PRINCIPAL ACADEMIC TUTOR
Francesco Grimaccia, Department of Energy, PoliMi

ACADEMIC TUTOR
Marco Lovera, DAER, PoliMi
Giorgio Guglieri, DIMEAS, PoliTo
Elisa Capello, DIMEAS, PoliTo
Mattia Giurato, DAER, PoiMi
Alessandro Niccolai, Department of Energy, PoliMi

EXTERNAL INSTITUTIONS
Nimbus S.r.l.

TEAM MEMBERS

Bruno Bajeli
Aerospace Engineering, Politecnico di Torino

Fausto Lizzio
Mechatronic Engineering, Politecnico di Torino

Andrea Maiani
Engineering Physics, Politecnico idi Milano

Antonio Marangi
Mechatronic Engineering, Politecnico di Milano

Ivana Mirchevska
Electrical Engineering, Politecnico di Milano

Giacomo Ornati
Mechatronic Engineering, Politecnico di Torino

Massimo Perini
Computer Science Engineering, Politecnico di Milano

Gabriele Roggi
Aeronautical Engineering, Politecnico di Milano

Fly-By-Sensor system for Photovoltaic energy plant monitoring (FBS-PV)

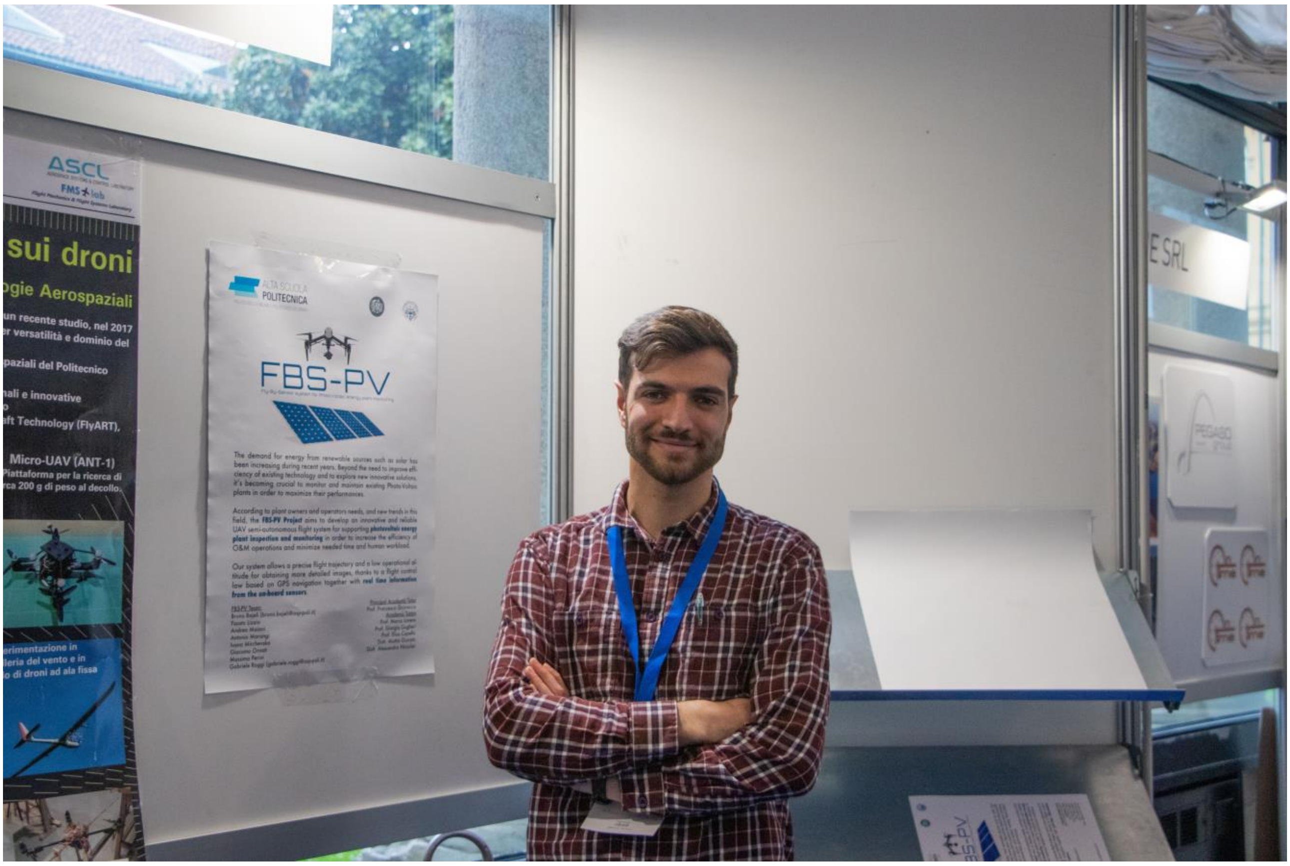
Executive summary

Photovoltaic (PV) electricity generation represents one of very few renewable energy sources with the potential to grow to very large scale. In recent years, it has experienced a significant growth, becoming one of the most prominent clean sources in the energy challenge. In order to counteract the degradation the PV plants are prone to, an effective Operations and Maintenance (O&M) represent a key aspect. Although, over the past few years, physical inspection of the PV panels by human workforce has represented the state of the art, today inspections are carried out normally thanks to the use of UAV (Unmanned Aerial Vehicle). The increasing reliability in autopilots and the development of interfaces for mission planning have encouraged the spreading of automatic systems for the UAV flight. These systems can drastically reduce the workload for the human operator, which can concentrate on the quality of the images captured and the scheduling of maintenance operations. On the other hand, the meter-level uncertainty of the Global Navigation Satellite System (GNSS) used for navigation purposes, as well as possible imperfections in the map used to plan the flight, make automatic systems not reliable and robust enough for the high accuracy tracking of the PV lines.

The FBS-PV concept regards the inclusion of on-board additional sensors to improve the UAVs' flight accuracy in trajectory during PV O&M procedures without the need of external compensation from human operators. Accuracy is guaranteed by the perfect overflight of the rows of photovoltaic panels thanks to the use of image vision-based controllers.

Key Words

Photovoltaic, Drone, Vision Control, Autonomous Flight



FBS-PV team participation at Dronitaly with Bruno Bajeli.

Project description written by the Principal Academic Tutor

