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Remote Sensing Synergies for Port Infrastructure Monitoring and Condition Assessment

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Abstract: There is an urgent need for the development of cutting-edge port infrastructure monitoring solutions that exploit different multimodal data towards timely optimal port management strategies and decision-making. Advanced monitoring applications allow for optimising maintenance, rehabilitation, and upgrade actions by assessing the structural integrity of port structures that is affected by a vast variety of stressors such as aging, imposed loads, inadequate maintenance treatments, human-induced factors, natural hazards, and the ever-changing climate. The purpose of this research is to enhance Remote Sensing (RS) port monitoring practices by investigating the potential of combining different types of RS methods to record and assess infrastructure condition. Two RS types of data, a) satellite imagery and b) aerial imagery from Unmanned Aerial Vehicle (UAV), were considered for structural monitoring at Lavrio port, located in northeastern Attica, Greece. In particular, the applied monitoring program was focused on its windward rubble mound structure where temporal changes in the armour layer were detected. Significant parameters regarding spatial resolution and UAV flight characteristics were further investigated aiming at ensuring high-quality data. The overall research indicated that RS synergies proved to be a promising practice for acquiring advanced spatial and temporal information on port infrastructure condition.

Keywords: Monitoring, port infrastructure, remote sensing, satellite imagery, unmanned aerial vehicles.

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1. Introduction

Ports are vitally important, stimulating economic development both nationally and globally. Port infrastructure is required to be of a high quality to enhance performance (Munim and Schramm, 2018). The integrity of port infrastructure is challenged by a number of stressors, including adverse marine environments, human-induced factors, and inadequate or absent maintenance, as well as impacts stemming from the climate crisis (Lauritzen et al., 2019; ASCE, 2021). Therefore, port operators are tasked with applying effective management policies to address these challenges and minimise their influence.

To provide a good asset management system that is compatible with continuous changes in financial allocations, it is important to establish a cost-effective and proactive monitoring program that can provide comprehensive data on the infrastructure's susceptibility to potential challenges (Rashidi et al., 2020). Implementing a periodical inspection scheme along with performing a detailed assessment of the structural condition of port structures supports decision-making processes and facilitates the prioritisation of maintenance, upgrade, and recovery actions (Lauritzen et al., 2019; Limongelli et al., 2019). Considering the above, the engagement of monitoring practices in asset life-cycle management allows for the estimation of structural integrity. Through targeted measurements and modelling applications, it is possible to estimate the loss of capacity and functionality of an asset. (Achillopoulou et al., 2020).

Currently, Remote Sensing (RS) techniques have been employed for infrastructure monitoring (Singhroy, 2021). RS approaches have gained momentum since they allow for both qualitative and quantitative measurements while providing temporal information between inspections without disrupting operation (Vaghefi et al., 2012). Advancements in infrastructure RS monitoring include the use of satellite imagery, and aerial imagery from Unmanned Aerial Vehicles (UAVs) for Close Range Photogrammetry (CRP) applications (Singhroy, 2021). Within the port industry, satellite imagery is mainly used for monitoring land use changes (Li et al., 2019), while UAV-based CRP applications have been used for recording infrastructure condition (Tsaimou et al., 2021). However, both approaches present limitations when they are used independently. For instance, obtaining detailed observations and condition identification with satellite data is quite challenging considering the compromise between spatial coverage and the resolution of satellite images (Dubovik et al., 2021). On the other hand, the periodical use of UAV-based CRP applications (Tsaimou et al., 2021) does not allow for the operator to monitor important changes in between the time intervals of the in situ inspections.

Based on the above, the present paper intends to enhance port monitoring practices by investigating the potential of combining two (2) RS types of data: a) satellite imagery and, b) UAV aerial imagery for CRP applications. To achieve this, a pilot multimodal RS monitoring program was applied at the port of Lavrio, located in northeastern Attica, Greece. Both types of data were used to periodically record, visualise, and locate the temporal changes observed in the armour layer of the windward rubble mound structure located within the domestic ferry domain at Lavrio port. The implementation of this combined framework is intended to provide measurable data to assess the structural condition and, consequently, the performance of the structure.

