

DEVELOPMENT OF UNMANNED AERIAL VEHICLE AT PADOVA UNIVERSITY

U. Coppa^a, A. Guarnieri^b, M. Camarda^b, A. Vettore^b

^aVesuvius Observatory – National Institute of Geophysics and Volcanology – Naples, Italy, coppa@ov.ingv.it

^bCIRGEO – Interdepartment Research Center for Geomatics, University of Padova - Italy, cirgeo@unipd.it

Commission V, ICWG IV

KEY WORDS: UAV, model helicopter, autopilot, aerial mapping.

ABSTRACT

In the last years UAV (Unmanned Aerial Vehicle) systems are become very attractive for various commercial, industrial, public, scientific and military operations. The tasks include pipeline inspection, dam surveillance, photogrammetric survey, infrastructure maintenance, inspection of flooded areas, fire fighting, terrain monitoring, volcano observations and so on. The impressive flying capabilities provided by UAVs require a well trained pilot to be fully and effectively exploited; moreover the flight range of the piloted helicopter is limited to the line-of-sight or the skill of the pilot to detect and follow the orientation of the helicopter. Such issues have motivated the research and the design for autonomous system guidance which could both stabilize and also guide the helicopter precisely along a reference path. The constant growth of research programs and the technological progress in the field of navigation systems, as denoted by the production of more and more performing GPS/INS integrated units, allowed a strong cost reduction and payload miniaturization, making the design of low cost UAV platforms more feasible and attractive.

In this paper we present the preliminary results of the low-cost autonomous model helicopter we developed for mobile mapping applications. Assessment of system performance is based on the measurements achieved by surveying a set of targets well distributed on a calibration field. The development of this aerial mapping system has been also based on the results derived from a flight simulation software implemented for determining the best setup for the servos.

1. INTRODUCTION

Over the last few years several improvements have been presented in the field of Unmanned Aerial Vehicles (UAV), which increased the interest towards such systems for various commercial, industrial, public, scientific and military applications. Typically, tasks include photogrammetric survey pipeline inspection, dam surveillance, inspection of flooded areas infrastructure maintenance, terrain monitoring, fire fighting, volcano observations and so on. Within the category of UAVs, helicopters play an interesting role as they are suited for many applications for which fixed-wing aircraft show operational difficulties. Indeed such crafts offer more flexible manouvers, as they allow for vertical take-off and landing, hovering and side flight.

The different flying characteristics of an helicopter with respect to fixed-wing systems, require more effort for the manual control via radio link. High piloting skills are needed for manual hovering and for keeping the ideal position and attitude along a pre-planned path; moreover the operation range of a manually piloted helicopter is limited to the line-of-sight or the skill of the pilot to detect and follow its orientation. Such issues have motivated the research and the design for autonomous system guidance which could both stabilize (i.e. reduce vibration and wind effects) and also guide the helicopter precisely along a reference path.

Latest developments in the field of navigation systems have led to miniaturized boards which integrate GPS and MEMS-based inertial units, enabling to fly UAVs in autonomous way. These new technologies allow low cost navigation systems to be integrated in model helicopters, though the advantage of small size positioning and orientation sensors come with a price of low precision. Nevertheless, the combination of GPS/INS sensors with image data for navigation represents a key factor to

achieve more precise and reliable results with respect to manually controlled UAVs.

In this paper we present the main features and preliminary results of a low-cost autonomous model helicopter, we developed over the last 2 years for aerial mapping applications. The primary goal of our model helicopter is to provide the user with a top view of the territory without resorting to more expensive classical aerial photogrammetry. The system is designed to collect data for mapping and land monitoring purposes working on areas which represent a difficult task for already existing ground-based mobile mapping systems. From this viewpoint our system can be regarded as a lightweight and low cost complementary mapping tool to existing MMS. According to project specifications, the model helicopter will be used to survey areas of limited extent such as open mines, little rivers, cultivated fields, not only to monitor the land evolution and local changes in the terrain morphology but also to discover illegal uses of land resources. A further example of its application deals with the mapping of small water channels located along the Venice lagoon, which cannot be accurately mapped through classical aerial photogrammetry.

The development of our aerial mapping system has been also based on previous results derived from the implementation of a flight simulation software aimed at the determination of the best setup for the servos (Guarnieri et. al., 2008).

