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Integration of a low-cost camera system for smart agriculture aboard tethered balloons and drones

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Abstract. The impacts of climate change on crops are intensifying and notably severe. This considering both natural disasters and the unpredictability of seasonal patterns, which lead to dwindling resources. Therefore, innovative methods are being sought to investigate plant health to reduce waste, intensify productivity, and ensure production continuity. This to date is feasible using satellite and Earth observation technologies in general; however, these pose some challenges for both individual farmers and local organizations. In fact, the cost of high-definition satellite images for surveys of individual crop fields can have very high costs that would not guarantee frequent analysis. On the other hand, other satellite observation strategies, which are cheaper, do not guarantee high ground resolutions and compromise, again, the success of the analysis. For the reasons just listed, a variety of alternative technologies have emerged that, integrated aboard Unmanned Air Vehicles (UAVs), guarantee high-resolution imaging for costs two orders of magnitude lower than satellite imaging. In this essay its described the potential of these devices and provide a brief description of the analysis conducted on crop fields considering their integration on board three different UAVs.

Introduction

Smart agriculture is an ever-increasing growth sector [1]. This is for various reasons, starting from increased production performance, reduced waste and environmental impact, and guarantees provided to end users when purchasing the product.

In recent years, the aerospace sector has focused on developing monitoring solutions that fall under the branch of Earth observation; these technologies and services, offered by governmental [2] and commercial [3] entities, include satellites capable of working in different wavelength of the visible, near-infrared and UV (Ultra Violet) spectrum. In fact, it is not new how, by means of multispectral analyses, a great deal of additional information can be obtained in the observation of nature. Satellite monitoring provides significant contributions from aspects of geology [4], water resources [5], pollution [6] and finally the health of humans [7] and vegetation [8].

However, this revolution is not without its limitations: just as it's impractical to saturate space with satellites, maintaining sporadic observations with satellite passages spaced four or more days apart isn't feasible. In addition, the boundary variables must not be forgotten, such as the atmosphere cloudiness that restricts the view on the ground, the still high cost for a precision satellite services, and the ground resolution that, in many cases, is not sufficient for analyses limited to narrow FOVs (Field of View).

Looking at the monitoring of specific crop fields, the individual farmer, but also a governmental verification body, may find it difficult to obtain repeated quantitative responses over an area of interest.

For these reasons, satellite data require integration with other types of observation technologies that are compact, easy to deploy, compatible with existing technologies, ready to use and easily accessible from an integration and possibly economic perspective.

The ATEMO (Aerospace Technologies for Earth Monitoring and Observation) project [9] aims to design and develop these technologies for integration on board mid-atmosphere vehicles such as drones, tethered balloons, and stratospheric balloons, which we will summarise as UAVs.

As part of this project, research activities have been defined that currently focus on the analysis of crop fields. This article will therefore describe these observations from the technology developed, to the on-board integration of UAVs and the innovative contribution to smart agriculture.

Description of analyses

Observations, including satellite monitoring, conducted in the agricultural field are, as mentioned earlier, multispectral. The combination of light information on various spectral bands provides indicators of vegetation health based on the principle that healthy plants emit or absorb different wavelengths than diseased plants. Various examples of this type of analysis can be found in the literature and have become an excellent ally for farmers and agricultural associations [10]. The best-known example is the NDVI (Normalised Difference Vegetation Index), an index that considers the red band at 695 nm, which is related to the absorption of chlorophyll by leaves, and the NIR (Near InfraRed) band 750 nm, which corresponds to the reflectivity of plants. These values are combined into a dimensionless coefficient that gives an indication of the health of the plant under examination and is summarised in the simple formula below (Eq. 1).

$$NDVI = \frac{Red-NIR}{Red+NIR} \tag{1}$$

In addition to this, various indices exist such as the GNDVI (Green Normalised Difference Vegetation Index), ENDVI (Enhanced Normalised Difference Vegetation Index) and many others summarised in official databases shared between researchers and scholars [11]. The diversity among these indices serves a dual purpose. It enables the determination of tailored coefficients for the analysis at hand, while also facilitating the identification of correlations between them when performed concurrently. Consequently, even with limited data, these correlations can be indirectly established. This inherent potential underlies the technologies discussed in this article. By hypothetically conducting high-resolution NDVI assessments on a cultivated field, scientists can validate less resolved satellite data and establish a baseline for monitoring that area, while still relying on technologies affected by certain limitations. However, they can address some of these obstacles and minimize others.

Based on this principle, however, integrating spectrometers on board a drone or tethered balloon is not a viable and cost-effective solution; for this reason, commercial cameras are selected, and, with appropriate optical filtering, wavelengths of interest are isolated. This ensures that almost all the bands seen from the satellite are compensated for and allows for a timely comparison.

