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From Space to Tree: multisensor and multiscale remote sensing based approach for monitoring monumental trees. The case of archaeological park of Colosseum in Rome. Preliminary results

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***Abstract* – The paper deals with a multi-scale, multi-sensor remote sensing approach ("from space to tree") based on the integration of Big satellite data analysis and proximal imaging sensing technologies ((thermal infrared camera, georadar, LiDAR) with the aim to support the management of historical and archaeological parks with a focus on: (i) analysing the health and changes in the tree, some of them affected by *Toumeyella parvicornis;* (ii) assessing the biomechanical stability of monumental trees; (iii) identifying critical issues at the vegetation-monument interface areas. The Colosseum Park in Rome is one of the 'scenarios-laboratories' selected for technology experimentation. The obtained results are the following: (i) the integration between the diverse sensors, in a multi-scalar perspective, combined with the knowledge of the end user's needs and application goals, leads to an improvement in the operability of the technologies; ii) in the case of the Colosseum, the minimum monitoring unit, using Sentinel 2, is the single tree; (iii) removing seasonality helps to better discriminate between healthy and diseased trees; (iv) the best period to identify the effects of *Toumeyella parvicornis* is Spring, especially May-June.**

I. INTRODUCTION

The monitoring of public parks and green areas, in particular those located inside and close areas of relevant historical and cultural interest, is a central issue [1] that cuts across several spheres of urban and supra-urban management and planning.

Assessing the health of vegetation not only concerns the conservation of cultural heritage, but also involves (i) specifically the preservation of the integrity of structures and the green heritage of the city and, (ii) as a whole, it also involves the safeguarding the health of citizens and, therefore, the whole municipality (those also addressing several Sustainable developing Goals of the Agenda 2030, particular SDGs 11).

With this in mind, in the context of an ESA-funded project, a multi-scale, multi-sensor remote sensing approach ("from space to tree", also named S23) has been developed and validated, with the aim to support the management of historical and archaeological parks with a focus on: (i) analysing the health and changes in the tree and vegetation blanket; (ii) assessing the biomechanical stability of monumental trees; (iii) identifying critical issues at the vegetation-monument interface areas

S23 defines the methodological trajectory of a multiscale project, based on earth observation technologies and 5G, devised by a private company (Digimat spa) and two public research institutes (ISPC and IMAA) of the National Research Council of Italy.

S23 approach relies on the use of a huge amount of heterogeneous data, including Sentinel 2 data, Very High Resolution (VHR) satellite multispectral imagery, along with close range remote sensed data (acquired using multispectral imagery on unmanned platforms), geophysics and in-situ sensors.

The Colosseum Park in Rome is one of the 'scenarios-laboratories' selected for technology experimentation also with the participative involvement of citizens through Living Labs (figure 1).

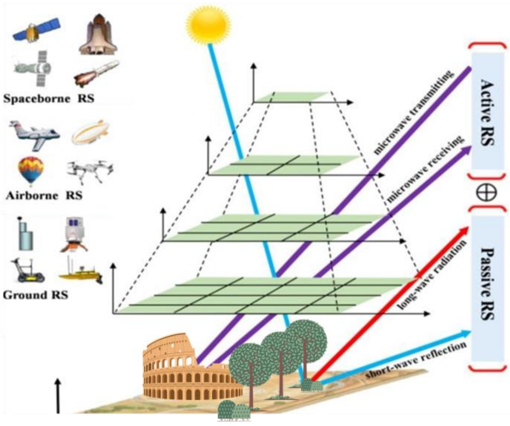

Fig. 1. The integrated multi-temporal and multi-scale approach devised in the S23 project (funded by ESA) for the monitoring of the natural heritage and monumental trees.

S23 system can be promptly applied to monitor the green areas/ heritage of the city today widely recognized as a hot issue to mitigate the effects of climate change; urban areas are widely recognized significant cause of climate change, and therefore, urban vegetation has a tremendous ecological importance and it is a fundamental factor to combat and mitigate climate change effects [2].

