System Design for Precision Weeding in Secondary Archaeological Sites

Mariagrazia Leccisi
Dipartimento di Scienze
Università degli Studi "Roma Tre"
Roma, Italy
mariagrazia.leccisi@uniroma3.it
https://orcid.org/0000-0003-2775-637X

Giuseppe Schirripa Spagnolo
Dipartimento di Matematica e Fisica
Università degli Studi "Roma Tre"
Roma, Italy
schirrip@uniroma3.it
http://orcid.org/0000-0003-0108-1335

Fabio Leccese
Dipartimento di Scienze
Università degli Studi "Roma Tre"
Roma, Italy
leccese@uniroma3.it
http://orcid.org/0000-0002-8152-2112

***Abstract*— For the enhancement of secondary archaeological sites, it is essential to provide intervention methodologies that reduce biodeterioration and allow fruition of the cultural heritage. One of the problems that afflicts minor archaeological sites is the presence of spontaneous vegetation (especially ruderal). In this work, we present the project of a weeding system that makes use of the methodologies used in precision agriculture. It is planned to use a drone for the identification of weed vegetation and for the administration of targeted quantities of herbicides. Furthermore, with the use of a multispectral sensor it is possible to monitor the effectiveness of the treatments.**

Keywords — sensor, multispectral, precision farming, archaeological sites, cultural heritage conservation

I. INTRODUCTION

Improving the management, conservation and use of minor archaeological sites means preserving our cultural heritage over time, contributing to the dissemination of knowledge and culture, but also developing the economic and tourist sector, especially in rural areas and small towns [1].

Sometimes, vegetation is one of the main deteriorating factors of archaeological sites [2-4]. The importance of vegetation development in the alteration of masonry and different types of artifacts cannot be overlooked (see Fig. 1).

Fig. 1. Archaeological site of Monte Torretta di Pietragalla (PZ – Italy).

The vegetation present in archaeological sites can be very significant [5, 6], especially in relation to certain types of substrates and the climatic conditions of the surrounding environment [7]. In some cases, the depth, dimensions, and distances reached by the roots can be considerable and their disintegrating action takes place even on very compact substrates [8, 9]. Furthermore, the chemical action generated by the production, at the radical level, of acid substances must be added to the mechanical action exercised by the growth of the underground parts [10]. Obviously, in some exceptional cases [10,11], the same vegetation can become a cultural asset; take, e.g., the Ta Prohm temple in Cambodia (see Fig. 2).

Fig. 2. Angkor Wat - tempiale dell'AT Prohm, Cambogia.

However, even in these cases, it is essential to control the damage caused by vegetation so as not to completely lose the cultural ruins.

In general, in archaeological sites the vegetation is weed and ruderal. The artefacts and above all the archaeological sites, if not subjected to systematic containment practices of the spontaneous plants, tend to be rapidly colonized or suffocated [12-16]. Fig. 3 shows the temple of Lokroi Epizephyrioi before and after a weeding operation.

Archaeological sites have protection constraints [17-19] that complicate normal cleaning and weeding procedures. In other words, the procedures and methods commonly adopted for cleaning the roadside or private driveways cannot be used. This, added to the economic constraints of those who must protect and manage secondary archaeological sites, means that very often these are abandoned to decay. Glyphosate is the active substance present in the herbicides currently most used in the world.