In the specific case of ATEMO, an attempt was made to still provide the calculation of at least two or three indices simultaneously, and therefore two cameras were used: one monochrome and one colour.

The colour camera, with triple-band filtering can, on its own, still allow the isolation of three bands; in fact, if distinct spectrum bands are selected and corresponding to the RGB channels of the camera, it is possible, with appropriate calibration of the vision system, to define distinct information on the three selected wavelengths ranges.

The monochrome camera, on the other hand, allows the acquisition of the single reference band corresponding to the filter inserted.

In the case of ATEMO, different filtering solutions can be integrated in this manner, and thus multiple vegetation indices can be defined; below, in Table 1, is a comparison between the bands available from a commercial satellite solution (Planet) and the filters that can be integrated on ATEMO.

***Table1**: Comparison of the acquisition bands of Planet satellites and ATEMO.*

Band name	Planet		ATEMO	
	Nominal Value	Bandwidth	Nominal Value	Bandwidth
Coastal Blue	441,5 nm	21 nm	470 nm	20 nm
Blue	490 nm	50 nm	475 nm	20 nm
Green I	531 nm	36 nm	550 nm	20 nm
Green	565 nm	36 nm		
Yellow	610 nm	20 nm	-	-
Red	665 nm	30 nm	695 nm	20 nm
RE (Red-Edge)	705 nm	16 nm	735 nm	20 nm
Infrared (>800)	-	-	800 nm	-
NIR (Near-Infrared)	865 nm	40 nm	850 nm	20 nm

The most used configuration during the initial system test campaigns was a triple-band 475nm, 550nm and 850nm filter on the colour camera and an RE (Red-Edge) bandpass filter. This is because the focus was on estimating the ENDVI and GNDVI mentioned above, and the NDRE (Normalised Difference Red-Edge index), the definition of which is indicated below (Eq. 2, Eq. 3 and Eq. 4).

$$ENDVI = \frac{(NIR+Green)-2*Blue}{(NIR+Green)+2*Blue} \tag{2}$$

$$GNDVI = \frac{NIR-Green}{NIR+Green} \tag{3}$$

$$NDRE = \frac{NIR-RE}{NIR+RE} \tag{4}$$

The above-mentioned indices are excellent for defining water stress, the subject of analyses conducted during the summer of 2023, however, subsequent filtering options will be tested, especially, those involving blue and near-infrared wavelengths that provide indications of diseases caused by pests and other pathogens that reduce regular plant activity.

Integration and Testing

The total ATEMO system, visible in Figure 1, has been tested aboard tethered balloons, however, reduced versions have been accommodated aboard drones and stratospheric balloons.

Low altitude configurations require high aperture optics, while on balloons reaching high altitudes (between 30 and 40 km) it is essential to change the aperture of the on-board optics.

For integration on-board tethered balloons, continuous analysis spanning the entire day is feasible, ensuring the accumulation of a substantial dataset that captures daily trends effectively. This entails a series of expedients in the definition of the payload such as energy autonomy, acquisition autonomy and the guarantee that, even in strong gusts of wind, the pointing of the cameras remains as stable as possible.