S23 does not have the ambition to replace the visual inspection and 'loving' care of agronomists and botanists but wants to provide them with support for prevention and management.

II. MATERIALS AND METHODS

The core of the S23 project consists in the development and set up an integrated multi-temporal and multi-scale approach for the monitoring of the natural heritage and monumental trees that, according to the Italian the constitution, are fully part of the cultural heritage being essentially the historical memory of the nation, and must be preserved to protect the environment built over time by man (figure 2).

Fig. 2. Detail of the landscape of the Colosseum Archaeological Park with monumental pine trees, some of which were planted by Giacomo Boni towards the end of the 19th century.

To this aim, in the S23 project we focused (among others) the Colosseum Archaeological Park that is not only an archaeological site but also an important green area that includes the Roman Forum and the Palatine, and has several species of trees, mainly pines and olive trees. In particular, pine trees are undoubtedly part of the Roman in particular and Italian in general landscape as the ruins and cobbled streets, but, unfortunately they are today severely under threat because affected by *Toumeyella Parvicornis*, a parasite that has been adversely impacted the Pinus trees mainly in the Campania and Lazio region in the recent years. Undoubtedly It is a national emergence and for this reason the main tasks in this part of the project have been mainly the:

(i) Evaluation of the possibility of using Sentinel-2 data for inter- and intra-year analysis, at the scale of the individual pine tree;

(ii) Early Automatic identification of the occurrence of anomalies in the health of trees in the Colosseum Park.

To this aim, both healthy and un-healthy pinus trees (Figure 3) were selected and analyzed using data and images from both remote (as satellite), and proximal sensing (as unmanned survey, herein also indicated as drone, an in situ sensors) acquired and stored as georeferenced layers in the web-GIS.

An integrated analysis system based on artificial intelligence has been implemented to analyze the data and to provide alerts about:

(i) The health status of trees in order to detect vegetation stress or diseases, before they become evident from visual inspection;

(ii) The stability of the trees by studying their response to external stress.

It should be noted that even a healthy shaft, without structural defects, is potentially subject to fall, this happens when the mechanical stresses to which it is subjected exceed its own strength (or its parts) or the sealing capacity of the soil. The isolation of the plant following the felling of neighboring plants or a bad anchoring of the roots can constitute elements of instability and can result in falling by uprooting.

In particular, concerning the satellite based analyses the assessment of the health status of trees has been obtained using satellite Sentinel-2 NDVI time series as available in Google Earth Engine (GEE) [3], an open cloud facilities.

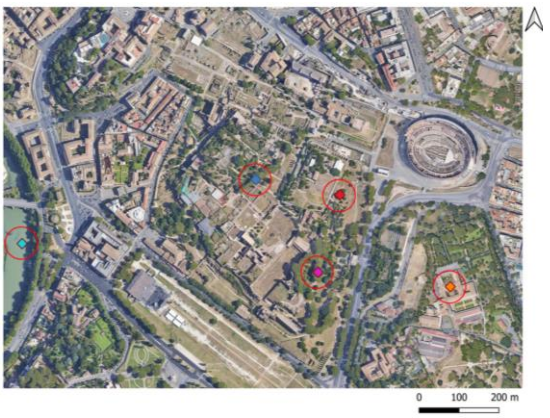

Fig. 2. The Colosseum Archaeological Park. The red circles indicate the single Pinus Tree monitored whose selection was agreed with the end user considering both those affected by Toumeyella parvicornis and those unaffected

Sentinel-2 NDVI time series is considered for the analysis. NDVI in the most widely used index for vegetation health status analysis, it is described in (1):

$$\frac{Nir - Red}{Nir + Red} \tag{1}$$

NDVI is used to identify the health of vegetation by measuring the difference in infrared reflectance with that of the visible red band. NDVI provides information on the spatial and temporal distribution of vegetation communities and biomass. High values of the vegetation index identify pixels covered by substantial proportions of healthy vegetation. Therefore, variations in NDVI values and in general in vegetation indices are indicative of variations in vegetation ongoing trend and dynamics.