2. Materials and Methods

2.1. Multimodal RS Monitoring Framework of Port Infrastructure

The ever-increasing interest in incorporating RS satellite imagery and UAV applications into monitoring approaches of civil infrastructure is depicted in the number of studies in various fields of civil engineering (e.g., Ham et al., 2016; Hoppe et al., 2019; Feroz & Dabous, 2021). Regarding port rubble mound structures, UAV-based practices have been applied for structural monitoring (González-Jorge et al., 2014; Henriques et al., 2017; Sousa et al., 2022). However, existing studies are focused on highlighting the UAV capabilities to record rubble mound structures based on single inspections. The development of a continuous monitoring program that allows for the implementation of frequent in situ inspections and, consequently, periodical assessments of port infrastructure performance has not been explored. There is also an evident lack of integration of RS satellite imagery in detailed port infrastructure monitoring.

The proposed multimodal RS monitoring framework for assessing port rubble mound structures consists of two (2) approaches: a) satellite imagery data acquisition and analysis and b) UAV-based collection of aerial imagery and photogrammetry process (Fig. 1). Regarding the satellite RS approach, high-quality imagery is integral to ensure appropriate precision for locating and mapping all spatial information required for identifying port infrastructure condition. Among the most common open-access satellite collections are those available from Landsat and Sentinel-2. The resolution of these collections limits their applicability for detailed monitoring of port infrastructure condition, especially when considering the scale of failures identified in port structures (e.g., armour layer damage of breakwaters). To address this challenge, other alternative commercial satellites can be used for acquiring high-resolution imagery (e.g., WorldView-3).

High-resolution satellite imagery includes panchromatic images that require further preprocessing analysis to improve spatial characteristics. The pansharpening process is used to generate higher-quality visual images by combining low-resolution multispectral satellite bands and a corresponding high-resolution panchromatic band. Geographic Information System (GIS) platforms include user-friendly tools that allow for applying pansharpening algorithms to satellite images. After producing the final multispectral image, details regarding the waterline or the toe line along the port structures can be acquired. This information is useful for recognising significant changes occurring in the armour layer of the rubble mound structures due to degradation, or informing on what repairs may need to be undertaken. To determine the waterline at the structure-water interface, the Normalized Difference Water Index (NDWI) (Domazetović et al., 2021) can be used as shown in Eq. (1):

$$\mathrm{NDWI}=\frac{\mathrm{C}-\mathrm{NIR2}}{\mathrm{C}+\mathrm{NIR2}} \tag{1}$$

where C is the spectral band for the structure and NIR2 is the spectral band near-infrared 2.

Waterline extraction is achieved by adjusting the thresholds for calculating the NDWI spectral index considering the specific characteristics of the examined area. Depending on data availability, waterline modelling can be applied to satellite collections obtained not only for specific dates between the time intervals of the performed in situ inspections, but also for dates before the initiation of the field inspection scheme.

The second approach of the multimodal RS monitoring framework engages a periodical scheme of Structure from Motion (SfM) applications with UAV-based photogrammetry (CRP) analyses. The precision and reliability of the photogrammetry results are affected by the features of the camera integrated into the UAV system. Consideration of other factors is also required, including weather conditions, number of Ground Control Points (GCPs), as well as flight altitude based on local restrictions from the existing environment (e.g. building and vessel height).

