SUPERVISION OF RAILWAY AREAS BY SATELLITE IMAGES

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ABSTRACT

This research aims at designing and implementing an innovative system for the monitoring of hydrogeological and anthropogenic hazards, identification and, therefore, prevention of these, with the aim of ensuring efficiency and safety for traffic on the railway network. The designed system uses SAR and optical images in order to achieve these goals. With the same input data, this system is able to monitor and detect also other possible hazards like vegetation encroachment and the edification of new buildings as well as the structural extension of old ones along the lines and the infrastructure. The system will allow to plan different types of analysis not only to obtain periodic results but also to carry out "on-demand" analyses. This on-demand feature allows the operator is able to provide higher resolution data and set specific parameters for artificial vision algorithms, in order to obtain more precise and accurate results. In addition, the system is designed to be integrated with other applications that use different data sources, in order to create future real monitoring and early warning system. The results obtained from the first experiments [1] with the techniques and the satellites constellations data mentioned above are promising and motivated us to continue towards the implementation of a final system. Given the strong scalability of the implemented platform, it can be shared with other European infrastructure managers to try to reach a common standard.

Keywords: Satellite Inspection; Artificial Vision; Infrastructure Monitoring, Early Warning Systems

BACKGROUND AND MOTIVATIONS

Landslides are responsible for huge human and economic losses worldwide, producing direct and indirect impacts on the population and the local communities. Italy is one of the European countries that is most severely and frequently hit by landslides, primarily triggered by heavy rainfalls, and favored by its peculiar geological, morphological, and tectonic setting. The Italian landslide inventory (IFFI, Inventario Fenomeni Franosi Italiani) includes more than 480,000 phenomena collected since 1999. The IFFI database covers almost 7% of the entire national territory. Known and most-of-all unknown or newly activated landslides have a considerable impact on regional and local entities, posing a frequent and not totally forecastable risk to the population. Brunetti et al. [2] reported that, in a 60-year time span between 1950 and 2009, more than 6000 people were killed by landslides with an average of 16 deadly events per year. Some events such as the 1963 Vajont outburst, the 1987 Val di Pola landslide, or the 1998 Sarno mudslides caused thousands of victims. All the Italian regions are hit by landslides with different temporal frequency. Guzzetti [3] collected thousands of events causing casualties and reported that Veneto (including almost 2000 victims for the Vajont outburst), Campania, and Lombardy are the regions that paid the highest human cost. Landslide typology and occurrence are strongly related to the geological and tectonic setting. Overall, rockfalls, rockslides, and rock avalanches in the Alpine arc and fast flows originated in volcanic ashes in the Campania region are the most hazardous and impactful phenomena. This brief overview of the economic and social impact of landslides in Italy shows the strong need for proper monitoring tools that could support landslide risk management procedures and long-term risk reduction practices.

Even vegetation can pose severe safety risks in a railway environment. For example, overgrown shrubs and trees can block clearance zones and trees or broken branches, by falling onto tracks, and therefore they represent a threat to operating traffic as they can cause severe damage to railway facilities. As the remediation of facilities and operational interruptions typically incurs high follow-up costs, vegetation control measures are extremely relevant to economic considerations. In order to maintain safe railway operation, lineside vegetation must be continuously monitored and maintained. Periodical maintenance works, like short rotation coppice [4] practices, are applied in order to control vegetation heights. Regular monitoring of vegetation development must be considered as an integral component of vegetation control measures. The required intensity of maintenance measures for woody vegetation is closely correlated with its position and distance to the track bed and the design of the railway track.

Another hazard that can cause serious safety risks in a railway environment is the unauthorized building along the railway line. Illegal construction accounted for a large slice of the Italian building sector for several decades during the second half of the 20th century. According to statistics, about a quarter of the buildings constructed in Italy between the 1960s and the 1980s were unauthorized [5], [6]. This phenomenon affected a variety of urban environments the length and breadth of the peninsula: it impacted rural and coastal settlements, small and medium-sized towns, and also affected the emerging metropolitan areas which were undergoing huge internal migration flows, Rome being the most notorious example [7].

