Motion analysis and Geo-location for aerial monitoring in the COMETS multi-UAV system

L. Merino, A.Ollero, J. Ferruz, J.R. Martínez-de-Dios and B. Arrue.

Dept. Ingeniería de Sistemas y Automática
Escuela Superior de Ingenieros. Universidad de Sevilla.
Camino de los Descubrimientos s/n 41092 Sevilla, Spain
{merino, aollero, ferruz, jdedios, barrue}@cartuja.us.es

Abstract

The present paper presents perception functions in a new project dealing with coordination and control of multiple heterogeneous Unmanned Aerial Vehicles (UAVs). This project considers detection and monitoring using heterogeneous low cost UAVs. The paper overviews some characteristics of the COMETS system and presents the low-level image processing layer called AIIP, including image stabilisation, motion object tracking and geo-location. The paper includes examples of the operation of some services offered by the AIIP obtained from forest-fire field experiments.

1. Introduction

In the last ten years, unmanned aerial vehicles improved their autonomy both in energy and information processing. Thus, many prototypes of autonomous aerial vehicles have been presented (see for example [1], [3] ,[8],[10], [12], [13], [14]).

Detection and monitoring are relevant missions of interest for many applications related to disasters, law enforcement and others. These missions usually require cameras in different positions to detect and observe the objectives and to locate them with precision enough. Furthermore, both panoramic and details views could be required for appropriated visualization of the scene. These simultaneous views could be very difficult to obtain by using a single aerial vehicle with different cameras due to the required mobility and the difficulties to control the vehicle and/or the cameras. Then, multiple UAV systems seem a suitable solution. Most efforts devoted to the study of multiple UAV have been devoted to homogeneous teams of airplanes. Thus, the problems are related to the control of multiple airplanes in close-formation flight, as for example in [6], [11]. On the other hand, some UAV and robotic projects, such as the BEAR project at Berkeley [14], consider cooperative aerial-ground robots systems.

This paper describes results obtained in the recently launched COMETS project, funded by the IST Programme of the European Commission. The main objective of the COMETS project is to design and implement a distributed control system for cooperative detection and monitoring using heterogeneous UAVs.

In order to achieve this general objective, the project involves the design and implementation of a control architecture, the development of new control techniques, and the integration of distributed sensing techniques and real-time image processing capabilities.

This project exploits the complementarities of different autonomous aerial systems in missions where the only way to guarantee the success is the cooperation between several autonomous vehicles due to the requirements on the required coverage and the different characteristics of the vehicles. Furthermore, this approach leads to redundant solutions offering greater fault tolerance and flexibility when comparing with the use of a single UAV with long endurance flight and important on-board capabilities.

Helicopters and non-rigid airships, or blimps, are involved in the project. Helicopters may flight close to the objects in smaller and constrained areas. They can provide detailed and “static” views of objects being monitored. On the other hand, blimps have significant surveillance capabilities and could provide the targets to the helicopters but have more difficulties to give a detailed view of the object due to manoeuvrability constraints. Furthermore the payload of autonomous small blimps is lower and the wind imposes important constraints.

It should be also noted that the helicopter communications with the control centre and the helicopter control could be simplified when a blimp is flying over, acting as a rely node. Furthermore, the blimp could provide views of the scene (helicopter and target) that could be useful for calibration. This is an important problem in applications where there are not clear natural landmarks.

Finally, the project also involves the cooperation between robotic aerial vehicles, teleoperated vehicles and conventional piloted vehicles. This approach will take benefit from the expertise of human operators in missions where the full autonomy is very difficult to achieve but pose additional coordination and control problems due to the variability of the human operators.

The COMETS project includes the demonstration in forest fire detection, localization and monitoring. This is a very challenging mission in which the cooperation of the UAVs is very valuable. Thus, a special site will be conditioned in Gestosa, near Coimbra (Portugal).

Section 2 of the paper overviews the COMETS system. Section 3 describes the characteristics of the so- called Application Independent Image Processing Services. Some basic functions of the AIIP are described in sections 4, 5 and 6. Section 7 presents some forest fire monitoring results obtained by using the above functions. Finally, the Conclusions, and References are presented.

