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# PILOT MONITORING SERVICE FOR CULTURAL HERITAGE BASED ON SATELLITE DATA AND PRODUCTS

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***Abstract***

*The potential of Earth Observation (EO) data for cultural heritage documentation and systematic monitoring is currently widely recognized. Considering the large spectrum of threats and the high importance of safeguarding, cultural heritage requires sustained monitoring that can efficiently be done based on a combination of satellite images having adequate spatial, spectral and temporal resolution, in-situ data and a broad-spectrum of ancillary data such as historical maps, digital elevation models and local knowledge. The present study showcases the features of a pilot cultural heritage monitoring service that was developed for several Romanian representative sites such as the Castle of Hunedoara, the Palace of Magna Curia, the Medieval Ensemble of Deva Fortress, the Alba Carolina Citadel, the archaeological sites of Micia and Germisara, etc., but can be upscaled at national or regional level. The monitoring service is composed of a Results Platform (based on open-source GeoServer and OpenLayers) and a near-real time Monitoring Platform (cloud computing through Google Earth Engine). The products that are ingested in the first platform are obtained using an approach tailored for each property type. Examples include old cartographic maps, historical satellite images, remote sensing radiometric indices, Copernicus products, displacement maps and many others. The products that are continuously generated within the second platform enable the early identification and assessment of natural and anthropogenic risks, thus representing a key element for cultural heritage protection. The pilot monitoring service was developed considering the requirements of the cultural heritage authorities that are administrating the above-mentioned sites, representing a reliable source of unparalleled knowledge regarding the potential threats and degradation risks.*

***Key words**: Earth Observation, cultural heritage, pilot monitoring service, GeoServer, Google Earth Engine.*

## INTRODUCTION

The importance of Earth Observation (EO) data for the different stages of the Cultural Heritage (CH) management process (e.g., inventory and documentation, condition assessment and monitoring, protection and promotion, etc.) is worldwide recognized.
Numerous studies demonstrated the benefits of using EO data for CH. It is a modern and non-destructive approach that enables efficient monitoring and mapping at multiple scales by using different spatial and spectral resolutions. The variety of the existing satellite sensors offers the possibility to combine different techniques in order to generate products tailored to the specific needs of each CH property. In addition, the free and open satellite data contribute to an accurate and rapid condition assessment and monitoring of CH. The capabilities of EO-based products for CH were demonstrated by various studies that included identification of architectural buried remains (Agapiou et al., 2012), the analysis and mapping of land use changes in cultural and archaeological landscapes (Tang et al., 2022), and the evaluation of the impact of climate change by measuring the air pollution, which constantly threatens the CH (Themistocleous et al., 2010). Furthermore, the current approaches allow a manifold CH monitoring by integrating radar and optical satellite data as well as additional data and technologies such as light detection and ranging (LiDAR) and data acquired by unmanned aerial vehicles (UAVs) and ground sensors that record essential

parameters. Nowadays, the information offered by the EO programs is increasingly used in various projects dedicated to the management of CH. A relevant example is the HERIPORT project, a digital heritage portal dedicated to preserving South African heritage, by using a collection of metadata from diverse heritage archives (https://heriport.cs.uct.ac.za). Another example is ARCH – Saving cultural heritage (https://savingculturalheritage.eu/). ARCH is an ongoing project dedicated to CH disaster risk management, by using an integrated approach that includes satellite, aerial and ground data. Other significant CH projects focused on the use of EO are: "SpaceToPlace - EO to Empower UNESCO Site Managers" (https://copernicus-masters.com/winner/spacetoplace-eo-empower-unesco-site-managers/) whose main objective is to train the United Nations Educational, Scientific and Cultural Organization (UNESCO) site managers to incorporate Copernicus Sentinel data for monitoring activities and HERACLES (http://www.heracles-project.eu/), a research project dedicated to resilience of CH against climate change effects.