2. SYSTEM COMPONENTS

Our proposed UAV consists of a Raptor 90 v2 model helicopter equipped with a pair of color lightweight Panasonic digital cameras (imaging system) and an autopilot system based on the MP2128^{HELI} board from MicroPilot. The cameras are mounted on a customized platform fixed below the helicopter cell

between the landing vats and are both looking in flight direction. A slight tilting and convergence angle is set up in order to allow enough overlap between acquired images. Figure 1 shows a close-up view of our model helicopter, while related technical specifications are presented in table 1.



Figure 1: The model helicopter Raptor 90 v2

Fuselage length	1410 mm
Fuselage width	190 mm
Height	465 mm
Main rotor diameter	1580 mm
Tail rotor diameter	260 mm
Total weight	4.8 kg

Table 1: Main technical specifications of the Raptor 90 v2

2.1 The navigation system

The model helicopter is equipped with the MP2128^{HELI} board autopilot that allows autonomous flight and provides a real-time attitude of flight. At a very small size (4cm by 10cm) and light weight (only 28 grams), the MicroPilot electronic circuit board integrates a 4 Hz GPS unit with antenna, three-axis accelerometers and gyros (IMU), relative airspeed probe, AGL ultrasonic altitude sensor, pressure altimeter and external servo board (Figure 2). While the GPS works at 4 Hz update rate, the remaining sensors (gyros, accelerometers, pressure altimeter and airspeed probe) collect data at 5Hz rate.



Figure 2: The MP2128^{HELI} board

Although the autopilot unit supports autonomous takeoff and landing, these features are not employed in our planned missions. Real-time control of flight parameters, servos and measuring sensors is ensured through the 2.4 GHz radio modem communication between the helicopter and the ground base station, consisting typically of a laptop on which the MicroPilot

Horizon software runs (Figure 3). Here the operator can set up the flight plan (up to 1000 waypoints), displaying the image acquisition points on a preloaded background map and upload all the required data to the MP2128^{HELI} board before or during the flight. The board can also be connected with payload cameras, thus enabling the user to schedule automatic shooting times. Therefore automated photogrammetric flights can be carried out by collecting images at the pre-planned waypoints.



Figure 3: The Micropilot HORIZON control software

2.2 The imaging sensors

The imaging system is based on a pair of color lightweight digital cameras, Panasonic Lumix DMC-FX3 (Figure 4), mounted on a specific structure which substitutes the original landing vats. Baseline and tilting of the cameras are setup in order to provide a sufficient side overlap between image pairs. Each Panasonic camera features a CCD size of 1/2.5" (see table 2) with actual resolution of 6 Megapixel and a focal length ranging between 35 mm and 105 mm (35 mm equivalent). This camera allows to acquire digital images with three different format sizes (4:3, 3:2 and 16:9) with a maximum resolution of 2816 x 2112 pixels. Image blurring due to unwanted vibrations are strongly reduced through the use of a MEGA O.I.S. (Optical Image Stabilizer), which ensures to capture high quality images in any shooting condition.



Figure 4: The Panasonic DMC-FX3 camera

CCD Size (inches):	1/2.5"
Image Resolution:	2816x2112, 2816x1880, 2816x1584, 2048x1536, 2048x1360
Focal Length (35mm equivalent):	35 - 105 mm
Zoom Ratio:	3.00x
Weight:	153g 5.4oz
Size:	94 x 51 x 24 mm 3.7 x 2.0 x 1.0 in

Table 2: Technical features of the Panasonic digital camera

Both cameras have been dismantled and properly modified in order to be connected to the MP2128^{HELI} board, thus enabling the system to automatically capture the images at the pre-defined acquisition points. During flights, the images are stored on the high-capacity memory cards (> 1 GB) of the digital cameras.

3. THE SIMULATION ENVIRONMENT

In order to evaluate in advance the main issues related with the development of an autonomous guidance system for our unmanned model helicopter, we decided to build a simulation software with Simulink, a Matlab programming environment based on the block scheme algebra (Guarnieri et al, 2008). The main goal of this approach was to define and to tune the set of servos needed for the helicopter control, avoiding any possible damage of the system components caused by a trial and error approach in a real environment. In order to reliably simulate the dynamics of our small-size helicopter, we took into account the effects of following components: main rotor, tail rotor, aerodynamic drag (wind effect) generated by the fuselage, horizontal and vertical fin. To this aim we considered four main servos: the collective pitch control, the cyclic stick, the collective stick and the throttle.