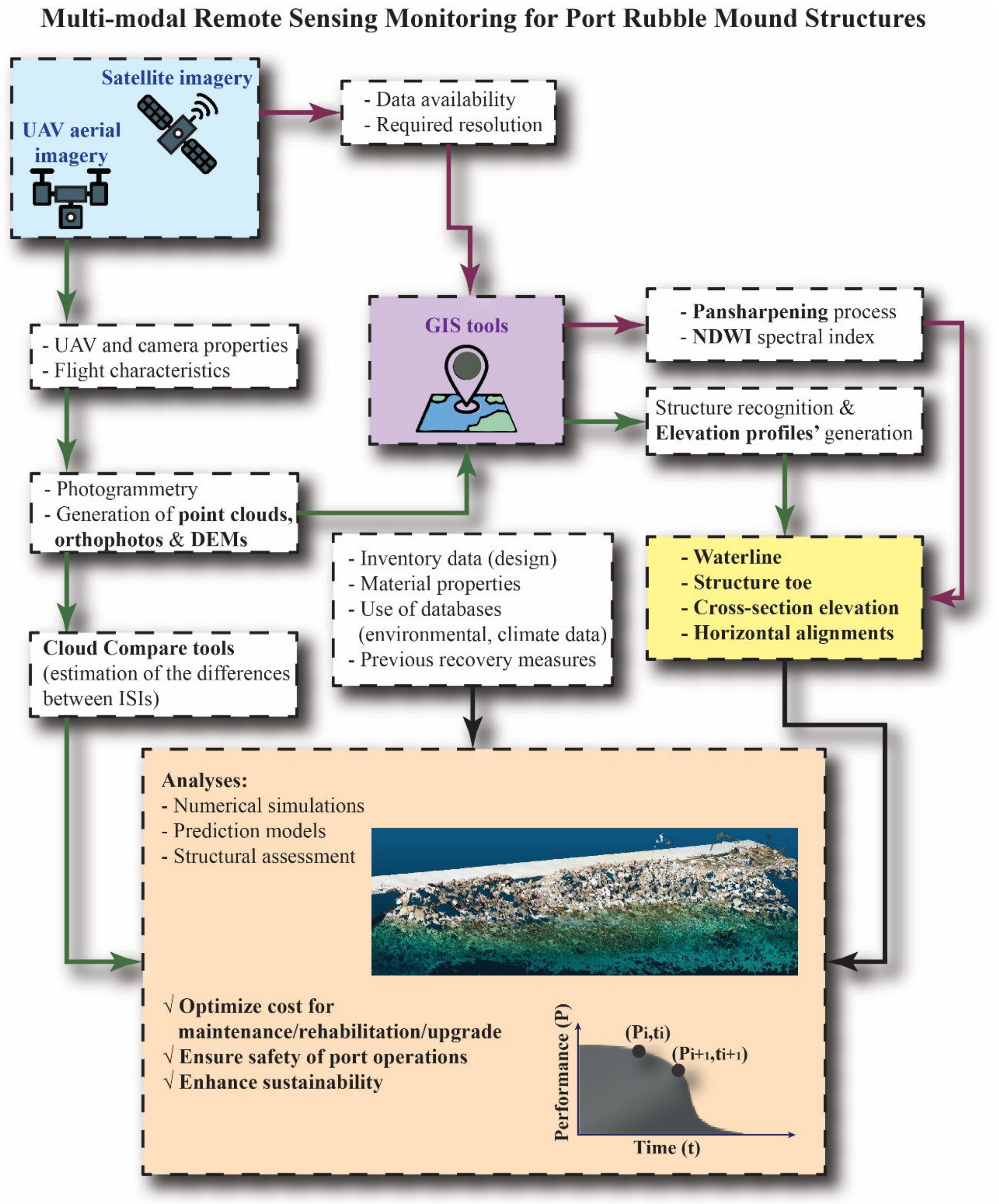


Fig. 1. Multimodal RS framework for port infrastructure monitoring towards assessing the structural performance of rubble mound structures

SfM enables the generation of three-dimensional (3D) point cloud models from a set of two-dimensional (2D) images collected during in situ inspections (Khaloo and Lattanzi, 2016). The 3D point clouds produced by applying the periodical monitoring scheme can be compared to detect potential changes in port infrastructure condition (i.e., the rubble mound structure under investigation) that have occurred during the time intervals between inspections. Comparative analyses of the dense point clouds can be combined with the GIS-based analyses of the relative orthophotos (georeferenced images) and Digital Elevation Models (DEMs), also generated using the photogrammetry. These can be used to visualise and assess the performance of the rubble mound structure between UAV flights. Performance assessment can be achieved by monitoring the waterline at the structure-water interface, the line of the structure toe, as well as the transverse and longitudinal profiles extracted by using GIS tools. For the case of two conducted in situ inspections i and i+1, a comparison between the estimated performances P_i and P_{i+1} estimated for t_i and t_{i+1} times of inspections, respectively (Fig. 1), allows for identifying the degree of loss of structure's integrity, and, consequently, examining the implementation of alternative recovery measures.