Nowadays, photovoltaic (PV) plant monitoring performed with unmanned aerial vehicle (UAV) technologies is growing in the operation and maintenance market for the capability to provide a low cost and effective tool in maintenance. In this context, innovative hybrid UAV platforms, especially in the light segment, can be used as an effective tool to perform accurate data acquisition in multidisciplinary application fields.
In this frame, being able to improve the flight control system by means of sensors data and, consequently, to improve the image acquisition process, can be an important added value in the market: in fact, it can impact on the time required and especially on the quality of the provided service.
The focus of the project is to develop an innovative fly-by-sensor system tailored for the PV monitoring application, receiving information about the flight from onboard sensors or by means of a wireless ground network or station. It is envisaged that control technologies beyond the state of the art in small-scale multirotor UAVs might be needed, specifically involving on-board planning/re-planning and optimization, possibly coupled with learning algorithms. The historical data can be profitably used as a first test set for the proposed system, while new data can be specifically acquired in new flights performed during the project period.

The project can be composed in different phases in which the students acquire the relevant know-how and then can develop and test their own system. In particular the foreseen project phases are:

- Analysis of the state of the art, both for what concerns the flight procedures and the fly-by-sensor technologies: in this phase the team can analyze how UAV flights are presently performed and can identify the current technical and commercial gaps. In parallel they can investigate the fly-by-sensors systems identifying what can be included in the system they will develop. Moreover, the different kind of existing sensors should be investigated in order to find the most appropriate for the specific UAV platform.
- Development of an innovative system tailored on the application of PV plant monitoring. The system can include onboard sensors and on ground wireless sensors network. In this phase, the students can exploit the knowledge obtained in the previous stage and the support of the tutors to develop their own system.
- Test of the proposed system, using simulation tools with the data available or using laboratory equipment. In this phase the students can further improve the developed system.
- Possible on field test, performed if the results of the previous testing phase are satisfactory.

Team description by skill

Bruno Bajeli, project manager. His contribution consisted in work planning, time scheduling, meetings organization and documentation management, graphic design of project logo and promotional video

Fausto Lizzio, worked on requirements and need analysis, stakeholders interview.