The whole block scheme implemented in Simulink is summarized in figure 5. Here the first block models the helicopter servos which are input into the second block, the dynamic model. In turn, this block outputs translational acceleration and angular velocity, related to the body frame, and position and attitude in the inertial frame, which are then fed into the measurement sensor block. Here noise is added in order to simulate as much as possible the real behaviour of the GPS, IMU and earth-magnetic sensors. The output of this block represents the (noisy) state of the system which is evaluated by an Extended Kalman Filter (fourth block). After that, the output of the filter is compared with a reference trajectory in order to determine again the values for the servos. This trajectory, acting as the feedback loop required in every control system, has been generated using position and attitude information derived by taking into account helicopter and digital cameras (Field of View) technical specifications.

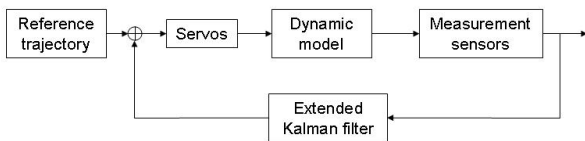


Figure 5. Block scheme of the simulation environment.

Since the autopilot board was purchased after the development of the simulation tool, the parameter values taken into account to simulate the behaviour of GPS, IMU and earth-magnetic sensors resulted to be different with respect to the Micropilot specifications. Therefore a specific helitrainer was built and a few tests were performed in order to properly setup the control parameters for servos and measuring sensors exploiting the results of previous simulations.

The helitrainer is basically a steel structure, fixed on the ground, which enables movements in all directions (i.e. roll, pitch and yaw angles are unconstrained) being the helicopter kept fixed to it (Figure 6). In such a way the UAV can be operated and flight

parameters properly setup avoiding any possible damage due to sudden loss of control.



Figure 6: The Helitrainer

4. THE TEST FLIGHT

After preliminary setup with the helitrainer, the overall system was calibrated in order to estimate all the parameters which define the relationships among the reference frame related to each measuring sensor. This is a fundamental step to allow the direct georeferencing of features selected on collected digital images. Since at the time of the first flight test the modified structure for the landing vats was not yet available, only one camera was used and set with the optical axis pointing orthogonally to the ground (normal view).

4.1 System calibration

Interior Orientation Parameters (IOP) of the digital camera were estimated in the lab with the iWitness software, then the whole system has been calibrated on a test field built in our campus, using 40 black and white square artificial targets as GCPs (figures 7 and 8). The size of these targets (30 cm x 30 cm) was chosen considering that the operational maximum height had to be limited to 30 m due to safety reasons.

Horizontal and vertical coordinates of the targets were determined in the WGS84 reference frame, by combining total station and GPS measurements.



Figure 7: Panoramic view of the calibration field.



Figure 8: Calibration targets as seen from the model helicopter.

4.2 Data acquisition

After system calibration a test flight was carried out covering the area of interest with a block of 3 strips. Images were collected at a flight velocity of 2m/s, while the shutter speed was set to 1/1000s. This very low time was selected in order to limit as much as possible the influence of the image motion, in conjunction with the built-in camera OIS. Residual blurring were mainly due to uncompensated vibrations of the imaging system platform. Considering a flight height of 25 m, a ground pixel size of about 9 mm and a maximum image resolution of 6 Megapixels in the 4:3 format, each image covered an area of about 25 m x 19 m. Assuming a 60% overlap along-track and a side overlap of 20 % the shooting time was set to 4 s. All these flight parameters are summarized in figure 8.

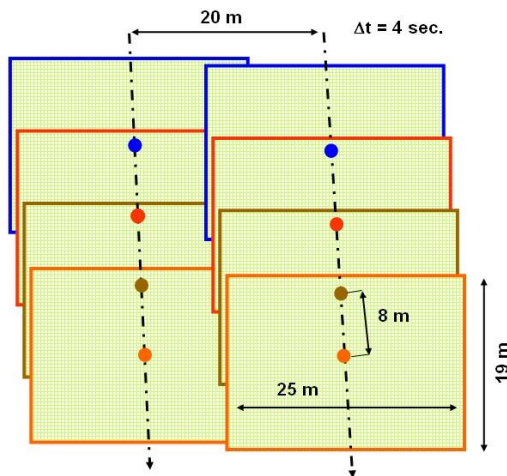


Figure 8: Example of the test flight plan (flight altitude 25 m).

4.3 Image processing

The image triangulation was carried out using the Leica Photogrammetry Suite (LPS) software. Interior orientation parameters were derived by the calibration performed in iWitness software. The approximate positions of the camera, calculated using the 12 states Kalman filter implemented in the navigation unit of the Micropilot board, were employed as initial values for the Exterior Orientation Parameters (EOP) estimate. After automated tie point extraction, the coordinates of a set of artificial targets, displaced along the strips (figure 9), were used as check points to evaluate the performance of the

model helicopter for mapping applications. The coordinates of these targets were manually extracted by the oriented images. Table 3 highlights the results obtained at this stage.