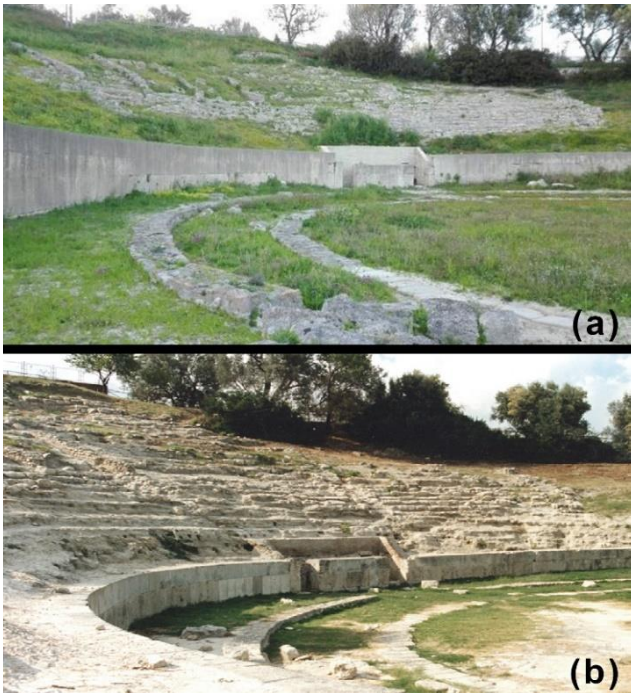

Fig. 3. Theater of Lokroi Epizephyrioi. The Greek theater was built near today's Locri (province of Reggio Calabria - Italy) in the 4th century BC. using a natural concave; heavily modified theater in Roman times. (a) Theater with the presence of ruderal vegetation. (b) Theater essentially devoid of vegetation.

In the European Union, the authorization to use glyphosate will expire on 15 December 2023. However, over the years public opinion has pushed for restrictions on its use. Therefore, several national and regional authorities have established restrictions on use. These limitations have long fueled a debate regarding possible alternative methods to be used to contain the biodeterioration phenomena produced by herbaceous, shrubby and tree plants in archaeological areas.

The use of drones or rovers is widespread in many working areas. In precision agriculture they are used to help farmers in their functions, partially replacing their activities. In fact, various devices are mounted on them to study the health of plants or soil, but also to deliver substances when needed. Fig. 4 shows two examples of drones for agriculture: the first is a commercial drone with a tank of 15 litres, being able to spray all over a crop; the second is a rover with a set of sensors capable of capturing data about water status, production, vegetable development or grape composition.

In the archaeological field, the use of rovers is not widespread due to their structure, which could damage archaeological relics; however, they can be easily used outside buildings and in all open areas, such as amphitheatres. Aerial drones, on the other hand, are more easily used in the archaeological field for information gathering, site mapping, and inspection of archaeological sites, as well as for video surveillance operations. On both rovers and drones, it is common to mount devices such as sensors or webcams; the limitation for aerial drones is the weight and location of the devices, however, there are specific devices of such size and weight that they do not interfere with the proper operation of drones. Since drones and rovers are already available for their use in agriculture, we propose using a drone (o rover) for early weed detection [20-23]. Furthermore, with the same drone, it is possible to intervene for weeding with minimal quantities of herbicide and sprayed only where necessary.

The proposed system can be customized and configured according to the monitoring needs of the specific application scenario, so furthermore, the system is friendly to both the archaeological site and the environment.

Fig. 4. Two examples of commercial drones for agricolture. (a) is the XAG V40 (4.2gal / 15L), a drone with a 15 liters tank, (b) is VINBOT, an all-terrain autonomous mobile robot with a set of sensors capable of capturing data about water status, production, vegetable development or grape composition.

In case of a theater or an open area a rover can be considered for the monitoring of the weeds, while in a scenario of an internal area or other sensitive areas the use of an aerial drone can be considered. The effectiveness of the weed monitoring system can be provided by a multispectral sensor through which you can monitor if the vegetation tends to dry out and at what speed. In other words, it is possible to check whether the quantity of product used is adequate. In addition, there is the possibility of verifying whether any atmospheric precipitation has affected the treatment. All this, allowing the use of herbicidal products in a targeted way and in minimum quantities. Obviously, it must be specified that the decision to use these products must be taken collectively only after all the experts have evaluated all the possible implications, including the analysis and preservation of the biodiversity that that vegetation could have created and guaranteed.

II. The Proposed System

In this context the proposed system consists of a rover (or drone) capable of monitoring the site of interest. Furthermore, the done/rover must not cause damage to the archaeological site, both during normal use and in the presence of accidental events. The self-driving rover (or drone) will be equipped with a camera, multispectral sensor, robotic arm, control computer and wireless communication system. Also, the system will be able to georeferencing the interesting points. Fig. 5 schematically shows the proposed system.