The RO-CHER project is a multidisciplinary project for the monitoring, conservation, protection and promotion of Romanian cultural heritage (http://ro-cher.rosa.ro/). The project was composed of 4 complementary component projects, namely: Monitoring of cultural heritage based on space technologies, Nanotechnology - an innovative approach of developing materials and methods for cultural heritage safeguarding, Integrated cultural heritage management (conservation, restoration and protection) and Cultural heritage promotion based on modern digital reconstruction technologies. Several CH test sites were selected for the project, including: Sarmizegetusa Regia, Ulpia Traiana Augusta Dacica Sarmizegetusa, the Medieval Fortress of Deva, the Magna Curia Palace, the Corvin Castle, the Roman Fort of Cigmau, the Micia Roman Fort and the Alba Carolina Citadel. All of the above-mentioned sites are representative both at national and international level (for example, Sarmizegetusa Regia is part of the UNESCO World Heritage). The selected test sites are located in Transylvania, a historically significant region containing a large variety of CH properties. The project's main goal was represented by integrated research dedicated to the study of the mobile and immobile cultural and historical heritage using new space technologies and classical in situ and ex situ analysis methods. One of RO-CHER's specific objectives focused on the development of a pilot CH monitoring service based on satellite data and products.

## MATERIALS AND METHODS

The Monitoring Service is based on open-source geospatial technologies and has two main components. With the goal of creating a sustainable flow of information to be provided by the service also after the completion of the RO-CHER project, the emphasis was put on the use of open access satellite data. Specifically, the project benefited by the free and open satellite data provided within the Copernicus Programme which is managed by the European Commission (https://www.copernicus.eu/).

Within the RO-CHER project, products derived from the data acquired by the Sentinel-1A/B satellites operating in the microwave portion of the electromagnetic spectrum were derived and integrated in the monitoring service. These satellites have a revisit period of 6 days at the equator. Using long series of synthetic aperture radar (SAR) images and specific acquisition and processing techniques (i.e., Persistent Scatterers Interferometry), the displacement along the line-of-sight (LOS) can be accurately derived.

Besides SAR data, satellite data in the visible, near-infrared, and short-wave infrared spectrum acquired by Sentinel-2A/B satellites was used. These satellites allow the monitoring of the areas of interest at a frequency of 5 days at the equator and 2-3 days at the latitude of Romania.

To the previously mentioned archive of multispectral satellite data, images acquired by the satellites of the Landsat Programme that has been operating since 1972, were added. Although having a lower spatial resolution of only 30 m compared to 10 m in the case of Sentinel-2 imagery, Landsat data offer unique and valuable information for the last 5 decades.

The Monitoring Service incorporates a Results Platform and a Monitoring Platform. The first platform is implemented on local infrastructure within the Romanian Space Agency (ROSA) and the second one is based on a cloud computing service. The first step towards the implementation of the Monitoring Service was to download and process satellite data. Sentinel-1 and Sentinel-2 data was downloaded from the Copernicus data distribution service by accessing the Open Access Hub available at the web address: https://scihub.copernicus.eu. Landsat images were downloaded from the Earth Explorer service provided by the United States Geological Survey (USGS) accessible at: https://earthexplorer.usgs.gov/.

The interferometric processing of Sentinel-1 data was performed using the ENVI software with the dedicated SARscape extension. The resulting data consisted of a vector dataset representing persistent scatterers which have as attributes the value of the vertical displacements (in mm/year) of the target points. The vertical displacements were computed in a subsequent phase based on the LOS displacements.

Landsat and Sentinel-2 multispectral imagery was processed using the SNAP (Sentinel Application Platform) open-source geospatial software. The processing resulted in a series of satellite products such as vegetation indices and false colour images for the test areas studied within the RO-CHER project. Some of these satellite products were used to extract thematic vector layers that show the progress of various aspects such as the urban evolution of the Alba Iulia city or the evolution of the Mureș riverbed.

The goal was to create an application that is easily accessible by the general public. For this purpose, a WebGIS application that offers the possibility to be accessed with any web browser was developed.

The Results Platform was created based on FOSS (Free and Open-Source Software) technologies that allow the easy management of geospatial data and their delivery to third parties, via the Internet. The development of such an application required a series of steps as illustrated in Figure 1. GeoServer is developed under open-source licence, enabling the users to share large geospatial datasets via standard protocols such as Web Map Service (WMS), Web Feature Service (WFS) and others, developed by the Open Geospatial Consortium (OGC). This software was used for the sharing of raster geospatial products developed within the RO-CHER project.

Displaying the data as a map required the use of the OpenLayers library, which allows the creation of interactive web maps. The web map was connected to the data stored in the GeoServer via WMS protocol.