Besides the significance of conducting proper data collection for both the satellite imagery and the UAV aerial imagery (i.e., selection of the appropriate satellite image collection and UAV equipment, as well as examination of UAV flight characteristics), the multimodal RS monitoring framework requires using appropriate software that enables reliable data analyses. Table 1 includes an indicative list of open and paid access software that is used.

The combination of both RS monitoring approaches seeks to reduce the restrictions (e.g. desired resolution or data availability on specific dates) imposed by the implementation of each approach separately. Therefore, RS synergies exploiting satellite imagery and UAV aerial imagery facilitate the development of an efficient monitoring framework aiming at: a) optimising the cost of the foreseen maintenance, repairs, and upgrade actions, b) reducing risks regarding port operations, and c) enhancing structure sustainability.

Table 1. Indicative software employed for the analysis

Software	Purpose	Data access	Documentation
Agisoft (v 1.6.4)	Photogrammetry process	Paid access	Agisoft LLC, 2020
CloudCompare	Comparison of dense point clouds	Open access	https://www.danielgm.net/cc/
QGIS (v 3.22)	Pansharpening algorithms Orthophotos’ & DEMs’ visualization and analysis	Open access	https://docs.qgis.org/3.22/en/docs/user_manual/

2.2. Case Study

The multimodal RS monitoring framework was applied at Lavrio port located in the south-eastern tip of Attica, Greece (37º42΄44 N, 24º3΄25 E) (Fig. 2a). The facilities of Lavrio port support a wide range of activities such as domestic ferry, yacht, and cruise shipping, along with fisheries, commercial activities and land exploitation (https://oll.gr/en/). Lavrio port holds a strategic position given its proximity to Cyclades islands and Athens International Airport “Eleftherios Venizelos”, as well as its location in relation to “Thriasio” logistic hub. Therefore, it is of paramount importance to ensure the functional and structural integrity of its infrastructure with targeted maintenance and repair measures. The constant obligation of both maintaining and upgrading Lavrio port operations and facilities requires a comprehensive knowledge of infrastructure condition and behaviour against uncertainties.

(b) (c)

Fig. 2. (a) Lavrio port located in the south-eastern tip of Attica, Greece, (b) Overview of the domestic ferry and the cruise domain, as well as the windward breakwater of Lavrio port based on the orthophoto generated by data collected during ISI-2, and (c) Representative photos of the domestic ferry and the cruise domain, as well as the windward breakwater of Lavrio port captured during UAV video recording of ISI-3

The performance of Lavrio port infrastructure is dependent on the undisrupted operation of its facilities and challenged by the physical aging induced by loading and environmental conditions. Considering this, the Laboratory of Harbour Works (LHW) of the National Technical University of Athens (NTUA) has initiated a pilot monitoring program of the infrastructure at the domestic ferry and the cruise domain, as well as the windward breakwater (Figs. 2b and 2c) seeking to promote competent life-cycle management of the relative structures.

The implemented monitoring program includes one (1) satellite imagery (SI) data acquisition and four (4) in situ inspections (ISIs) (Fig. 2b and Table 2). Its initiation took place with the application of ISI-1 (2020-02-10), while ISI-2, ISI-3, and ISI-4 were conducted later, following a twice-a-year field inspection approach. Since no data was available before the first in situ inspection, the acquisition of satellite data that precedes ISI-1 (i.e., 2019-05-30) allowed for providing additional information regarding port infrastructure condition, thus enhancing the monitoring database that was produced.

Satellite imagery was acquired by a commercial Earth observation satellite, WorldView-3, while a UAV system, DJI MAVIC 2 pro, was employed for the conduction of the in situ inspections. Tables 3 and 4 present the satellite sensor resolution and the characteristics of the UAV-integrated camera, respectively. Table 5 includes the ground resolution values from the UAV-collected data. The lower resolution of the satellite data (compared to the one of UAV data) did not allow for a detailed inspection of the port infrastructure. However, it does provide adequate information regarding infrastructure condition, as presented below in Section 3.