Last but not least hazard for the railway environment is the illegal dumping, sometimes called fly-tipping, that refers to the intentional and illegal abandonment of waste in unauthorized public or private areas, usually to avoid tipping fees and save on transport time and cost, or simply for the sake of convenience [8]. Illegal dumping is not only a nuisance in its own right but can also lead to many other problems [9]. It is a human health concern and can damage the environment in a variety of ways. Fly-tipped waste causes habitat destruction, wildlife deaths, and is a major source of soil and underground water pollution. It also causes aesthetic damage to the natural landscape. When illegal waste dumping is discovered, local governments often dispatch an abatement crew to clean it up as quickly as possible because the contained oil, solvents, fuel, rusted metal, and batteries can cause severe environmental damage. Such clean-up comes at great expense.

The current monitoring system of the railway environment is based on direct inspection of operators, who periodically travel along the lines and the infrastructures. Inspections are performed by foot, with special transport vehicles or from train cabins, also checking the presence of vegetation that might cover signals or walkways. The monitoring of the railway infrastructure using the current approach, in some cases assisted by aerial images captured with drones, while presenting high spatial resolutions, does not allow an optimal coverage of the Italian Railway Network. The satellite missions of Earth Observation (EO) of the European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA), such as Sentinel-2 or Landsat-8, allow to acquire high resolution satellite images (10-30 mt) on very large areas and in every region of the earth with a period of 5/6 days. It is worth noticing that the use of space assets would significantly increment the frequency of relevant data, allowing a more efficient check of the status of the infrastructure. With a higher amount of frequent data is possible to perform data analysis with Artificial Intelligence based tools in order to enforce predictive maintenance along with alert in case of faults and natural diseases. In this context, in order to mitigate the hydrogeological risk on the railway infrastructure, RFI is interested in the observation of landslides, areas with displacement anomalies and areas with known instability. Floods also fall into this category of risk, and it is therefore necessary to be able to locate flooded areas as a consequence of an event on one hand and be able to identify areas that are potentially at risk of flooding on the other hand. As for the activities of monitoring and control of vegetation and buildings along the railway line, there are specific directives in some articles of DPR 753/80. In particular, for the control on vegetation (Figure 1), art. 52 states that trees expected to reach a maximum height of more than four meters shall not be planted at a distance from the nearest rail less than the maximum attainable height increased by two meters.

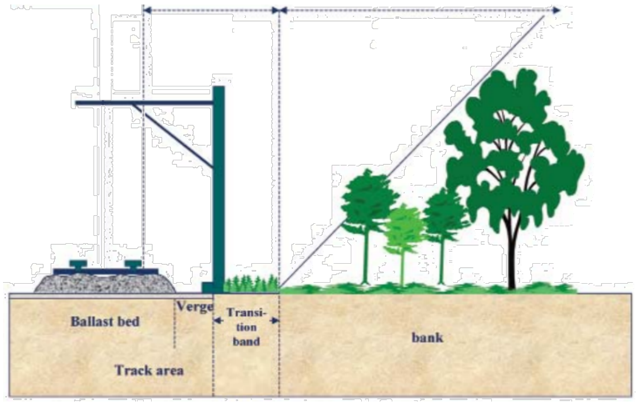

Figure 1 Control of Vegetation

As for the control of the buildings instead art. 49 states that buldings must not be located at a distance, to be measured in horizontal projection, less than thirty meters from the limit of the nearest rail.

OBJECTIVE

The objective of the Research Project is the development of an application capable of integrating images from satellite missions with the most advanced techniques of identification of objects based on AI (Artificial Intelligence) for an effective identification of possible danger situations and planning of maintenance interventions with a predictive approach. Recent advances in image processing and machine learning applied to satellite imagery enable rapid, effective and innovative services to identify and analyze the state of the railway infrastructure. To achieve these objectives it is necessary first of all to collect all the functional requirements of the system to be implemented, in order to identify all its functionalities. In particular, the system in question must therefore be a valid support for the monitoring and control activities described and in particular it must allow two types of analysis:

1. **"On Time" monitoring**: Using optical satellite data, automatic and periodic analyses are carried out in order to monitor all hydrogeological risk zones, vegetation and buildings in the vicinity of the railway route and surface movements for the detection of disruption. The functionality therefore provides data for the automatic and periodic acquisition of satellite from sources chosen by the operator. Several Image Processing techniques, such as Persistent Scattering Interferometry, Change Detection and Spectral Unmixing, are applied on these images. Results are represented as maps where each element contains information related to a specific region of the corresponding area. These results are eventually stored in the system in the form of shape files and made always available for consultation by the operator.
2. **Control "On Demand"**: every functionality specified for the “on time” monitoring is put at the disposal of the user that can, every time he needs it, run a desired type of analysis on satellite images. The user can select either satellite data already present on the platform or loaded externally. These "on demand" analyses are also stored on the system and always made available for future consultations in the form of shape files.