2. The COMETS system

The COMETS system is being designed to allow the cooperation of UAVs in detection and monitoring tasks. Thus, simultaneous views of the event being monitored will be possible, improving the event perception and allowing each aircraft to benefit from the data gathered by others. Improving fault tolerance capabilities and flexibility play an important role. The COMETS system (see figure 1) includes a Ground Segment, and several heterogeneous UAVs which form the Flying Segment. The COMETS demonstration will involve the cooperation of three heterogeneous vehicles provided by three partners of the COMETS project: The KARMA autonomous airship of the LAAS [8], the MARVIN autonomous helicopter of the Technical University of Berlin [10] and a teleoperated helicopter provided by Helivision and upgraded and integrated by the University of Seville. Moreover the COMETS system will allow the future integration of UAVs with more on-board capabilities and also the possibility to define and execute different types of missions, with different targets.

The architecture of the COMETS system is being designed to reduce risk in the operation. The UAVs are linked to the Central Station, but also the possibility of direct interaction between UAVs for coordination and cooperation is allowed, and different mechanisms for the cooperation of UAVs are possible including centralized and decentralized schemes.

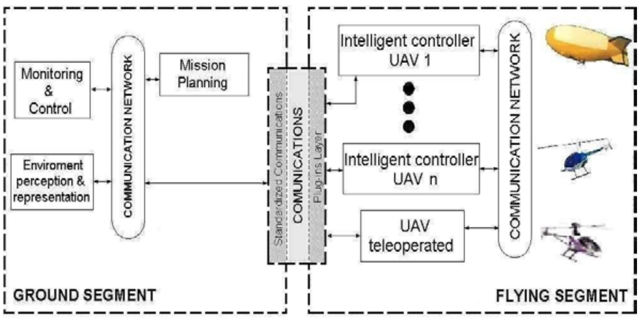

***Figure 1** : The COMETS system.*

The Communication system provides real-time properties, guaranteed bandwidth and fault-tolerance. COMETS has a blackboard communication system (BBCS) which uses a memory structure that is virtually shared between all communication nodes.

The Mission Planning provides a high level definition of the Mission by applying path planning techniques. The Monitoring and Control system provides functions for the monitoring of each individual UAV.

The Perception System is used for the modelling of the scenario observed by the UAVs, detection of events, localisation and monitoring. The inputs to this system are the signals received from the UAVs and the cartographic data provided by other subsystems in the Ground Segment. Co-operative perception from the information provided by several UAVs is performed on the Ground Segment. However, the UAVs can also have local perception functions.

The Perception System has four subsystems: Application Independent Image Processing, (AIIP); Detection/Alarm Confirmation, Localisation and Evaluation Service, (DACLE); the Event Monitoring Service, (EMS); and the Terrain Mapping Service (TMS).

AIIP deals with the image processing functions that are common to DACLE, EMS and TMS and is the core of the Perception System. This subsystem will be described in the next section.

3. The AIIP subsystem

The Application Independent Image Processing receive from the UAVs N image channels (sequences of images), telemetry data and corresponding uncertainty estimation, which should be synchronized with the image data.

The AIIP offers the following services: image stabilisation; image geo-referencing; tracking service (an object on the image plane is tracked over the sequence of images by means of image processing); and camera orientation control if available in the UAV.

Motion analysis from the image sequences delivered by the UAVs is an important part of the AIIP.

Several services of the AIIP are based on a feature matching algorithm that provides point correspondences between frames. It has been designed to deal with larger displacements than most optical flow methods can manage, so that it can be useful in a system with potentially severe bandwidth restrictions, with low frame rates of the images provided by some UAVs. The method is an improved version of the described in [5]. Features are defined by fixed-size blocks of pixels, selected with similar stability criteria as those defined in [16]. A set of matching candidates is selected for each image; they are used in a *direct matching process* to generate a data base of matching pairs. The pairs are validated by analyzing the residual correlation error and the building of clusters of features which keep approximately the same shape in both frames.

The major change from the approach taken in former versions is the generation of the matching pair database

Figure 2 *: Stabilization procedure. Three frames and the same frames after stabilization.*

through a predictive approach. A small set of correlation pairs is used to generate hypothesis, which guide the selection of candidates that match the previously known cluster structure, thereby avoiding most of the costly correlation-based search. This approach is a clear advantage when large feature displacement is expected between frames, and the motion of individual features cannot be easily predicted. As a result, low processing times can be achieved with standard processors.