Table 2. Collected multimodal data

Data collection	Data source	Date
SI-1	WorldView-3	2019-05-30
ISI-1	UAV flight at 48 m height	2020-02-10
ISI-2	UAV flight at 56 m height	2020-09-04
ISI-3	UAV flight at 76 m height	2021-02-10
ISI-4	UAV flight at 56 m height	2021-07-09

Table 3. Spatial resolution of the WorldView-3 satellite imagery (DigitalGlobe)

Panchromatic	Visible near-infrared	Short-wave infrared
31 cm	1.24 m	3.70 m

Table 4. UAV camera characteristics

Model	Resolution	Focal distance	Pixel size
L1D-20c (10.26 mm)	5472 x 3648	10.26 mm	2.41 x 2.41 µm

Table 5. UAV data ground resolution

Data collection	Ground resolution (cm/pixel)
ISI-1	1.06
ISI-2	1.21
ISI-3	1.66
ISI-4	1.17

Within the context of investigating the capabilities of both RS monitoring approaches (i.e., the use of both satellite and UAV aerial imagery), to map port infrastructure defects and failures, the present research is focused on the windward rubble mound structure of the domestic ferry domain (Fig. 2b). The case of the specific rubble mound structure was considered to be a suitable example to highlight the potential of the RS-based monitoring program due to the temporal changes in the armour layer observed during inspections. Further analysis of these changes is included in the following section.

3. Multimodal RS Data Analysis and Results

Data collected with satellite imagery acquisition and UAV applications at Lavrio port was analysed following the multimodal RS monitoring framework described in Section 2.1. In particular, regarding WorldView-3, satellite imagery (SI-1) pansharpening algorithms were implemented with QGIS tools to create a high-resolution image (Fig. 3). Further analysis of this image enables the extraction of the waterline at the interface between the windward rubble mound structure and the water, as well as the toe line (Fig. 5) by applying a user-defined threshold NDWI$\leq$0.2.

Extraction of the waterline was achieved with a high percentage of precision, while toe line extraction was an approximation, close to the actual line since the presence of the water layer prevents the identification of the precise location of the underwater armour layer limit. Both lines are useful for further comparison with the ones extracted from the in situ inspections (Fig. 5) aiming at identifying significant changes that occurred during the time interval of the obtained data.