Figure 9: Example of a strip

Control Point accuracy (RMSe)	
Horizontal (m)	0.08
Vertical (m)	0.15

Table 3: Results of aerial triangulation performed in LPS software.

The low level of achieved accuracy, with respect to the expected one, is mainly due to following factors: uncompensated vibrations of the imaging system mounting, mid-resolution of acquired images and the GPS sensor. The latter was indeed operated in standalone mode, though the Micropilot board allows for DGPS accuracy by means of a proper add-on module to be integrated on the board itself.

5. CONCLUSIONS

In this paper we have presented the preliminary results of a test flight of a low-cost autonomous model helicopter, we developed for mobile mapping applications. Given the capability for surveying areas of limited access, the proposed model helicopter can be regarded as a complementary mapping tool of already existing and well proven ground-based mobile mapping systems. Although the results concerning the first photogrammetric test were not enough satisfying, improvements

can be definitely achieved by solving for issues related to the navigation subsystem and to the camera mounting.

Wang, Y., Yang, X., Stojic, A., Skelton, B., 2004. Toward higher automation and flexibility in commercial digital photogrammetric systems. IAPRS, Vol. XXXV, p. 838-840, Istanbul, Turkey..

References

Bendea, H. F., Chiabrande, F., Tonolo, F. G., Marenchino, D., 2007. Mapping of archaeological areas using a low-cost UAV the Augusta Bagiennorum Test site. XXI International CIPA Symposium, Athens, Greece.

Eisenbeiss, H., 2004. A mini unmanned aerial vehicle (UAV): system overview and image acquisition. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. XXXVI-5/W1, on CD-ROM.

Eisenbeiss, H., K. Lambers and M. Sauerbier, 2005. Photogrammetric recording of the archeological site of Pinchango Alto (Palpa, Peru) using a mini helicopter (UAV). International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. XXXIV-5/C34, pp. 238-243.

Eisenbeiss, H., 2007. Applications of photogrammetric processing using an autonomous model helicopter. Revue Française de Photogrammetrie et de Teledetection. Symposium ISPRS Commission Technique I "Des capteurs a l'Imagerie", n°185 (2007-1), Saint-Mande Cedex, France.

Fahey, D.W., A.J. Gasiewski, M. Aslaksen, S. Summers, C.D. Jennison, N. Trongale, J.H. Churnside, J.W. Elkins, D.F. Hurst, T. Jacobs, M. Klein, S.J. Oltmans, B.W. Orr, J.D. Sellars, L.C. Freudinger, K. Dunwoody, K.H. Rosenlof and E. Ray, 2005. The NOAA Unmanned Aerial System (UAS) Demonstration Project Using the General Atomics Altair UAS. AIAA 2005-6923, Arlington, VA.

Guarnieri A., , "Accuracy enhancement of unmanned helicopter positioning with low cost system", XXIth ISPRS Congress, Beijing, China. Horcher, A., Visser, R.J.M., 2004. Unmanned aerial vehicles: Applications for natural resource management and monitoring. Proc. of COFE (Council on Forest Engineering) *Annual Meeting* 2004.

Lambers, K., Eisenbeiss, H., Sauerbier, M., Kupferschmidt, D., Gaisecker, T., Sotoodeh, S., Hanusch, T., 2007. Combining photogrammetry and laser scanning for the recording and modelling of the late intermediate period site of Pinchango Alto, Palpa, Peru. *J. Archaeol. Sci.* 34:1702-1710.

Herwitz, S.R., L.F. Johnson, R.G. Higgins, J.G. Leung and S.E. Dunagan, 2002. Precision agriculture as a commercial application for solar-powered unmanned aerial vehicles. AIAA 2002-3404, Portsmouth, VA, USA.

Pueschel, H., Sauerbier, M., Eisenbeiss, H., 2008. A 3D model of Castle Landenberg (CH) from combined photogrammetric processing of terrestrial and UAV-based images. XXI ISPRS Congress, Beijing, China, 03.-11. July 2008.

Rovira-Más, F., Zhang, Q., Reid, J.F., 2008. Stereo vision three-dimensional terrain maps for precision agriculture. *Comput. Electron. Agr.* 60:133-143.

Rugino, G. and A. Moccia, 2005. Integrated VIS-NIR Hyperspectral / Thermal-IR Electro-Optical Payload System for a Mini-UAV. AIAA 2005-7009, Arlington, VA, USA