Andrea Maiani, worked on problem definition, ideas generation, design of the solution.

Antonio Marangi, worked on computer vision and graphics development, on field interviewer.

Ivana Mirchevska, worked on state of the art, aerial camera analysis of PVs, final presentation.

Giacomo Ornati, software developer. Worked on concept formulation, simulation setup, image processing and algorithm implementation.

Massimo Perini, worked on project requirements, state of the art analysis, evaluation of alternatives and website development.

Gabriele Roggi, software developer. His main activities regarded problem formulation and algorithm implementation with focus on the integration between vision and flight control laws.

Goal

This project aims to explore and study innovative “fly by sensor” systems for Unmanned Aerial Systems (UASs) applied to energy plant monitoring with reference to photovoltaic power plant.
The main objective of this project is to develop an innovative system capable of automatically create an optimized flight plan exploiting data coming from a proper set of sensors, placed on the aircraft or on a ground control station.
The specific objectives of the project are:

- Analyze the existing fly-by-sensors technologies identifying the specific advantages and the disadvantages;
- On the basis of the state of the art, propose a specific system for the PV monitoring application;
- Analyze the performance of the proposed system using historical data previously acquired or coming from new flights performed by the selected industrial partner with specific attention to the group needs;
- Potential laboratory or in field testing of the proposed solution.

Understanding the problem

At present, the maintenance of photovoltaic systems using UAVs can be divided into two categories:

Manual flight: a pilot flies the drone in manual mode following it along the entire length of the photovoltaic plant. The images obtained are of excellent quality, but the time required to complete the operation is very long, so the costs are high. In addition, there is little repeatability of the photos as they are taken in manual mode.

Automatic Flight: In this case the operator relies on the autopilot software for overflight. His task is simply to create a trajectory thanks to the software in the ground control computer. Compared to manual flight, the time required for flight operations, as well as costs, significantly decrease. However, the trajectory of the UAV is often incorrect or misaligned with respect to the PV line to track, leading to poor quality images. This is mainly due to three factors:

1. Error in the positioning of waypoints during the mission planning phase
2. Error due to incorrectly geotagged maps
3. GNSS error during flight

Our goal is therefore to try to obtain the quality of the images taken in manual mode but using automatic flights to limit the time and cost of maintenance operations.

Mission planning in a ground station for automatic flight

Exploring the opportunities

To solve the mentioned problems of automatic flight, three possible solutions have been analyzed:

1. **Usage of RTK**: Real-time kinematic (RTK) positioning is a satellite navigation technique used to enhance the precision of position data derived from satellite-based positioning systems. It relies on a reference station and is able to provide up to centimeter-level accuracy. Adopting this technology would only improve the accuracy of the GNSS feed but would not eliminate imperfections in the mapped positions of the panels and imprecision in the setup of waypoints.
2. **Image recognition with tag**: Optical tags can be cheap passive devices located on ground or on the PV panels. Under the assumption of knowing the exact georeferenced position of these tags, the drone can exploit this information to reconstruct its position with respect to the panels themselves. This will lead to the correction of both GNSS and geotag error. However, this solution is characterized by a high invasiveness with respect to the plant since, before the actual maintenance operation, the plant must be suitably prepared through the installation of multiple devices.
3. **Vision-based solution**: A subsystem in the companion computer of the drones analyzes the real time video stream looking for errors in the flight plan caused by the GNSS and map inaccuracies and/or bad operator orders. Using a fly-by-sensor approach with only on-board devices makes this solution far more interesting for potential customers: they don’t have to place and remove multiple tags every time or buy expensive external devices. The drone should use the information provided by the camera to correct the operator input in order to follow precisely the PV panels rows. Clearly, as drawback, it is worth noting that the development of such an algorithm requires a high effort from the software and hardware architecture point of view. However, both GNSS accuracy and waypoints setup problems are solved using only technologies bundled with the drone, therefore leading to a more effective solution.