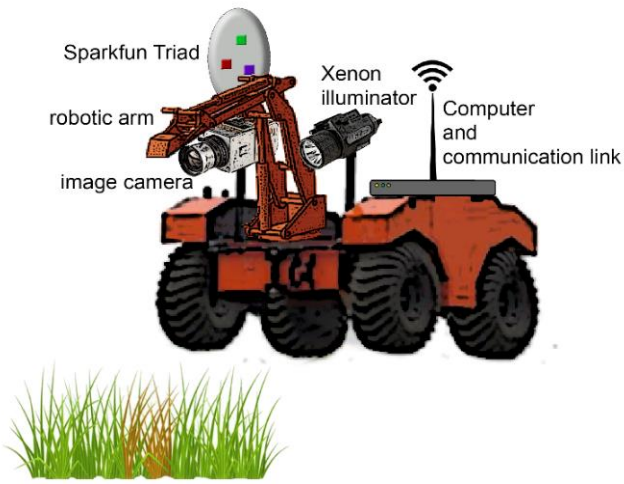

Fig. 5. Schematic of the proposed sistem.

Through preventive programming, it will monitor the archaeological area; through the image camera and/or the multispectral sensor it will identify the areas to be weeded, and the robotic arm will spread the least programmed quantity of herbicide. The treated areas will be georeferenced to be able to subsequently verify the effectiveness of the treatment. The images and spectra captured with the multispectral sensor depend on the lighting. To allow comparative checks in successive times, time interval of a few days - time necessary for the herbicide to perform its function, weeding is expected to be carried out at night using artificial lighting. For this purpose, the rover (or drone) is equipped with a Xenon Illuminator (Currently a normal lamp used for headlights in cars).

From a technical point of view, the development of a specific drone for this type of application in the archaeological field is a very complex project; in fact, issues arise related to the sizing of the structures and the hardware used, as well as the choice of drone motion sensors and evaluation of the surrounding environment. Also, the acquisition of data and its interpretation to determine whether and how much product to spray involves specific algorithms that need to be implemented. We are working on all these issues, but this paper in detail, focuses attention on the aspects of evaluating and recognizing weeds in an archaeological context, and the changes that occur because of weeding.

Our work focuses particularly on the usage of a multispectral sensor, for the collection of the spectral responses of the weeds to a source of illumination, detecting the necessity of an intervention as spraying substances.

After this introduction describing and contextualizing our project, section 3 will describe the preliminary tests carried out with the multispectral sensor for weed detection and its temporal monitoring. Finally, section 4 will describe the sensor used and the results obtained from the comparison of the spectra, in the various situations considered, with related conclusions.

III. PRELIMINARY TESTS

To verify the effectiveness of the proposed system, some preliminary tests were carried out (without using the rover). Before and after weeding, images were acquired at night and under artificial lighting. Fig. 6 shows a picture of a weed before and after weeding with acetic acid.

Looking at the pictures you can see the effects of the treatment, while Fig. 7 shows a picture of a weed before and after weeding with acetic acid.

In this last case, a consistent meteorological precipitation occurred 32 hours after the treatment. If you look at the images, before and after the treatment, you can see that weeding has only partially taken place, further intervention is necessary to obtain the desired result.

Furthermore, the background and partial weeding makes it difficult for an automatic decision by an artificial intelligence system. In any case, a properly trained neural network could arrive at acceptable results, with no difficulty identifying weeding effectiveness.

Artificial intelligence applied to image analysis is very useful in these cases; however, if you are dealing with an archaeological site, the images to be acquired, memorized, and processed require great computing capacity and above all memory. Also, training the network can be very time consuming, limiting the use of these instruments in a post-processing phase.

Fig. 6. Weeding carried out with acetic acid. (a) Image before treatment. (b) Image 5 days after treatment. In the period of time that elapsed between the two acquisitions, there was a consistent meteorological precipitation.