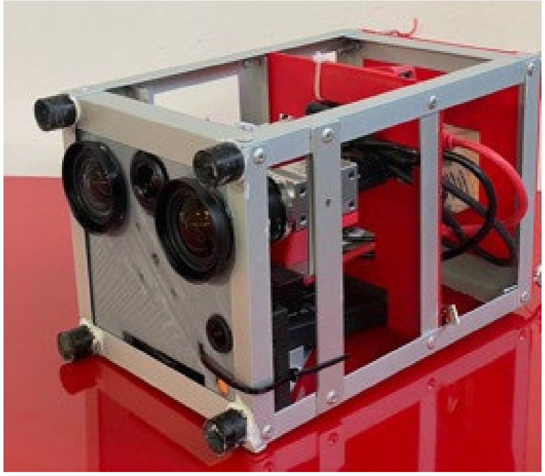

Figure 1*: ATEMO system.*

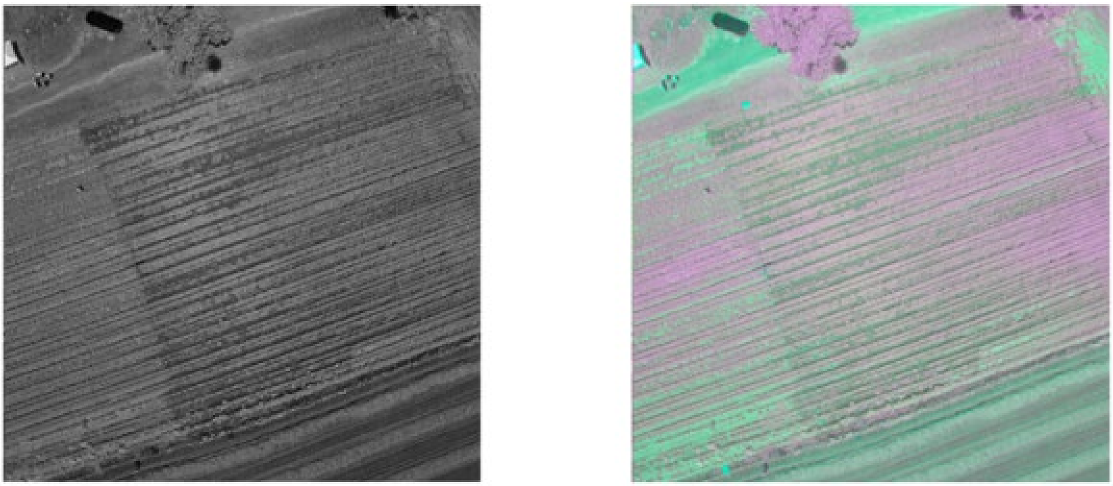

Figure 2*: Field test in Cortona (Arezzo), summer 2023: on the left the image of the monochrome camera with NIR filter and on the right the image of the colour camera with triple-band filters.*

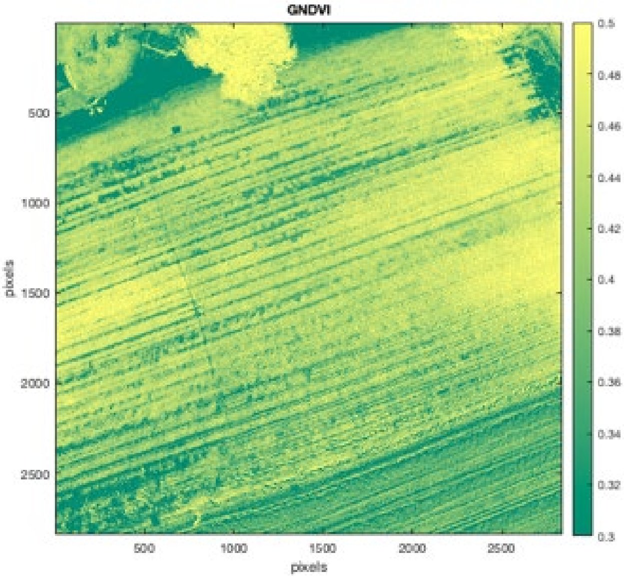

Figure 2*: Example of GNDVI index extrapolation from the photos in Figure 2.*

This is not the case with integration on-board drones which, although they can make multiple passes during a day, have a limited flight time. In this case, the adaptability of the acquisition system is also considered, which for geometric reasons will have to have an angle of inclination to consider when processing the data but above all when defining the flight itinerary. In fact, if the tethered balloon remains stationary at altitudes between 50 and 100 m, the drone flies over the area of interest keeping lower, guaranteeing more defined images but needing to move over the field to cover the entire surface under examination.

In the case of the stratospheric balloon, as mentioned earlier, narrower optical systems are used, and less focused analysis is performed. The lightness of the payload imposed by the flight leads to a reduction in the number of instruments on board, for example, in a test campaign conducted in Pisa, only a single camera (the colour one) was mounted with a triple-band filter.

The testing of the device actively involved the research team and provided several comparable images indicative of its correct functioning and support in the determination of vegetative indices. Above, in Figure 2, is an example of a shot taken by the two cameras with the tethered balloon; while Figure 3 shows an example of reworking to calculate a vegetation index.

Conclusions

In conclusion, ATEMO proves to be a low-cost, versatile, and useful solution for the effects induced by adverse climatic events on crops. During the first test phase, estimates of vegetation indices such as ENDVI, GNDVI and NDRE were conducted with different autonomous flight systems. The tethered balloon proved to be very useful as it allows long autonomous samplings by granting a better manageability of the vehicle by the operator, the drone is more effective for the very accurate analysis of plants and to have resolutions of the order of magnitude of a leaf dimensions. Finally, tests from a tethered balloon, with a system similar to that on the ground, open the way for future comparisons for the validation of satellite data.

The uses of devices such as the one described are varied; soon, the aim is to extend the spectrum of analysis, for example by zooming in on indices to study vines potentially attacked by pests and prevent their spread. In general, the contribution of these technologies is and will be an important resource for fighting climate change and increasing data for analysis and prevention.

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