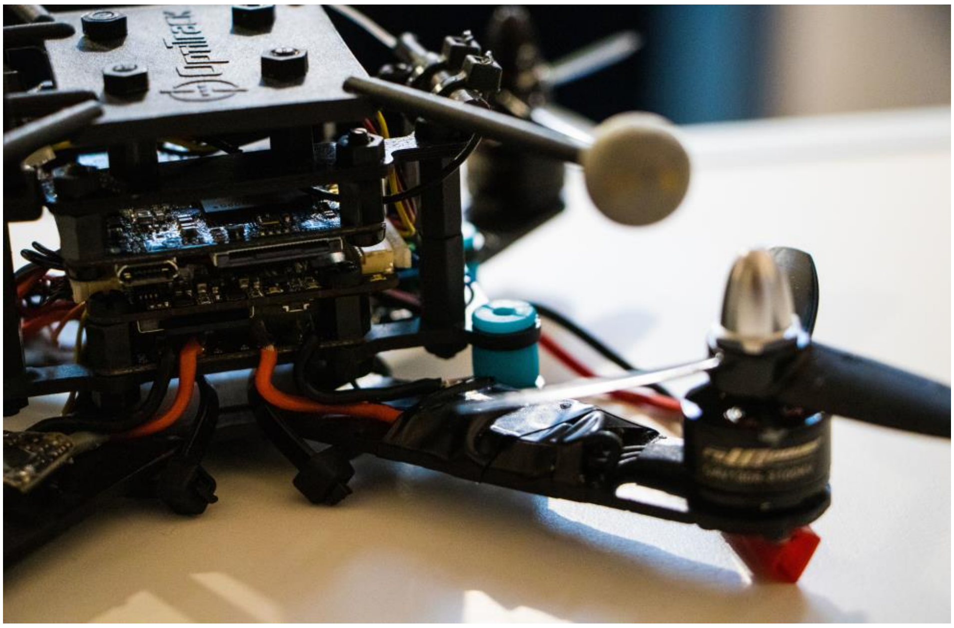
Gabriele Roggi looking at the control station equipment during operations on the Lodi photovoltaic plant.

Generating a solution

The solution chosen is the third proposal. As previously mentioned, the development of an integrated algorithm on an UAV is a very delicate task. Bugs or wrong tuning of parameters can trigger hazardous behavior or induce crashes. To avoid such consequences, the software has been tested in a software-in-the-loop simulation environment for the open-source autopilot firmware PX4. It is implemented using the Gazebo simulator and exploiting the Robotic Operating System (ROS) as an interface among the different architecture components. This simulator can replicate the entire UAV architecture, comprehensive of all the sensors, i.e., gyroscopes, accelerometers, range sensors, GNSS receivers and the camera the UAV is provided with. In this framework, the overall performance is appropriately quantified and compared with the state-of-the-art solution.

The FBS-PV concept regards the inclusion of on-board additional sensors' information to improve the UAVs' flight accuracy during PV O&M procedures without the need of external compensation from human operators. Among the sensors available, cameras have notably several advantages in terms of low weight, low power consumption and low price. Exploiting suitable techniques for image processing, these sensors can provide valuable information about the position and the attitude of the vehicle with respect to the target, in this case represented by the PV rows.

The results have highlighted excellent characteristics in terms of accuracy and robustness, and the software has shown itself as a valuable tool for improving the performance of PV O&M tasks. In particular, the computer vision techniques used can estimate the position of the UAV with respect to the PV panel with an error lower than 50 cm. At the same time, the correction inputs sent to the drone makes it align to the PV panels' rows with the same level of accuracy.



Details of FCU and Companion computer on a real drone at Dronitaly

Main bibliographic references

[1] F. Grimaccia, M. Aghaei, M. Mussetta, S. Leva, P. Bellezza Quater, (2015), Planning for PV plant performance monitoring by means of unmanned aerial systems (UAS), DOI 10.1007/s40095-014-0149-6, Springer.

[2] J. F. Canny, Finding edges and lines in images, Report AI-TR-720, MIT Artificial Intelligence Laboratory, Cambridge, MA, 1983.

[3] P. P. Acharjya, R. Das, D. Ghoshal, Study and Comparison of Different Edge Detectors for Image Segmentation, Global Journal of Computer Science and Technology Graphics & Vision, Volume 12, Issue 13, 2012.

[4] PX4, https://px4.io/.

[5] MAVROS, http://wiki.ros.org/mavros.