4. Image stabilization

The cameras installed on aerial means are usually affected by vibration. These vibrations can be mechanically compensated by high quality gimbals. However, these devices are expensive, and their weight is generally not suitable for the limited payload of many UAVs. A low-cost, light positioning device can be used if vibrations are cancelled through image processing.

Let the vibration be a pure rotation around the optical center, as can be the case in a hovering helicopter. Then, it is possible to choose one frame as reference, and to refer the rest of frames to that one. The transformation in this case is a simple homography [1]. The same mathematical description can be also applied with translational motion if the scene features are quasi planar.

The transformation between frames is computed from the raw point correspondences output by the feature matching method, using statistically robust algorithms. Oultiers, i.e. point correspondences that do not follow the homography model, are detected and discarded in the process. Once the homography matrix is obtained, the new image can be warped in order to match the reference frame.

Mobile or changing objects, such as fire, can now be analyzed from a stable viewpoint.

5. Moving objects tracking

One of the AIIP functions is object tracking. An object in the image plane, described by some characteristics, has to be tracked over a sequence of images. A first developed technique is the tracking of moving objects in 2D scenes. This could be applied for UAV identification in a multi-UAV environment.

In this section, a method to detect moving objects is described. The objects are given to the AIIP by higher functions as a template. The object detection procedure consists of two stages: first, regions with independent motion are detected on the image plane. Afterwards, a template searching strategy is used to locate the vehicle among the regions obtained.

5.1. Independent motion estimation

The procedure described in section 4 for image stabilization register the frames according to a 2D transformation, a homography. This transformation is valid for planar scenes (the case we consider here) or rotating cameras. The homography computation technique is able to detect outliers, i.e., regions corresponding to points that do not follow the 2D model. These points could correspond to structures that do not lay in the reference plane (objects with parallax), and also to objects that moves independently (and both).

The parallax corresponding to static objects over the reference plane should satisfy the epipolar geometry. In this case, this means that the residual motion of these objects (once the motion induced by the reference plane is subtracted) forms an epipolar field, and this could be used to distinguish this kind of regions from regions with independent motion [7]. However, this approach is not

Figure 4*: Top row: Left to right: Points tracked, outliers detected, candidate regions after clustering. Bottom row: helicopter detection in several frames.*

considered here. The regions selected will be considered as candidates for the second stage. This method considers that the scene is approximately 2D (or, at list, the regions with 3D parallax are sparse).

A clustering procedure is carried out, grouping regions inside a certain area that could belong to the same object. Figure 4 shows the independent motion analysis procedure.

5.2. Object identification

The second stage tries to detect the desired object among the candidate regions generated by the independent motion estimation procedure. Often, some temporal consistency constraints are used for this second step. However, the frame rate could be not enough in this application for this approach.

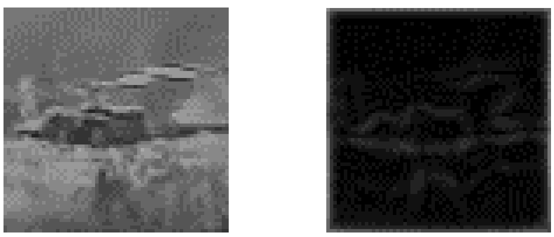

Figure 3 *: Templates used for object identification.*

A template-based approach to this second stage has been tested. A stored template of the vehicle to be detected is assumed (given as a gray-level patch). The template is searched in a area around the points given by the motion detection step.

A phase-only matched filter is used for object localization [2]. The main advantage with respect to normalized correlation is a much shaper peak. Also, the method is robust in the presence of noise.

Figure 3 shows the templates used. Left image shows the original template. However, better results can be obtained if the derivatives of the template are used for searching, instead of the original template.

6. Geolocation in 2D scenes

The AIIP subsystem should provide the geographical position of the interesting objects detected, i.e. geo-locate these objects. A method for geolocation in 2D scenes has been implemented.

If the scene considered can be approximated by a planar surface, the relation between the points of the surface and their corresponding pixels on the image plane is also an homography.

$$s\mathbf{p} = \mathbf{HP} \tag{2}$$

$$\mathbf{H} = \mathbf{A}[\mathbf{r}_1 \quad \mathbf{r}_2 \quad \mathbf{t}] \tag{3}$$

where $\mathbf{p}=[u\ v\ 1]^T$ are the homogeneous coordinates of a pixel, $\mathbf{P}=[X\ Y\ 1]^T$ are the coordinates of the corresponding point on the reference plane and s is a scale factor. This relation is invertible. Thus, if $\mathbf{H}$ is known, we can obtain the geo-location of a given object on the image plane.