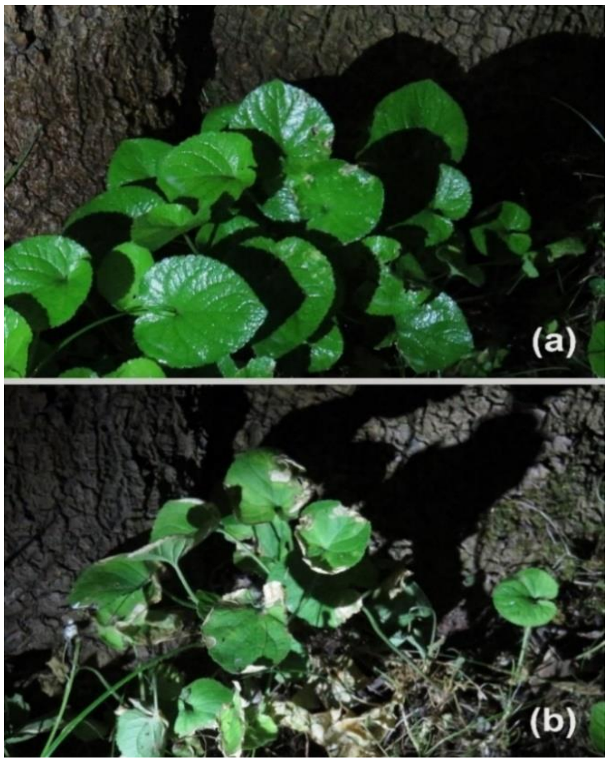

Fig. 7. Multrispectral sensor AS7265x used in our esperimental test.

Considering the management difficulties of secondary archaeological sites, we hypothesized to use a multispectral sensor to control weeding. In this case, various vegetative indexes can be used as parameters for controlling the effectiveness of weed control. In other words, the vegetative index is compared before and after weeding: a decrease in vegetative indices corresponds to better weed control, while an increase in vegetative indices indicates inefficiency.

The acquisition of spectral data and the calculation of a vegetative index is very simple and commits a very low amount of resources that allows the system to be used in real time.

IV. THE MULTISPECTRAL SENSOR

The use of multispectral sensors is widely studied in the field of precision agriculture [24] with the aim of improving production from a qualitative point of view. For example, it can be used to analyse fruit ripening [25-27] or the chlorophyll content in plants [28], or even for crop monitoring.

To check the effectiveness of weeding, it is possible to use the vegetation index. The evaluation of the vegetative index is based on the principle that when a plant is illuminated, it transmits part of the energy, reflects another part, and absorbs a certain amount.

This depends on various factors, including the spectrum with which the plant is illuminated, the angle of incidence but also the type of plant, the amount of chlorophyll present, the thickness of the leaves and other physical and chemical properties of the plant itself.

From this, we deduce the possibility of identifying the state of the plant by analysing its spectral response to lighting for specific wavelengths.

There are many methods using spectral response analysis, often also using hyperspectral or multispectral imaging techniques using special cameras. The limit of the camera is in the saving and processing times of the images, much longer than the acquisition of spectral data.

For example, the study of the reflectance of a plant in the red, green, blue and infrared ranges allows us to determine the amount of chlorophyll, allowing us to evaluate whether the plant is green, i.e., the vegetative stage, or is brown, i.e. in withering stage.

For our experimentation, we used the sensor SparkFun Triad [29]. Fig. 8 shows it used in our experimentation.

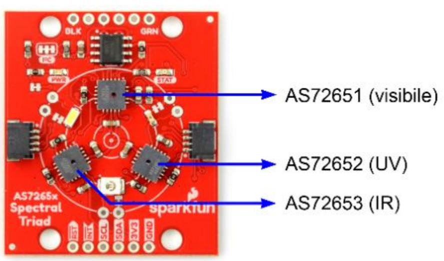

Fig. 8. Spectrum obtained with AS7265x sensor relative to the situation illustrated in figure 6a

This sensor is a multispectral sensor. It combines three sensors: AS72651, AS72652 and AS72653 [30-33]. In this way, it can detect light from 410 nm (UV) to 940 nm (IR). In addition, it is capable of measuring 18 individual light frequencies with an accuracy of up to 28.6 nW/cm^2 and an accuracy of ±12%.

- AMS OSRAM AS72651 has spectral response on 610 nm, 680 nm, 730 nm,760 nm, 810 nm, 860 nm.
- AMS OSRAM AS72652 has spectral response on 560 nm, 585 nm, 645 nm, 705 nm, 900 nm, 940 nm.

AMS OSRAM AS72653 has spectral response on 410 nm, 435 nm, 460 nm, 485 nm, 510 nm, 535 nm.

