fit two rangefinders in the payload bay and only one SLR. This would be important if, for example, you wanted to simultaneously shoot a natural color mission and an infrared color mission.

Figure 4. Canon 650 Powershot.

A Canon Powershot 650 compact camera was flown on the MAKO for several missions, including one over Cedar Key Florida. An example of the imagery obtained with this camera is shown in Figure 5. In this example, the objective of the mission was to detect pelican nests located in the trees. It was possible to detect the nests but impossible to see whether or not eggs were present.

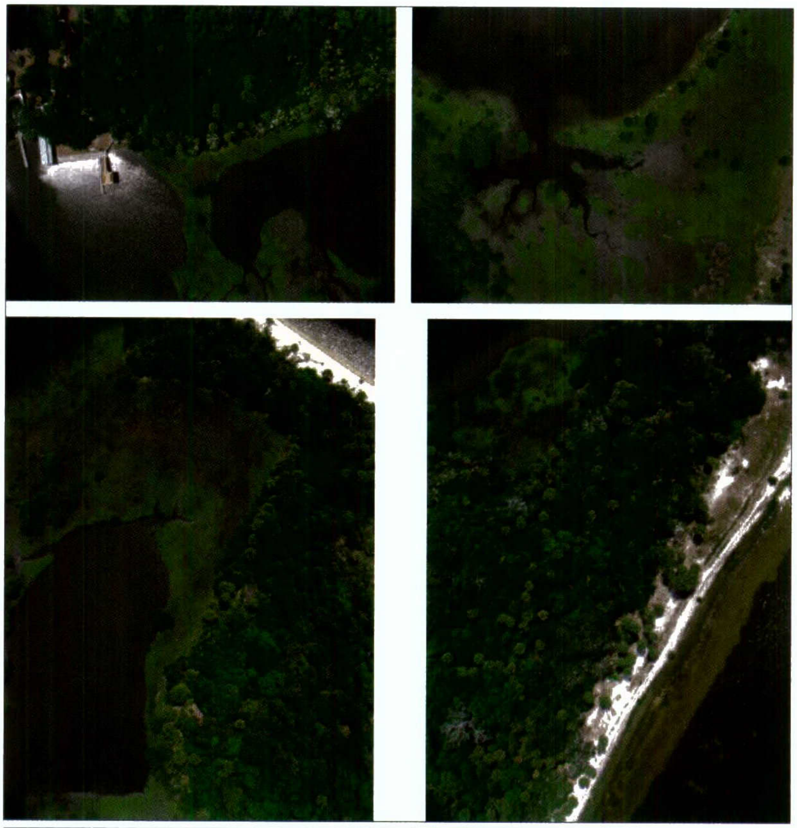
Figure 5. Images from the Canon Powershot 650 of Seahorse Island, Florida.

The second major difference between a compact rangefinder and a DSLR for UAV applications is the size of the sensor. The sensor on most compact rangefinders is a fraction of that on most DSLRs. For a given number of pixels, the larger sensor allows for larger pixels or photo sites which then provide wider dynamic range and lower noise at high ISO (International Organization for Standards) sensitivity levels. As a consequence, DSLRs produce better quality images in general, but especially under high contrast or low light situations.

Compact rangefinder cameras, in general, are optically inferior to even standard grade lenses designed for a DSLR camera. One reason for this are the design compromises needed for variable focal length lenses found on all compact cameras as opposed to fixed focal length lenses.

DSLRs have only one lens, and a mirror diverts the image from the lens into the viewfinder. That mirror then retracts when the picture is taken so that the image can be recorded on the sensor. An advantage of a DSLR over a compact rangefinder is sensor size. The larger the sensor, the better the image quality will be. The largest sensors are referred to as "full-frame," and are the same size as 35 mm film (the image format is 24 mm × 36 mm). These sensors are used in DSLRs too heavy for most UAVs. Most DSLRs use a smaller sensor commonly referred to as APS-C sized, that is, approximately 22 mm × 15 mm, which is about 40 percent of the area of a full-frame sensor. Other sensor sizes found in DSLRs include the Four Thirds System sensor used by Olympus that is 26 percent of full frame.