Four correspondences between points on the terrain and pixels on the image plane would be enough to compute the transformation. Artificial landmarks could be used to compute the relation, although it is not likely to have those marks in a real fire. However, the parameters of the homography are related to the position and heading of the camera and its focal length [17]: $\mathbf{A}$ corresponds to the internal camera parameters, $\mathbf{r}_1$ and $\mathbf{r}_2$ are the two first columns of the rotation matrix, and $\mathbf{t}$ the translation vector of the transformation that relates the coordinate system attached to the reference plane and the camera coordinate system). If these parameters are known, an initial transform can be computed. In the COMETS system, the vehicles considered have sensors that can provide an initial estimation of the position and heading of the cameras. Then, these data can be used to obtain an initial estimation of **H**.

Once an initial transform has been computed, the tracking procedure described in section 3.1 can be used to update this information through the image sequence:

- The feature matching procedure selects initially several regions to be tracked. The location of these regions is obtained by using the initial transform.
- The tracking procedure obtains the new positions $\mathbf{p}_i=[u_i,v_i]^T$ of the regions in each frame. These positions are used to update **H**.

7. Monitoring in COMETS

As it has been stated, the COMETS system will be demonstrated in forest fire detection and monitoring activities. In this section some results obtained by using the functions described in the above section for forest fire monitoring are presented.

The real-time estimation of fire features is very important for the prediction of the forest fire behavior and the planning of the fighting activities. These features are the fire front position, flame length, flame height, rate of spread and fire base width [15].

The forest fire monitoring includes the computation of a 3D model of the fire from the above mentioned characteristics. It is based on the application of several algorithms previously developed by the authors including: infrared image segmentation by means of robust automatic threshold computation in gray-scale images, flame segmentation by means of color image processing, and procedures to combine the infrared and visual analysis to derive the 3D model of the fire[9].

An important information to be provided is the dynamic evolution of the fire contour. The perception system will use the above mentioned techniques to segment the fire in the images, classify the pixels belonging to the fire front base (over the terrain) and the corresponding pixels at the top of the flames. Furthermore, by using the procedures described in the previous section, the pixels of the fire base can be automatically geo-located. Some tests have been carried out on images taken during the experiments of controlled fires that were carried out in Gestosa (Portugal) in 2000 and 2002.

Figure 5 shows the evolution of the fire front each 20 seconds in an experimental fire which took place in the Gestosa obtained from aerial images. The experiments corresponds to a linear burn of a 100-meter long, 100-meter width plot.

The results have good concordance with the estimation obtained by means of traditional techniques (manual recording of data during the experiment).

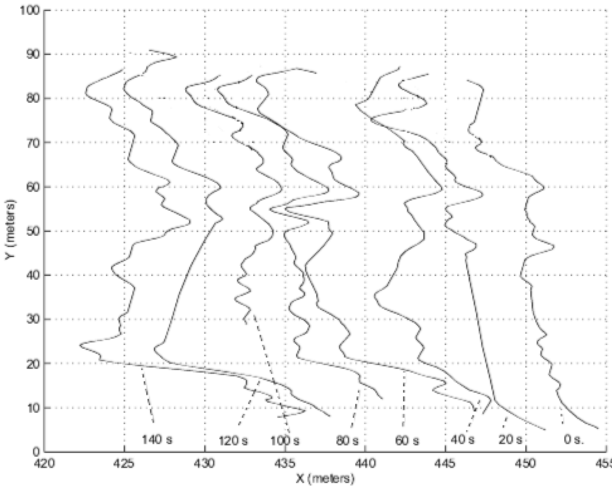

***Figure 5**: Fire front evolution (plot g520 Gestosa 2002). The plots burned is 100 meters width (Y axis) and 100 meters depth (X axis).*

8. Summary and Conclusions

This paper presents some results obtained in the COMETS project devoted to the design and implementation of a distributed control system for cooperative detection and monitoring using heterogeneous low cost UAVs. The COMETS project exploits the complementarities of different low cost autonomous aerial vehicles in missions where cooperation between several autonomous vehicles is the best way to guarantee success. The main missions considered in the project are forest-fire early detection and monitoring.