The high number of wavelengths permits to evaluate some vegetation index to identify the status of health of weed; we focused our attention on the Normalized Difference Vegetation Index (NDVI) that is the most widely used vegetation index in precision agriculture [30, 34].

The NDVI is defined as:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

It assesses the presence of photosynthetic activity by relating the red spectrum, where there is absorption by chlorophyll, and the near-infrared spectrum where leaves reflect light to avoid overheating. Index values are typically between -1 and +1. The presence of vegetation takes values greater than 0.2.

The sensor was placed about 30 cm from the weeds under artificial light conditions to overcome the problem of sunlight variability, and data were collected for 18 bands.

Figures 9 and 10 show the spectra obtained with the AS7265x sensor relating to the situations illustrated in figures 6(a) and 6(b).

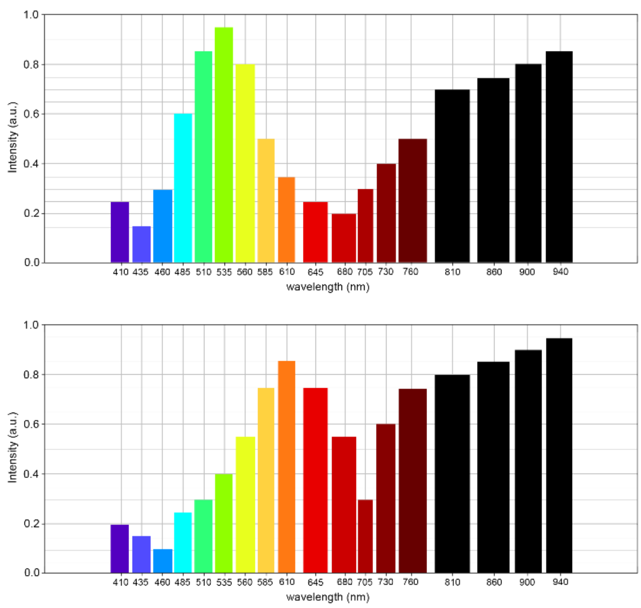

Fig. 9. Spectrum obtained with AS7265x sensor relative to the situation illustrated in figure 6b.

Figures 11 and 12 show the spectra obtained with the AS7265x sensor relating to the situations illustrated in figures 7(a) and 7(b).

There is no specific definition for NDVI, as the index parameters depend on the individual sensor and the bands available. In our case, we have 4 bands for infrared (760 nm, 810 nm, 860 nm, 900 nm) and 2 bands for red (645 nm, 680 nm), so we thought of calculating all possible vegetative indices (there are 8 vegetative indices in total) and sum them to get a generic indication of the health of the weed.

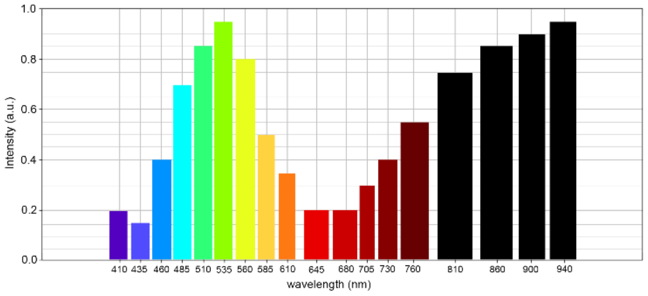

Fig. 10. Spectrum obtained with AS7265x sensor relative to the situation illustrated in figure 7(a).

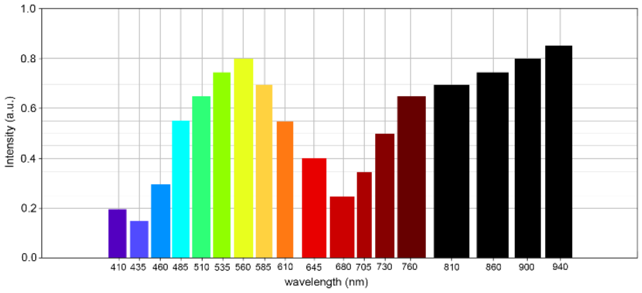

Fig. 11. Spectrum obtained with AS7265x sensor relative to the situation illustrated in figure 7b.