Another advantage of DSLRs over compact digital cameras is that DSLR cameras allow the user to change lenses. The ability to exchange lenses to select the best lens for the mission is very important. The MAKO has flown lenses as small and light as the standard grade Olympus Zuiko 25 mm lens when resolution was not paramount to the mission and lenses as large and heavy as the higher grade Olympus Zuiko 50 mm lens when resolution was important.

Many lens manufacturers produce three grades. Olympus, for example, produces standard, high grade, and super high grade lines of lenses. The difference between the grades is quality of materials, including glass, and build quality. Typically, higher grades of lens are larger and heavier. Image quality difference can be pronounced (see Figure 6).

The Olympus Zuiko 25 mm standard grade lens produced a relatively low resolution image compared with the 35 mm standard grade lens. The 50 mm high grade lens produced a significantly higher resolution image than the other lenses.

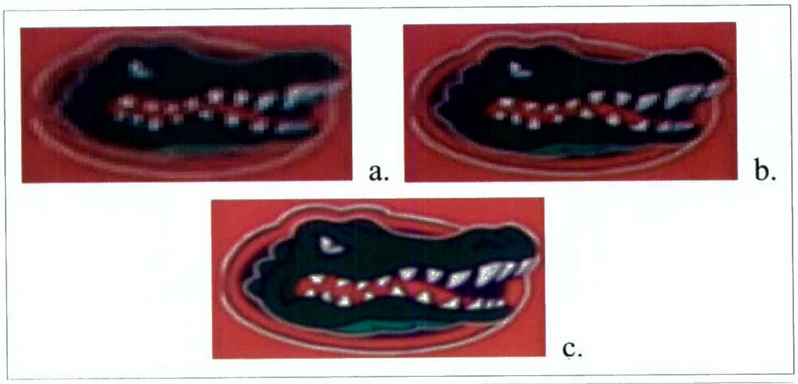

Figure 6. Images from (a) 25 mm vs. (b) 35 mm vs. (c) 50 mm Olympus lenses for equivalent focal length.

Figure 7. Olympus E-420 DSLR camera with Olympus Zuiko 25 mm pancake lens.

The Olympus 420 DSLR

The primary imaging sensor on the MAKO is an Olympus E-420 DSLR camera (see Figure 7). This digital camera was selected primarily for its compact size and robust feature set, including a software interface that allows complete control of the camera settings, exposure triggering, and captured image transfer to the host.

An Olympus Zuiko 25 mm standard grade pancake lens was selected because of its light weight and compact size. A weight and size comparison between the 420 and other popular DSLRs is shown in Table 1. An important consideration in moving to a DSLR over the Canon Powershot 650 was superior optical performance. The overall success of the platform as a remote sensing tool relies as much on the quality and resolution of the final imagery as on the spatial accuracy of the georeferencing.

During a typical mission, the Olympus 420 is operated at the shortest possible exposure speed to minimize the effect of motion blurring. As a result, aperture priority mode is usually set to an exposure duration of 1/2000th of a second or higher and an ISO sensitivity of 100. The Olympus automatic exposure-metering program, set to shutter priority, normally sets the aperture to f/2.8 with these parameters under normal daylight conditions. No discernable motion blurring occurs at these settings, and increasing the

Type	Olympus E-420	Nikon D60	Canon EOS 450D
Dimensions (mm)	129.5 × 91 × 53	126 × 94 × 64	129 × 98 × 62
Weight (g) (no battery)	380	471	475

Table 1. Olympus E-420 size and weight comparison with similar cameras.

exposure duration to 1/4000th of a second does not result in a marked improvement in sharpness and has less contrast in low-light conditions.

Image Capture Rate

The TruePic III Image Processor enables the camera to shoot at up to 3.5 frames per second in sequenced shooting and full megapixel mode, until the buffer space of the memory card reaches capacity. Our capture rate is limited to about 2.2 seconds, the time it takes to trigger an image capture, focus and expose the sensor, process the image, and transfer it to the payload computer.