The paper mainly deals with the COMETS perception system. Particularly, several functions of the low-level image processing subsystem called AIIP are presented: image stabilization, motion object tracking and geo-location. The motion object tracking is applied to the tracking of one aerial vehicle from the images obtained from another. Furthermore, the paper includes some results obtained from forest-fire field experiments performed in Gestosa (Portugal), that have been obtained by applying the geo-localisation technique above presented. The results are encouraging and demonstrate the interest of the UAV techniques in this challenging application.

Acknowledgment

The work in this paper has been mainly developed in the COMETS project (European Commission, Information Society Technologies Programme, IST- 2001-34304). The authors thank the cooperation of the partners in the specification and design of the system, as well as to other members of the COMETS team at the University of Sevilla.

References

[1] O. Amidi, T. Kanade and K. Fujita. " A visual odometer for autonomous helicopter flight". *Proceedings of IAS-5*, 1998.

[2] Q. Chen, M. Defrise and F. Deconinck. "Symmetric phase-only matched filtering of Fourier-Mellin transforms for image registration and recognition". In *IEEE Transactions on PAMI*. Vol. 16. No. 12. December 1994.

[3] A.H. Fagg, M.A. Lewis, J.F. Montgomery and G.A. Bekey. "The USC Autonomous flying vehicle: an experiment in real-time behaviour-based control". In *Proceedings of the IROS 1993*, IEEE.

[4] O. Faugueras and Q.-T. Long. *The Geometry of Multiple Images*. The MIT Press, 2001. ISBN 0-262-06220-8.

[5] J. Ferruz and A. Ollero. Integrated Real-Time Vision System For Vehicle Control in Non-Structured Environments. *Engineering Applications of Artificial Intelligence*, pp. 215-236, Vol. 13, No. 3, Mayo 2000.

[6] F. Giulietti, L. Pollini and M. Innocenti. Autonomous formation flight. In *IEEE Control Systems Magazine*. December 2000.

[7] M. Irani and P. Anandan. "An unified approach to moving object detection in 2D and 3D scenes". In *IEEE Transactions on PAMI*. Vol. 20. No. 6. June 1998.

[8] S. Lacroix, I.K. Jung, P. Soueres, E. Hygounenc and J.P. Berry. The autonomous blimp project of LAAS/CNRS. Current status and research challenges. In *Proceedings of Aerial Robotics Workshop, IROS'02*, EPFL Lausanne, Switzerland, October 2002.

[9] A. Ollero, J.R. Martínez-de-Dios, B.C. Arrue, L. Merino and F. Gómez-Rodríguez. "A perception system for forest fire monitoring and measurement". In *Proceedings of the FSR 2001*. University of Technology. Helsinky, Finland, November 2001.

[10] V. Remuss, M. Musial and G. Hommel. ''MARVIN'', an autonomous flying robot based on components of the shelf. In *Proceedings of Aerial Robotics Workshop, IROS'02*, EPFL Lausanne, Switzerland, October 2002.

[11] C. Shumaker and S.N. Singh. "Non-linear control of multiple UAVs in close-coupled formation flight". *AIAA Guidance, Navigation and Control Conference*, 2000.

[12] S.B. Stancliff and M.C. Nechyba. "Learning to fly: modeling human control strategies in an aerial vehicle". *Proceedings of the FCRAR*, 2000.

[13] M. Sugeno, M.F. Griffin and A. Bastia. "Fuzzy hierarchical control of an unmanned helicopter". *17th IFSA World Congress*.

[14] R. Vidal, S. Sastry, H.J. Kim, O. Shakernia and D.H. Shim. "The Berkeley Aerial Robot project (BEAR)". In *Proceedings of Aerial Robotics Workshop, IROS'02*, EPFL Lausanne, Switzerland, October 2002.

[15] D.X. Viegas. "Innovations and solutions in fire behaviour prediction issues. Forest fires: needs and innovations". In *Proceedings of the Delfi International Symposium*, pp. 164-173, Athens, Greece, 1999.

[16] Tomasi, C. (1991). Shape and motion from image streams: a factorization method *(Ph.D. Thesis)*, Carnegie Mellon University.

[17] Z. Zhang. "A flexible new technique for camera calibration". In *IEEE Transactions on PAMI*. Vol. 22. No. 11. November 2000.