Already from the images one can see a decrease in values in the infrared bands, and an increase in the red band, indicating a deterioration in chlorophyll production processes, which is all the greater the drier the weed is (Fig.6b).

	Fig. 6a	Fig. 6b
Total NDVI	3.98	0.65

Table 1. the total NDVI for the figures 6a and 6b.

	Fig. 7a	Fig. 7b
Total NDVI	4.6	3.09

Table 2. the total NDVI for the figures 7a and 7b.

Table 1 shows the total NDVI for Fig. 6a and 6b, showing a high decrement in Total NDVI, while the Table 2 shows a less important decrease in value, as weeding failed due to rain.

The comparison of the various spectra, and the result from calculation of NDVI shows the potential of the spectra obtained with the sensor AS7265x to identify the correct weeding.

CONCLUSIONS

In this work, we are proposing a simple, cheap, and easy to use weeding system for early weed detection and eventually for a prompt intervention with minimal and controlled quantity of substances, preserving the health of the site.

A spectral sensor which provides for 18 spectral wavelength, 20 nm wide, visible and NIR channels from 410 to 940 nm have been used; one of the possible configurations provides four sensors to analyse both the ground and the walls of the site.

The sensor can be easily mounted on a rover or on a drone, and by an application the calculation and analyses of one or more vegetation indexes is possible, to evaluate the status of health of the weeds and the effectiveness of the treatments.

Obviously, the decision to use specific weeding products will be the result of a collegial analysis where experts of different fields can justify this choice, contemplating surely the architectural and historical aspects, but even the biological ones that have arisen over time.

REFERENCES

[1] J. Gamboa, "Why Preserve the Minor Sites? Identity, Heritage, and Urban Life Quality," in: Archaeological Heritage in a Modern Urban Landscape, SpringerBriefs in Archaeology. Springer, Cham. 2015, pp. 73–94, https://doi.org/10.1007/978-3-319-15470-1_4

[2] Z. Hosseini, G. Zangari, M. Carboni, G. Caneva, "Substrate Preferences of Ruderal Plants in Colonizing Stone Monuments of the Pasargadae World Heritage Site, Iran," Sustainability, vol. 13, no. 16, 2012, article number 9381. https://doi.org/10.3390/su13169381

[3] G. Caneva, M.P. Nugari, O. Salvadori, "Plant Biology for Cultural Heritage," in Biodeterioration and Conservation, Getty Publications, 22 Jan. 2009, ISBN-13: 978-0892369393

[4] L. Celesti-Grapow, C. Ricotta, "Plant invasion as an emerging challenge for the conservation of heritage sites: the spread of ornamental trees on ancient monuments in Rome, Italy," Biological Invasions, vol. 23, 2012, pp. 1191–1206. https://doi.org/10.1007/s10530-020-02429-9

[5] L. Celesti-Grapow, C. Blasi, "The Role of Alien and Native Weeds in the Deterioration of Archaeological Remains in Italy," Weed Technology, vol. 18, Invasive Weed Symposium, 2004, pp. 1508-1513. https://www.jstor.org/stable/3989683

[6] M. Lisci, M. Monte, E. Pacini, "Lichens and higher plants on stone: a review," International Biodeterioration & Biodegradation, vol. 51, no. 1, 2003, pp. 1-17. https://doi.org/10.1016/S0964-8305(02)00071-9.

[7] S. Ceschin, F. Bartoli, G. Salerno, V. Zuccarello, G. Caneva, "Natural habitats of typical plants growing on ruins of Roman archaeological sites (Rome, Italy)," Plant Biosystems, vol. 150, no. 5, 2016, pp. 866-875. https://doi.org/10.1080/11263504.2014.990536

[8] G. Caneva, S. Ceschin, G. De Marco, "Mapping the risk of damage from tree roots for the conservation of archaeological sites: the case of the Domus Aurea, Rome," Conservation and Management of Archaeological Site, vol. 7, no. 3, 2006, pp.163–170. https://doi.org/10.1179/135050306793137403

[9] F. Bartoli F, Romiti F, Caneva G (2017) "Aggressiveness of *Hedera helix* L. growing on monuments: evaluation in Roman archaeological sites and guidelines for a general methodological approach," Plant Biosystems, vol. 151, n. 5, 2017, pp. 866–877. https://doi.org/10.1080/11263504.2016.1218969

[10] F. Bartoli, A. Casanova Municchia, Y. Futagami, H. Kashiwadani, K.H. Moon, G. Caneva, Biological colonization patterns on the ruins of Angkor temples (Cambodia) in the biodeterioration vs bioprotection debate, International Biodeterioration & Biodegradation, vol. 96, 2014, pp.157-165. https://doi.org/10.1016/j.ibiod.2014.09.015.