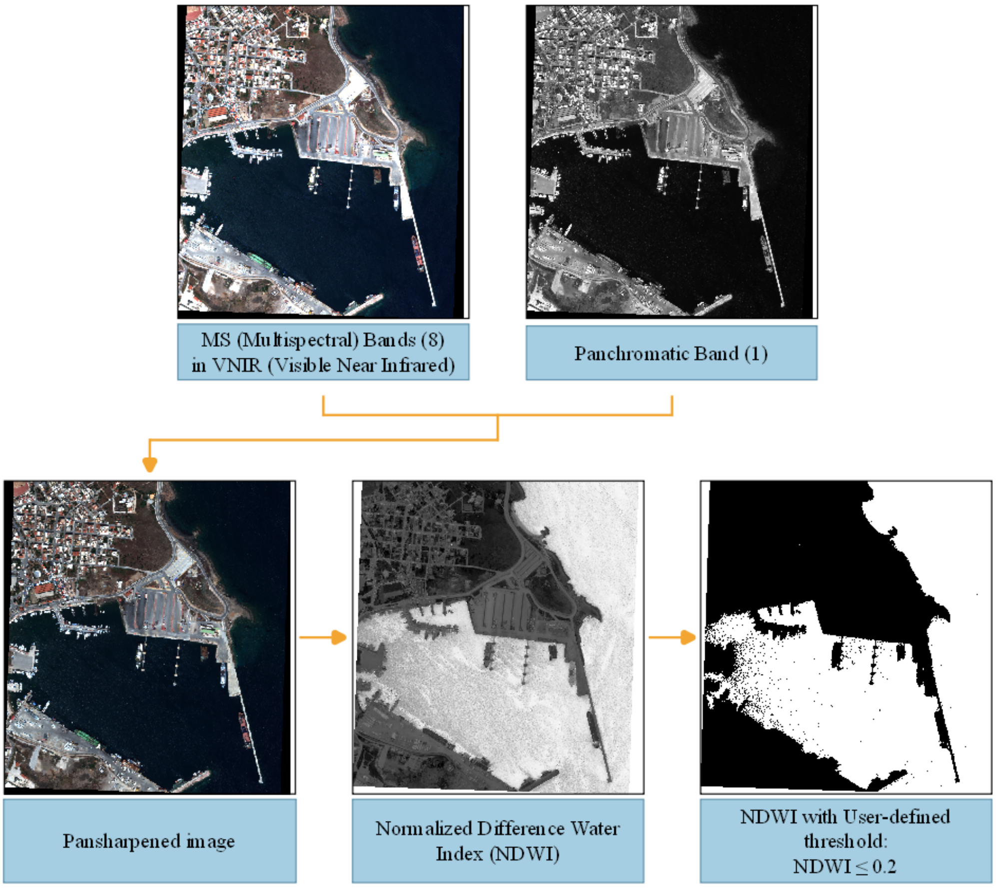


Fig. 3. Satellite image analysis for the Lavrio port region

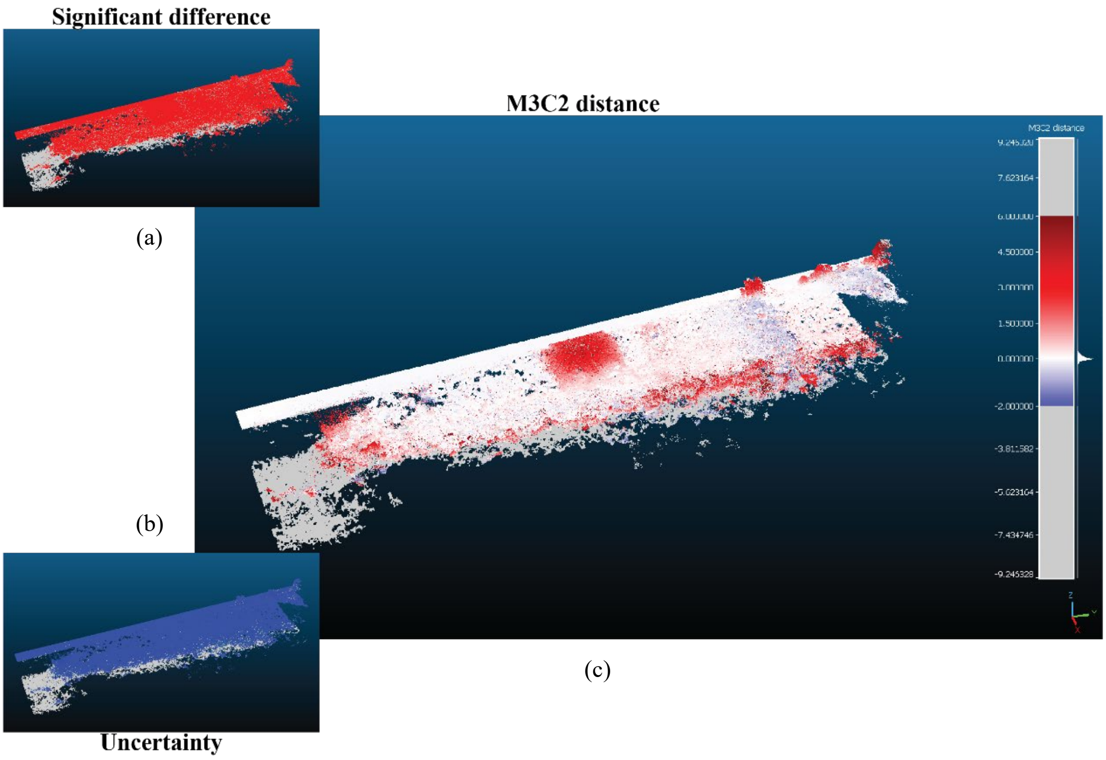


Fig. 4. Dense point clouds comparison for ISI-1: 2020-02-10, and ISI-3: 2021-02-10: (a) Significant difference between the two point clouds, (b) Uncertainty when comparing the two point clouds, and (c) Calculated M3C2 distance between the two point clouds indicating the areas of identified variations