After the collection of functional requirements and the choice of artificial intelligence techniques to be implemented, a design phase of the system architecture must be planned. Succesively to this phase, a first prototype will be built and a testing and validation phase on the filed will be planned.

METHODS

Through the involvement of a highly specialized research institutions in the space sector we worked together to define the system requirements and to identify a series of algorithms for image processing useful to achieve all the goals. Thanks to the development, in recent years, of space missions dedicated to Earth observation and derived image analysis techniques facilitate the monitoring and control of extended linear infrastructures.

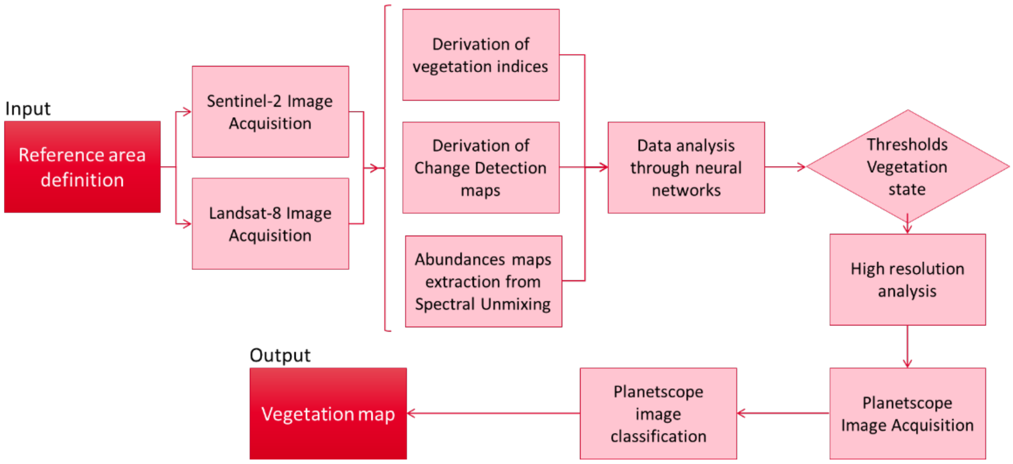

Figure 2 Algorithmic Approach for Vegetation Monitoring

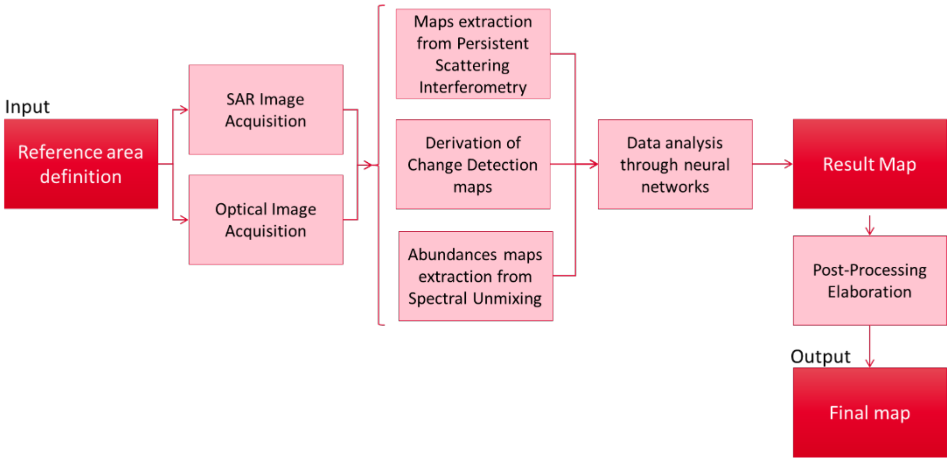

Figure 3 Algorithmic Approach for monitoring of hydrogeological and anthropogenic hazards