Other vector layers were directly introduced in the web map by saving them as GeoJSON and directly linking them to the source code. An intermediate step was to connect the web application to the available WMS service at http://www.geo-spatial.org/geoserver/. Through this service, a collection of historical maps could be accessed and introduced as base maps in the Results Platform.

The advantage of the open-source technologies mentioned above offers administrators the opportunity to interact with the source code, allowing a wide customization of the final product.

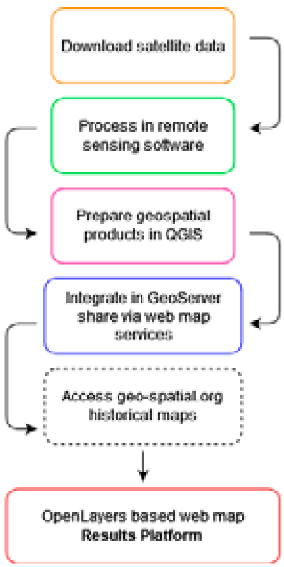


Figure 1. Implementation layout of The Results Platform

The second component of the Pilot Monitoring Service is designed for the continuous monitoring of the cultural heritage objectives through the use of satellite imagery. The Monitoring Platform allows users to access all images acquired by Sentinel-2 satellites over the areas of interest, starting from the beginning of the mission (i.e., 2015) until the current date. Users can observe the Earth's surface through both natural and false colour images, but also through spectral indices. The implementation of such a platform required a series of steps as shown in Figure 2. In order to provide this service, the technical solution relied on the Google Earth Engine cloud computing platform. This platform provides users with both a global archive of satellite and geospatial data, as well as the necessary geoprocessing tools. Accessing algorithms and data is done through JavaScript. The configuration of an application that addresses the specific needs of CH monitoring was performed through the Code Editor interface.

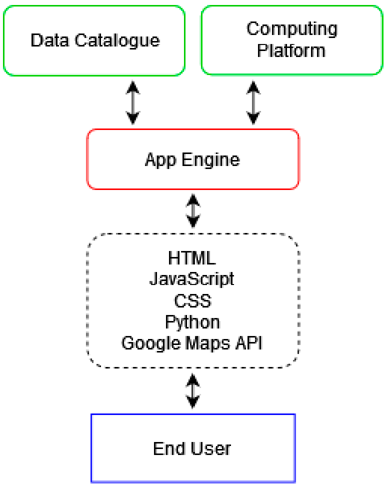


Figure 2. Functioning layout of The Monitoring Platform

## RESULTS AND DISCUSSIONS

Each CH site included in the project presents different challenges for conservation, therefore multiple types of monitoring methods were applied resulting in a series of geospatial data which were stored and distributed to the general public through the Pilot Monitoring Service.

As mentioned before, the Results Platform was created using open-source solutions and is used for storing and viewing all the geospatial products obtained from the analysis carried out in the project on the 8 CH sites (Figure 3). The menu is structured according to the cultural objectives monitored within the project, each of these objectives having assigned a series of results that can be selected for display.

The platform stores vector and raster datasets, implemented in the form of thematic layers. Some examples are: satellite images, plans and maps, vegetation indices, evolutions of urban surfaces or riverbeds.

Figure 3. The Results Platform (base map: © OpenStreetMap contributors)

The vector datasets include: the administrative boundaries of the objectives (the approximate limits of the 8 analysed objectives), the Mureș riverbed evolution, vertical displacements (using Persistent Scatterers Interferometry - PSInSAR) for Corvin Castle, ancient constructions, and Alba-Iulia city surface area evolution. Specifically, the vector dataset contains the following products:

- The boundaries of the objectives which is a polygon vector layer representing the approximate limits of the CH properties, each polygon containing information about the name and the description of the CH;
- The Mureș riverbed evolution (Figure 4) is a polygon vector layer representing the Mureș riverbed in 3 different moments of time: year 1926, year 1968 and year 2018;
- The displacement map for Corvin Castle was obtained using the PSInSAR method and it is containing displacement velocities measured in mm/year. It is a point-type vector layer representing the vertical displacements of ground and / or buildings; the map was generated based on series of Sentinel-1A/B data acquired from ascending and descending orbits.
- Ancient constructions which are line and polygon vector layers containing information about 3 of the cultural heritage sites studied in the RO-CHER project, namely: Micia, Sarmizegetusa Regia and

Sarmizegetusa Ulpia Traiana. These layers represent the outline of ancient buildings and each polygon holds information about the respective building;

- Alba-Iulia's urban growth evolution (Figure 5) is a polygon vector layer that represents the limits of the city of Alba Iulia in 4 different moments of time (year 1926, year 1967, year 1988 and year 2018).