Vegetation dynamical processes are difficult to study since they affect the complex soil–surface–atmosphere system, due to the existence of feedback mechanisms involving human activity, ecological patterns, and different subsystems of climate. The use of satellite time series along with statistical analysis techniques can be helpful in understanding the functional characteristics of vegetation dynamics and enable the reporting of ongoing trends at a detailed level [4].

At the end of this operation, the indices were added to each single image taken into consideration within the filtered Sentinel-2 collection.

Once this operation was completed, the system proceeded to segment the entire collection on a temporal basis, according to a time window set by the user, which can be varied to return analyses that take into account the maxima (or averages) of a relative span of time. By varying this time window it was possible to analyse the collection month-by-month, year-by-year, or season-by-season.

Once this division has been established, the system applies a reduction (i.e. creates an average, or selects maxima) to the data, so that it can be managed. The result of the entire process is a new data collection, extremely reduced compared to the initial one, which contains an image-per-time window (i.e. an image for each of the units set by the user in the time Window).

All the data acquired in the field and from RS, were then entered into a Web-GIS platform, useful to the user, in this case the Colosseum Archaeological Park, to assess in real time the health status of the vegetation being studied.

III. RESULTS

Figure 4 shows the satellite NDVI temporal behavior for the Pinus tree under investigations.

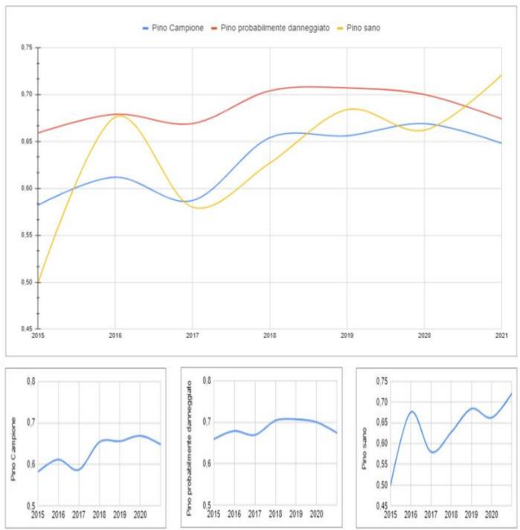

Fig. 4. NDVI temporal behavior based on Sentinel-2 Satellite data for the Pinus tree under investigation.

In particular, the red and yellow curves refer to pinus affected by *Toumeyella parvicornis* and pinus unaffected. *Toumeyella parvicornis* is a parasite capable to cause devastating effects to pine trees up to death. The analysis of the satellite data enabled the spectral characterisation of healthy and unhealthy pine trees, and as a whole an important result of our investigation is the evidence that Sentinel 2 NDVI time series at 10 m data does enable us to clearly discriminate between Pinus affected by the parasite and those unaffected. This can be due to the fact that the best period to identify the effects of Toumeyella parvicornis is spring, especially May-June, when the NDVI of healthy and unhealthy pine trees shows the highest difference.

The satellite data investigations were complemented with close range analyses, including 3d photogrammetrical modelling [5] and infrared thermography (IRT), performed using drone and ground penetrating radar (GPR) prospection [6]. Some example are shown in Figure 5 and 6. The morphological characterization of the trunks and crowns on a photogrammetric basis, the thermal anomalies detected on the bark with IRT, reflectors recorded in the radargrams, added further information on the health status of those pines that exhibited NDVI values typical of unhealthy trees, confirming, moreover, the validity of the multiscale approach (from satellite to proximal sensing) in the study of characterizing the tree cover, at the scale of the single tree. The result is a platform that includes: (i) archival acquired data related to the trees analysed, (ii) data acquired by the expert agronomists of the Colosseum Park, (iii) real-time data acquired from control units placed on the trees under study (e.g. oscillation correlated with meteorological data acquired in real time from a weather station mounted for the project), (iv) data acquired by drone (e.g. 3D, IRT), (v) data acquired by satellite on a weekly or bi-weekly basis (e.g. Sentinel-2 data). The platform is a portal that the end-user (e.g. Colosseum Archaeological Park) can freely consult and displays (i) a Web-GIS containing the position of the monitored trees, (ii) tree-related data, and (iii) early-warning information in the case of anomalous parameters (figure 7).