[11] J. Li, M. Deng, L. Gao, S. Yen, Y. Katayama, J.D. Gu, "The active microbes and biochemical processes contributing to deterioration of Angkor sandstone monuments under the tropical climate in Cambodia – A review," Journal of Cultural Heritage, vol. 47, 2021, pp. 218-226. https://doi.org/10.1016/j.culher.2020.10.010.

[12] G. Caneva, A. Pacini, L. Celesti Grapow, S. Ceschin, "The Colosseum's use and state of abandonment as analysed through its flora," International Biodeterioration & Biodegradation, vol. 51, no. 3, 2003, pp. 211-219. https://doi.org/10.1016/S0964-8305(02)00173-7.

[13] P.L. Burch, S.M. Zedaker, „Removing the invasive tree ailanthus altissima and restoring natural cover," Journal of Arboriculture, vol. 29, no. 1, 2003, pp. 18-24. Available at: http://biblio-proxy.uniroma3.it/scholarly-journals/removing-invasive-tree-ailanthus-altissima/docview/220363399/se-2 (Accessed: May 2023).

[14] E. Cicinelli, F. Benelli, F. Bartoli, L. Traversetti, G. Caneva, "Trends of plant communities growing on the Etruscan tombs (Cerveteri, Italy) related to different management practices," Plant Biosystems, vol.154, no.2, 2020, pp. 158–164. https://doi.org/10.1080/11263504.2019.1578286

[15] M. Gaertner, J.R.U. Wilson, M.W. Cadotte, J.S. MacIvor, R.D. Zenni, D.M. Richardson, "Non-native species in urban environments: patterns, processes, impacts and challenges, Biological Invasions, vol. 19, 2017, pp. 3461–3469. https://doi.org/10.1007/s10530-017-1598-7

[16] L. Celesti-Grapow, P. Pyšek, V. Jarošík, C. Blasi, "Determinants of native and alien species richness in the urban flora of Rome," Diversity and Distributions, vol. 12, 2006, pp. 490–501. https://doi.org/10.1111/j.1366-9516.2006.00282.x

[17] Code of Cultural Heritage and Landscape entered into effect in Italy, Available at: http://www.normattiva.it/uri-res/N2Ls?urn:nir:stato:decreto.legislativo:2004-01-22;42 (Accessed: May 2023).

[18] L. De Bruycker, Y. Girault, "Constraints and stakes in enhancing archaeological landscapes in the digital age" in International Journal of Geoheritage and Parks, vol. 6, no. 1, 2018, pp. 75-94. https://doi.org/10.17149/ijg.j.issn.2210.3382.2018.01.006.

[19] E. Cicinelli, G. Salerno, G. Caneva, "An assessment methodology to combine the preservation of biodiversity and cultural heritage: the San Vincenzo al Volturno historical site (Molise, Italy)," Biodiversity and Conservation, vol. 27, 2018, pp. 1073–1093. https://doi.org/10.1007/s10531-017-1480-z

[20] P. Daponte, L. De Vito, L. Glielmo, L. Iannelli, D. Liuzza, F. Picariello, G Silano, "A review on the use of drones for precision Agriculture," 1st Workshop on Metrology for Agriculture and Forestry (METROAGRIFOR), IOP Conf. Series: Earth and Environmental Science, vol. 275, 2019, article number 012022. https://doi.org/10.1088/1755-1315/275/1/012022

[21] A. Mukherjee, S. Misra, N.S. Raghuwanshi, "A survey of unmanned aerial sensing solutions in precision agriculture," Journal of Network and Computer Applications, vol. 148, 2019, article number 102461. https://doi.org/10.1016/j.jnca.2019.102461.