Figure 4. Mureș riverbed evolution (year 1926 is selected) (base map: © OpenStreetMap contributors)

Figure 5. Alba Iulia urban evolution (year 1926 is selected) (base map: © OpenStreetMap contributors)

The raster dataset includes general raster products, specific raster products and historic maps. The general raster products were generated for all 8 cultural heritage sites, such as Corine Land Cover (CLC) maps, CORONA and Landsat 5, 7 and 8 images and high-resolution images. In detail, the raster dataset contains the following products:

- Corine Land Cover or CLC, a raster file provided by the Copernicus program. It is a 1:100.000 scale map and it represents homogeneous landscape models and land cover classes that were extracted from satellite data. The RO-CHER project made use of CLC data for the years 1990, 2000, 2006, 2012 and 2018 for all 8 cultural heritage objectives;
- CORONA images are high-resolution images obtained between 1960 and 1972, during the United States of America (USA) espionage programme. These images have a high spatial resolution and are particularly useful for observing changes in built-up areas, street plots and the state of CH. The images for Micia, Germisara, Sarmizegetusa Ulpia Traiana, Corvin Castle and Sarmizegetusa Regia were acquired in 1968 and the image for Alba Iulia on June 5, 1967 (Figure 6);
- Landsat 5, 7 and 8, and Sentinel-2 images are displayed as natural colour images (representations of reality as perceived by the human eye). The images used within the project are acquired at different times, as follows: Landsat 5 images for years 1984 and 1995, Landsat 7 images for 2003 and Landsat 8 images for 2019, so that observations about changes over time can be made accordingly. All Landsat images have a spatial resolution of 30 m;
- High resolution images are represented by images acquired by the Planet satellites within the Planet satellite programme and which have a spatial resolution of 3 m. The Planet images used within the project were acquired for the year 2020.

Figure 6. CORONA image of the Alba Iulia city, June 5th, 1967 (© US Geological Survey)

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Beside these general raster datasets, a series of specific raster products were derived from satellite images, but only for some of the 8 CH sites analysed in the project. These are: land cover products, urban heat island products, false-colour imagery, Normalised Difference Water Index (NDWI), CH plans, runoff maps, Simple Ratio Vegetation Index (SR), Normalised Difference Vegetation Index (NDVI) (Figure 7) and an orthophoto image. As shown in Figure 7, the values of the NDVI allow the evaluation of the health state of the forest that overlaps with the limits of the Sarmizegetusa Regia archaeological site. Using a multitemporal series, the unhealthy trees which could endanger the integrity of the archaeological remains could be identified.

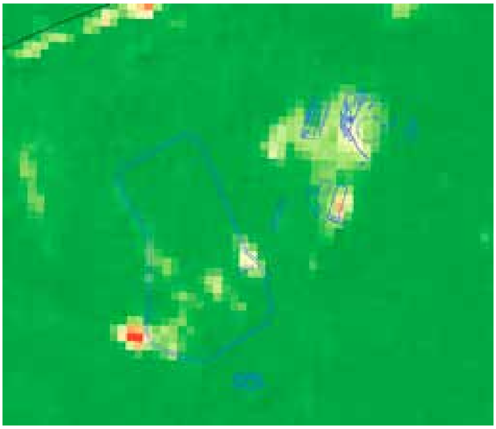

Figure 7. NDVI for Sarmizegetusa Regia objective - in blue: footprints of ancient structures (© Contains Modified Copernicus Sentinel data, 2021)