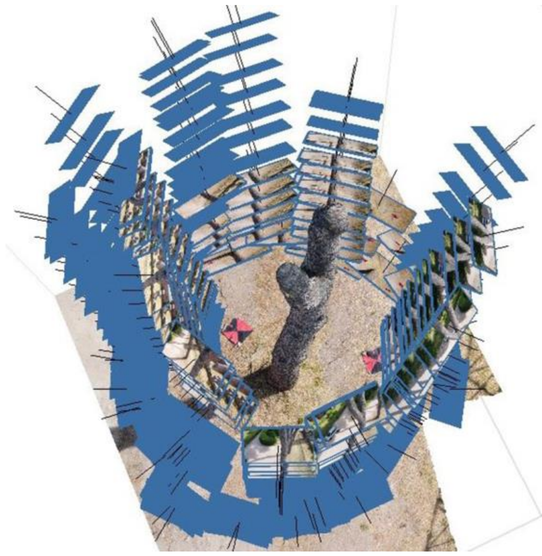

Fig. 5. Photogrammetric 3d modelling for the morphological characterization of tree trunks.

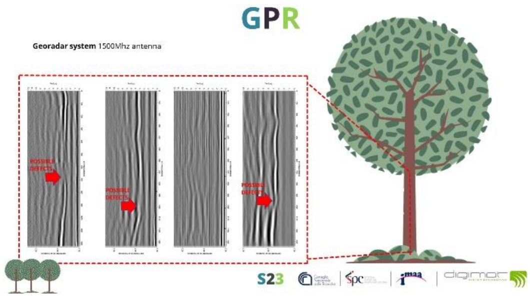

Fig. 6. GPR Radargrams highlighting some reflectors maybe due to potential pathologies of the trunk.

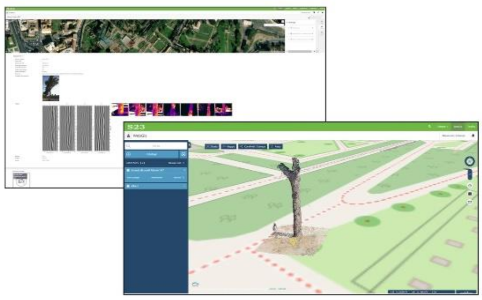

Fig. 7. Example of the created platform interface showing two screens containing GPR, IRT data and the georeferenced three-dimensional model of one of the monitored trees.

IV. CONCLUSIONS

The innovative approach, based on the integration of Big satellite data analysis and proximal imaging sensing technologies (thermal infrared camera, georadar, LiDAR and other georeferenced optical cameras, already successfully applied by CNR in other cultural heritage contexts) provided useful results on the health state of the trees, some of them affected by *Toumeyella parvicornis*.

The obtained results are effectively used by the management unit of the Park. As a whole, the lessons learned were the following: (i) the integration between the diverse sensors, in a multi-scalar perspective, combined with the knowledge of the end user's needs and application goals, leads to an improvement in the operability of the technologies; (ii) in the case of the Colosseum, the minimum monitoring unit, using Sentinel 2, is the single tree; (iii) removing seasonality helps to better discriminate between healthy and diseased trees; (iv) the best period to identify the effects of *Toumeyella parvicornis* is Spring, especially May-June.

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