In particular, the space missions of our interest are:

- The **Sentinel-1** mission comprises a constellation of two polar-orbiting satellites, operating day and night performing C-band synthetic aperture radar (SAR) imaging, enabling them to acquire imagery regardless of the weather. Sentinel-1 is the first of the five missions that ESA is developing for the Copernicus initiative.
- The Copernicus **Sentinel-2** mission comprises a constellation of two polar-orbiting satellites placed in the same sun-synchronous orbit, phased at 180° to each other. It aims at monitoring variability in land surface conditions, and its wide swath width (290 km) and high revisit time (10 days at the equator with one satellite, and 5 days with 2 satellites under cloud-free conditions which results in 2-3 days at mid-latitudes) will support monitoring of Earth’s surface changes.
- **Landsat-8** is an American Earth Observation satellite. Providing moderate-resolution imagery, from 15 metres to 100 metres, of Earth's land surface and polar regions, Landsat 8 operates in the visible, near-infrared, short wave infrared, and thermal infrared spectrums.

- **COSMO-SkyMed** is the first Earth observation mission designed for dual purposes, both civil and military. It is developed by the Italian Space Agency in cooperation with the Ministry of Defense and is based on a constellation of satellites, equipped with synthetic aperture radars (SARs) which operate in the X-band (and are, therefore, capable of seeing through the clouds and in the absence of sunlight).
- Planet's **PlanetScope** satellite constellation is designed to observe Earth. By using several small satellites, CubeSats, the constellation produces three to five meters high resolution images of Earth. The flock collects images from latitudes that are within 52 degrees of Earth's equator. A large portion of the world's agricultural regions and population lie within the area imaged by the flock. Planet's Dove satellites are CubeSats that weighs 4 kilograms (8.8 lb) (1000 times lower than legacy commercial imaging satellites), 10 by 10 by 30 centimetres (3.9 in × 3.9 in × 11.8 in) in length, width and height, orbit at a height of about 400 kilometres (250 mi) and provide imagery with a resolution of 3–5 metres (9.8–16.4 ft) and envisaged environmental, humanitarian, and business applications.

The data obtained from the techniques mentioned above are successively analyzed through artificial intelligence algorithms in order to obtain a real early warning system (EWS). Early warning systems (EWSs) are designed to effectively and efficiently disseminate appropriate information related to disaster events, in the form of alarms or warnings, to vulnerable communities before or during a disaster so that proactive and preventive measures can be taken to minimize the loss and damage associated with such events. The use of artificial intelligence (AI) can enable EWS to mine early warning signals from this data, so that proactive and preventive measures for disaster mitigation, preparedness, response and recovery can be planned leading to timely alerts and warnings being disseminated to the relevant stakeholders [10]. The techniques used for processing these images are:

- **Persistent Scatterer Interferometry** (PSI) is a powerful remote sensing technique able to measure and monitor displacements of the Earth's surface over time. Specifically, PSI is a radar-based technique that belongs to the group of differential interferometric Synthetic Aperture Radar (SAR) [11].
- **Change Detection** can be defined as the process of identifying differences in the state of an object or phenomenon by observing it at different times. This process is usually applied to earth surface changes at two or more times. The primary source of data is geographic and is usually in digital format (e. g., satellite imagery), analog format (e. g., aerial photos), or vector format (e. g., feature maps).
- **Spectral unmixing** is the process of decomposing the spectral signature of a mixed pixel into a set of endmembers and their corresponding abundances. Endmembers are spectra of the pure materials present in the image and abundances at each pixel represent the percentage of each endmember that is present in the pixel. [12]

Eventually, using the system, an user can perform some post-processing elaboration on this map to obtain a more concise result.

Figure 2 shows the approach followed to chart vegetation growth on a referenced area. Data acquired from different constellation of satellites is processed using the techniques described above. The artifacts obtained at this stage are vegetation indices, change detection maps and abundances maps. Vegetation indices is a single value used to distinguish vegetation from other elements present in the acquired data; change detection maps highlight variation over time; abundance map is used to estimate density of vegetation. These parameters are processed by an artificial neural network. Results from the neural network are post-processed until we obtain a vegetation map. In addition, if the user wants to perform more precise analyses, it is possible to use the images obtained from PlanetScope.