In addition to these two types of raster datasets (i.e., general and specific), two more products / maps can be viewed and analysed at national level within the Results Platform, namely: Romanian Lambert-Cholesky Map (Figure 8) and the 3rd Military Mapping Survey of Austria-Hungary (Figure 9). The Romanian Lambert-Cholesky Map (in Romanian language, the so-called *"Planurile Directoare de Tragere"*) are Romanian military maps at a scale of 1:20.000, in Lambert-Cholesky projection, developed between 1916 and 1959 (Crăciunescu, 2010), thus useful for viewing the monuments and landmarks as existing in the first half of the 20th century. The technical details of the cartographic projection are lost, hence there may be small differences between the Romanian Lambert-Cholesky Map and the other products of the platform. The 3rd Military Mapping Survey of Austria-Hungary (Figure 9) are topographic maps, at a scale of 1:200.000, made during the third topographic survey of the Habsburg Empire military, starting in 1869 (Crăciunescu, 2006). Like the Romanian Lambert-Cholesky Map, this set of maps is useful for viewing sights and performing comparisons with newer maps.

Figure 8. Romanian Lambert-Cholesky Map showing the city of Alba Iulia (source:geo-spatial.org)


Figure 9. The 3rd Military Mapping Survey of Austria-Hungary showing the city of Alba Iulia (source:geo-spatial.org)

As previously mentioned, the Monitoring Platform (Figures 10 and 11) is a web application built using Earth Engine Apps. The scope of this platform is to allow near-real-time monitoring of the CH objectives that were studied within the RO-CHER project.

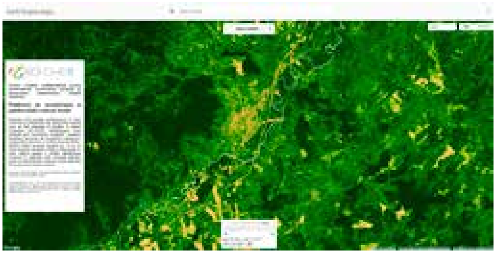

Figure 10. The Monitoring Platform - NDVI (© Contains Modified Copernicus Sentinel data, 2021)

Figure 11. The Monitoring Platform - NDWI (© Contains Modified Copernicus Sentinel data, 2021)

The monitoring is performed based on Sentinel-2 satellite imagery, using various spectral compositions and indices (NDVI, NDWI). This application can be extended to include other CH sites considering that the satellite images systematically provided by the Copernicus Programme are free, open and at a global scale.

**Other results**

During the final stage of the project, several online training sessions were organised. The training sessions were dedicated to the end users and partners of the project representing local authorities responsible for CH management. The goal of the training sessions was to explain how to access remote sensing data and products, and how to use these products for CH monitoring. The sessions strengthened the capacity of end users to learn about the state-of-the art remote sensing products and the software used to visualise these products. Users were trained to correctly interpret the geospatial products available on the platform. Subsequently, based on the feedback received during the sessions, the two platforms of the pilot monitoring service were updated in order to meet the end user needs and expectations.

## CONCLUSIONS

The easily accessible pilot monitoring service developed in the framework of the RO-CHER project enabled the integration of a very wide range of geospatial products in a standardised and organised manner as well as the systematic monitoring of CH objectives even after the project's completion. This valuable tool is appreciated by archaeologists and the wider community of CH specialists as well as by the general public, considering that it is offering a broad perspective, over a long period of time on the evolution of the studied CH objectives. The service can be also used both for educational or research purposes and as a mean for promoting CH and its environment.

The use of open-source data and mostly open-source software guarantees sustainability by eliminating excessive costs that can accumulate over long periods of operation. Another aspect regarding the sustainability of the service was the integration within the Monitoring Platform of satellite data from missions that are planned to be extended for an indefinite period of time.

EO definitely offers sustainable means for the CH documentation, monitoring, planning of risk mitigation and preservation measures, and promotion. Especially in the current context in which CH is globally endangered by different threats (e.g., climate change, uncontrolled urban development, land conversion, severe weather events, sudden ecological and geological events, etc.), the continuous and many-sided monitoring is essential.

Another important aspect is the interdisciplinary character required for a robust approach in support of an efficient CH management. In the last years, the gap between the CH specialists and the EO community is steadily reducing due to the successful studies that demonstrated the unique potential of EO satellite imagery for producing useful and timely information for CH.

Some of the activities conducted in the frame of the RO-CHER project are continued within the "Artificial Intelligence & Earth Observation based services for cultural heritage monitoring (AIRFARE)" project that is funded through the "Transfer to the economic operator" programme. AIRFARE aims to advance the

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technology readiness level (TRL) of the solutions developed within RO-CHER.

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