Examples of the images taken with the Olympus 420 are shown in Figure 8. Figure 8a shows Indian Canal on Lake Okeechobee and Figure 8b was taken in the Florida Everglades.

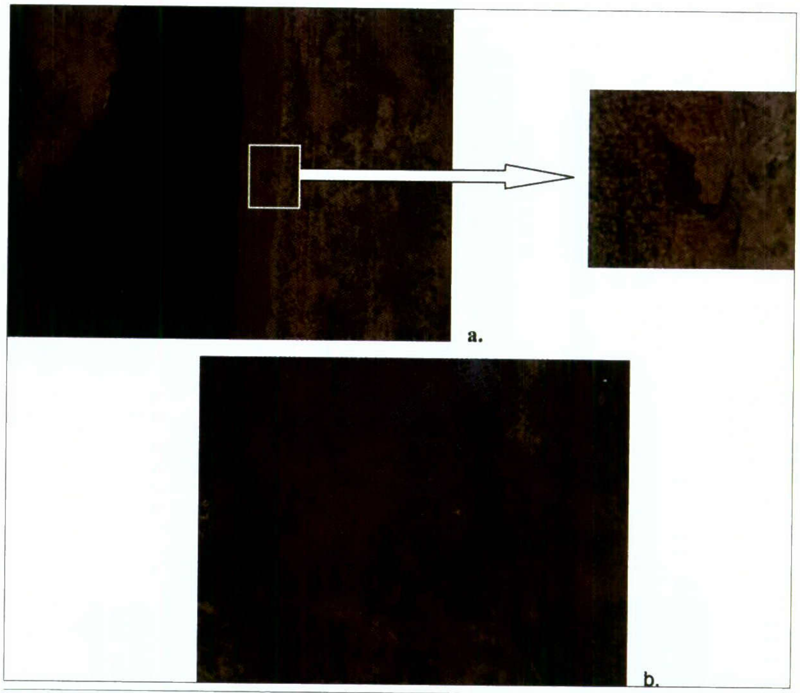

Figure 8. Examples of images from the Olympus 420 from (a) Lake Okeechobee and (b) the Everglades.

Experimental Work and Performance Analysis

Applications the MAKO has been used for thus far fall into two categories: (1) detection of physiological changes in vegetation not perceptible by the human eye and (2) wildlife inventories. For the first category, the MAKO has been used to detect the reaction of vegetation in Lake Okeechobee Florida to herbicides. Imagery was taken before and after application of the herbicide. It was found that the imagery was able to display a change in the spectral reflectance of the vegetation before it became visually obvious. This is very useful because agencies that regularly apply herbicides need a method to measure the efficacy of their treatments. The UAV is a much more efficient means of doing so than fieldwork.

In the second category, the UAV has been used to perform inventories of wading birds in Florida. The DSLR system allows the interpreter to count eggs in nests of some birds. It can also detect reptiles such as alligators and large snakes. Such applications are of obvious benefit given that the number one cause of fatalities of field Fish and Wildlife Service employees are plane crashes. If the UAV can serve as a surrogate to manned flights, many lives will be saved.

Conclusions

Small inexpensive UAVs such as the MAKO have a large number of potential applications and promise to open a new era in remote sensing. We found that the advantages of a DSLR compared to a compact rangefinder camera or an HDV make it a better choice. DSLRs have better image quality, more lenses to choose from, and usually more versatility in terms of exposure control. As the design of UAVs improves with respect to payloads, DSLRs can be mounted with higher-quality (and heavier) lenses that will further expand the potential applications.

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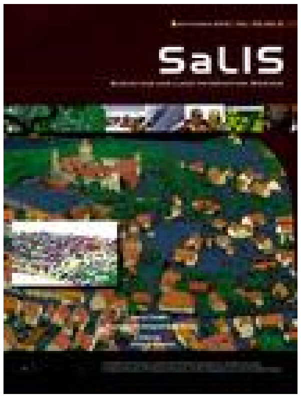

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