UAV collected data was analysed with Agisoft software to generate the required dense point clouds, DEMs, and orthophotos. A preliminary examination of the CRP results was conducted by comparing the four (4) dense point clouds with the CloudCompare software. Fig. 4 illustrates the change detection results for the dense point clouds of ISI-1: 2020-02-

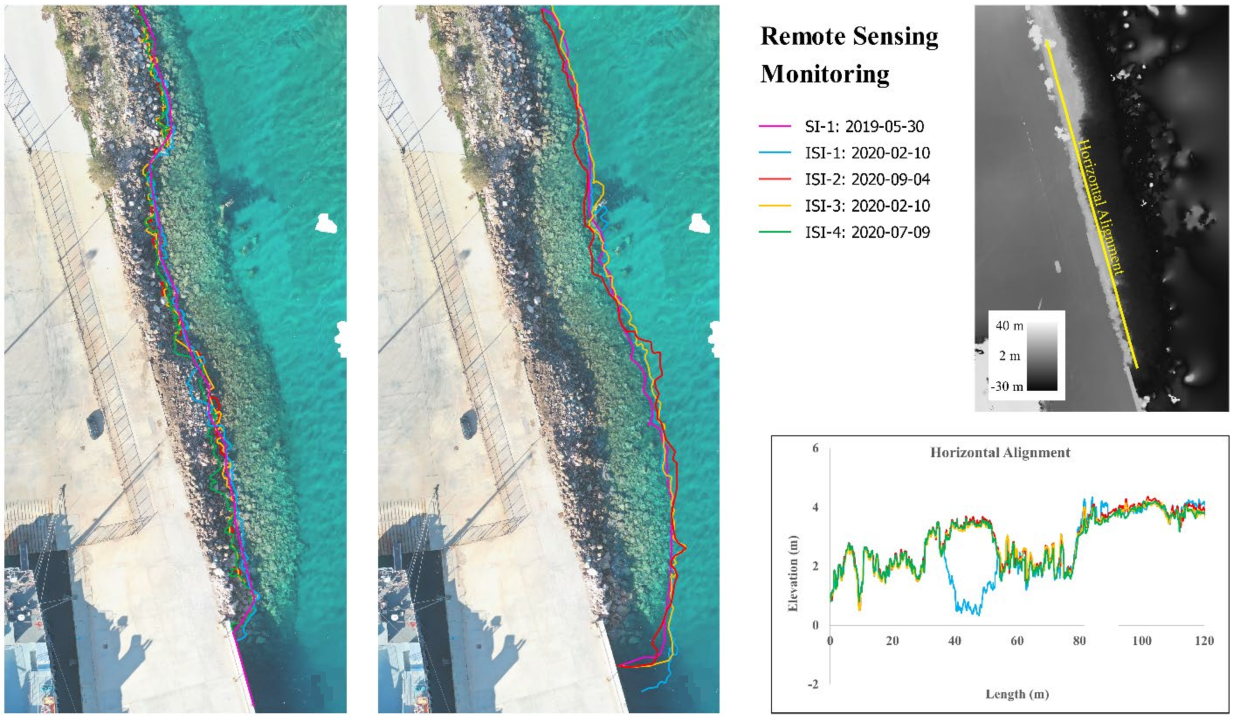
10 and ISI-3: 2021-02-10, showing the changes occurring within one year in the rubble mound structure. Three types of image outputs were produced: a) the significant difference, b) the uncertainty, and c) the M3C2 distance. The red color illustrated in the image of significant difference (Fig. 4a) indicates that the two datasets are different and can be further evaluated. The blue color in the image of uncertainty (Fig. 4b) indicates that no uncertainties affected by factors such as point cloud roughness between the two datasets are identified, thus permitting reliable point cloud comparison. The calculated M3C2 distance refers to the change amount between the two datasets. As shown in Fig. 4c, one area with significant change was detected approximately at the center of the rubble mound structure.