[22] A. Botta, P. Cavallone, L. Baglieri, C. Colucci, L.; Tagliavini, G. Quaglia, "A Review of Robots, Perception, and Tasks in Precision Agriculture," Appl. Mech., vol. 3, 2022, pp. 830-854. https://doi.org/10.3390/applmech3030049

[23] J.P.L. Ribeiro, P.D. Gaspar, V.N.G.J. Soares, J.M.L.P. Caldeira, "Computational Simulation of an Agricultural Robotic Rover for Weed Control and Fallen Fruit Collection — Algorithms for Image Detection and Recognition and Systems Control, Regulation, and Command". Electronics, vol. 11, 2022, article number 790. https://doi.org/10.3390/electronics11050790

[24] J. Krause, H. Grüger, L. Gebauer, X. Zheng, J. Knobbe, T. Pügner, A. Kicherer, R. Gruna, T. Längle, J. Beyerer, "SmartSpectrometer — Embedded Optical Spectroscopy for Applications in Agriculture and Industry," Sensors,vol, 21, 2021, article number 4476. https://doi.org/10.3390/s21134476.

[25] M. Zhang, M. Shen, Y. Pu, H. Li, B. Zhang, Z. Zhang, X. Ren, J. Zhao, "Rapid Identification of Apple Maturity Based on Multispectral Sensor Combined with Spectral Shape Features," Horticulturae, vol. 8, 2022, article number 361. https://doi.org/10.3390/horticulturae8050361

[26] M. Noguera, B. Millan, J.M. Andújar, "New, Low-Cost, Hand-Held Multispectral Device for In-Field Fruit-Ripening Assessment," Agriculture, vol. 13, 2023, article number 4. https://doi.org/10.3390/agriculture13010004

[27] W. Hu, D.W. Sun, J. Blasco, "Rapid monitoring 1-MCP-induced modulation of sugars accumulation in ripening 'Hay-ward'kiwifruit by Vis/NIR hyperspectral imaging," Postharvest Biology and Technology, vol. 125, 2017, pp. 168-180. https://doi.org/10.1016/j.postharvbio.2016.11.001.

[28] N.M. Trang, T.K. Duy, T.T.N. Huyen, L.V.Q. Danh, A. Dinh, "An investigation into the use of a low-Cost NIR integrated circuit spectrometer to measure chlorophyll content index. International Journal of Innovative Technology and Exploring Engineering, vol. 8, no. 7C2, 2019, pp. 35–38. Available at: https://www.ijitee.org/wp-content/uploads/papers/v8i7c2/G10090587C219.pdf (Accessed: May 2023).

[29] SparkFun Triad Spectroscopy Sensor. Available at: https://www.sparkfun.com/products/15050 (Accessed: May 2023).

[30] OSRAM, "ams AS7265x Smart Spectral Sensor", Available at: https://ams-osram.com/products/sensors/ambient-light-color-spectral-sensors/ams-as7265x-smart-spectral-sensor (Accessed: May 2023).

[31] S. Moinard, G. Brunel, A. Ducanchez, T. Crestey, J. Rousseau, B. Tisseyre, "Testing the potential of a new low-cost multispectral sensor for decision support in agriculture, Precision agriculture '21, 2021, pp. 411 – 418. https://doi.org/10.3920/978-90-8686-916-9_49.

[32] Schirripa Spagnolo, G., Leccese, F. Led rail signals: Full hardware realization of apparatus with independent intensity by temperature changes (2021) Electronics (Switzerland), 10 (11), art. no. 1291, . DOI: 10.3390/electronics10111291. WOS:000659664100001, eid=2-s2.0-85106632171.

[33] Leccese, F., Schirripa Spagnolo, G. LED-to-LED wireless communication between divers. (2021) Acta IMEKO, 10(4), 80-89. doi:10.21014/acta_imeko.v10i4.1177. eid=2-s2.0-85122826679.

[34] L. Duncan, B. Miller, C. Shaw, R. Graebner, M.L. Moretti, C. Walter, J. Selker, C. Udell, W. Warden, "A low-cost weed detection device implemented with spectral triad sensor for agricultural applications, HardwareX, vol. 11, 2022, articol number e00303. https://doi.org/10.1016/j.ohx.2022.e00303.