In a similar way, Figure 3 depicts the approach used to analyze hydrogeological and anthropogenic hazards. The images acquired by SAR and Optical sensors are processed in order to extract features that are successively analyzed with neural networks in order to identify some anomalies. These anomalies are notified to the user and shown in an intermediate map. The user can perform some post-processing elaboration on this map to obtain a more concise result. For example, it is possible highlight areas of interest, change color maps or customize a legend symbol.

THE SYSTEM ARCHITECTURE

The system, in addition to having to meet all the functional requirements, must be designed considering also the following:

- Minimum hardware requirements to run the algorithms;
- Define the deployment (use of cloud tools, use of physical machines, etc.);
- System compliance with company security policies

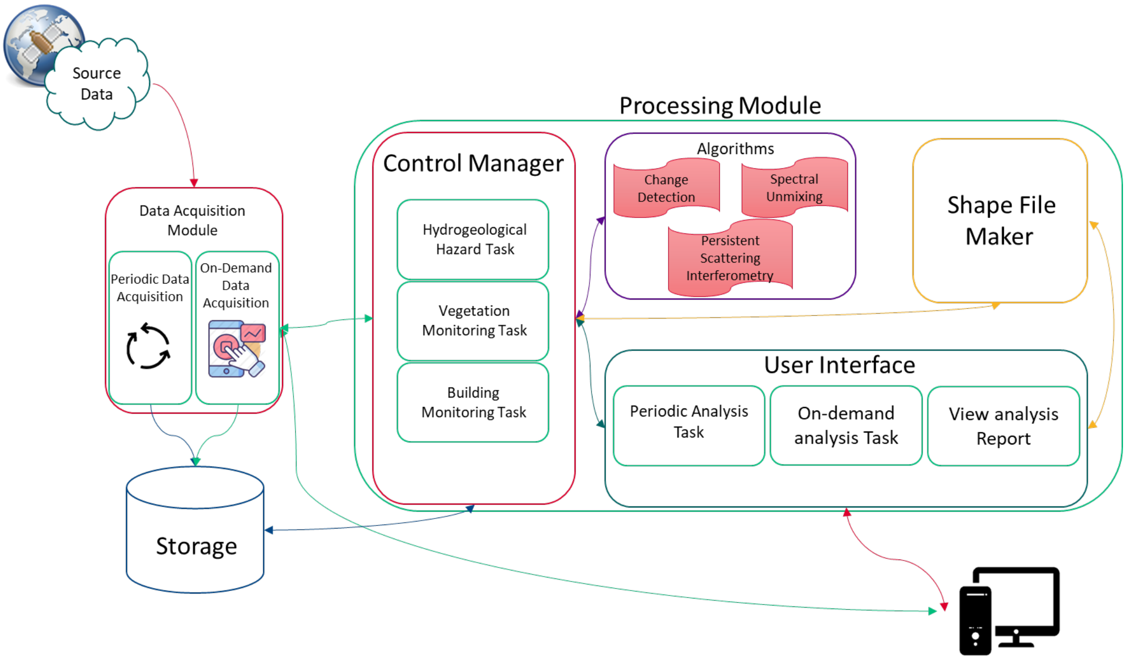

Figure 4 *System Architecture*

Figure 4 shows a functional block diagram of the resulting System Architecture. The functional blocks are:

- **Data Acquisition Module**: Provides access to databases containing satellite images of the various constellations (eg Sentinel-1, Sentinel-2, Landsat-8, CosmoSkyMed and PlanetScope) and acquires the images useful for carrying out the required analyzes. This module must have two methods of access
    - Periodic: To acquire the images useful for the "On Time" Monitoring function;
    - On Demand: To acquire the images useful for the "On Demand" Control function in case the user wants to select a specific image, not already included in the periodic acquisitions.

  Once the images have been acquired, the module saves them in a local storage owned by RFI. The user can also upload satellite images in his possession to the storage (eg through USB mass memories).
- **Algorithms**: This is the module containing the implementation of artificial vision algorithms (eg Persistent Scattering Inteferometry, Change Detection and Spectral Unmixing) suitable for meeting the functional requirements of the system in question. More details about the algorithms are provided in the previuos section.
- **Control Manager**: Represents the software layer that coordinates the different modules of the system with each other to complete the required functionality. In particular, its functions are:
    - Take, from the local storage, the images necessary for the requested analysis;
    - Invoke the algorithms involved in the functionality;
    - It receives the output of these algorithms and forward them to the shape file preparation module;
    - Store the generated shape file in storage
    - Take the shape file and forward it to the User Interface module when the user intends to consult it
- **User Interface**: It is the graphic interface where the user can take advantage of the features made available by the system. Through this module, the user can then program the periodic analyzes that the system will have to carry out, for example by selecting the data source from which to take the images, set some parameters of the algorithms and more. It will also be able to carry out on-demand analyzes on data in its possession and consult the shape files obtained.

CONCLUSION

The results obtained from the first experiments with the techniques and the satellites constellations data mentioned above, are promising and have motivated us to continue towards the implementation of a final system. Actually Specification of the system architecture has been already realized and the first prototype is expected to be completed by 2023.

From an industrial standpoint, the installation of the system is clearly beneficial for RFI. In fact, the system shall have main impact on the monitoring and maintenance activities since it aims to reduce the time to obtain the results and costs of the different analyses since it is no longer necessary to use services provided by third parties.

Research-wise, the system is the absolute first effort in Italy to update existing railways monitoring systems by providing a flexible and scalable product that use image processing algorithm on SAR and optical images in order to obtain results.

Given the strong scalability of the implemented platform, it can be shared with other European infrastructure managers to try to reach a common standard. Additionally, the modular structure of the system is flexible enough to host a wide variety of applications and therefore provides a fully customizable interface which may suite different user requirements.

BIBLIOGRAPHY

[1] E. RAZZANO, R. ESPOSITO, F. RANAURO, V. STANZIONE, M. D'ERRICO, F. IACOBINI, S. ROSINI, G. MARIOTTI, G. FICCO and D. FILIPPETTO, "Feasibility of a space-based system for Railway Infrastructure Monitoring," in *WCRR*, Tokyo, 2019.

[2] M. Brunetti, S. Perrarucci, M. Rossi, S. Luciani, D. Valigi y F. Guzzetti, «Rainfall thresholds for the possible occurrence of landslides in Italy,» *Nat. Hazards Earth Syst. Sci.,* vol. 10, pp. 447-458, 2010.

[3] F. GUZZETTI, «Landslide fatalities and the evaluation of landslide risk in Italy,» de *Engineering Geology*, 2000, pp. 89-107.

[4] Elsevier, «Coppice - an overview,» *Comprehensive Renewable Energy,* 2012.

[5] F. Zanfi, «The Città Abusiva in Contemporary Southern Italy: Illegal Building and Prospects for Change,» *Urban Studies,* vol. 50, nº 16, pp. 3428-3445, 2013.

[6] W. Santagata, Libro bianco sulla creatività: per un modello italiano di sviluppo, EGEA, 2011.

[7] A. Clementi y F. Perego, La Metropoli" spontanea": il caso di Roma, 1925-1981: sviluppo residenziale di una città dentro e fuori dal piano., Edizioni Dedalo, 1983.

[8] L. Weisheng, «Big data analytics to identify illegal construction waste dumping: A Hong Kong study,» *Resources, Conservation and Recycling,* vol. 141, pp. 264-272, 2019.

[9] M. R. Esa, A. Halog y L. Rigamonti, «Strategies for minimizing construction and demolition wastes in Malaysia,» *Resources, Conservation and Recycling,* vol. 120, pp. 219-229, 2017.

[10] R. Lamsal and K. T.V. Vijay, "Artificial Intelligence and Early Warning Systems," in *AI and Robotics in Disaster Studies*, Palgrave Macmillan, 2020, pp. 13-32.

[11] M. Corsetto, O. Monserrat, M. Cuevas-Gonzalez, N. Devanthery and B. Crippa, "Persistent Scatterer Interferometry: A review,," *ISPRS Journal of Photogrammetry and Remote Sensing,,* pp. 78-89, 2016.

[12] L. W. Chen Shi, "Incorporating spatial information in spectral unmixing: A review,," *Remote Sensing of Environment,* vol. 149, pp. 70-87, 2014.