The results of the CloudCompare analysis were particularly useful as they provided a preliminary overview of the detected changes. This was followed by a more detailed assessment of the periodically recorded condition of the structure. The QGIS platform was used to further examine both the analysed satellite image and the generated DEMs and orthophotos of all four (4) inspections, aiming to visualise the changes and provide quantitative data.

Figs. 5a and 5b illustrate the extracted waterlines and the toe lines, respectively, based on image interpretation of the satellite and the photogrammetry data. Similarly to the satellite imagery approach, the toe lines of in situ inspections involve a degree of uncertainty due to the water influence in photogrammetry results. The toe line of ISI-4 is not included in Fig. 5b since wave-induced disturbances prevailing during UAV data collection affected the reliability of DEM estimation around the sea area. Nevertheless, toe line extraction continues to provide useful information in terms of detecting significant changes below the sea level during monitoring applications.

Considering the above, no major alterations between the five (5) waterlines are observed except in some localised areas. Detailed examination of the extracted toe lines indicates that the armour layer units tend to accumulate towards the south part of the rubble mound structure. This is particularly noticeable in the extracted toe line of ISI-2 (Fig. 5b).

Fig. 5c shows an indicative example of the horizontal alignment (longitudinal profile) of the rubble mound structure at the domestic ferry domain of Lavrio port as produced by using the QGIS profile tool. Taking into account the results from the comparison of the dense point clouds (Fig. 4), major changes in the armour layer were detected in the middle area of the structure. The transition from the light blue line (ISI-1) to the red line (ISI-2) can be explained by the fact that maintenance actions have been conducted between these inspections, including the placement of additional armour units at the area with the lowest elevation.



(a) (b) (c)

Fig. 5. (a) Waterline, (b) toe line, and (c) an indicative longitudinal profile for the rubble mound structure of the ferry domestic domain at Lavrio port as produced by the analysis of the two multimodal data, i.e., satellite imagery (SI-1) and aerial imagery (ISI-1, ISI-2, ISI-3, and ISI-4)

The QGIS profile tool was also used to quantify the changes observed in the orthophotos of the rubble mound structure (Fig. 6a) by creating the transverse profile lines from the raster layer produced from the DEMs (Fig. 6b) for each in situ inspection. To achieve this, twenty (20) equally distant transverse sections were placed along the rubble mound structure to show the elevation changes of the transverse profiles during the time intervals of the in situ inspections (Fig. 6c). The start of the section lines corresponds to the crest of the structure, while the end of the section lines corresponds approximately to the toe of the structure.

Figs. 6d and 6e illustrate two (2) profile lines for two sections, namely Section 6 which is beyond the red area depicted in Fig. 4c, and Section 12 which is included in this area. Section 6 (Fig. 6d) shows that no significant changes are observed during the time intervals of the in situ inspections. Significant changes were noticed at the elevation of the armour layer of Section 12 (Fig. 6e). As derived from the profile line of ISI-1, the lowest elevation was recorded at the first in situ inspection. Following ISI-1 data analysis, the profile output of ISI-2 indicates that repairs have been performed to address the damage resulting in a markable elevation increase. However, the periodical implementation of the UAV-based monitoring program reveals that despite the maintenance actions, the degradation of the armour layer continued after the distance of 6 m from the crest of the structure.

As already mentioned, the precision of the results is reduced within the underwater photogrammetry data. ISI-4 profile line stops just before the interface between the structure and the water due to the wave-induced disturbances at sea level. Despite the uncertainties stemming from the water influence, the profile lines under the water provide an adequate estimation of significant changes up to the toe of the structure. The noticeable differences between the underwater profile lines of Section 12 (Fig. 6e) follow the findings of the comparison of the above-water profile lines and show an elevation increase due to additional armour units.

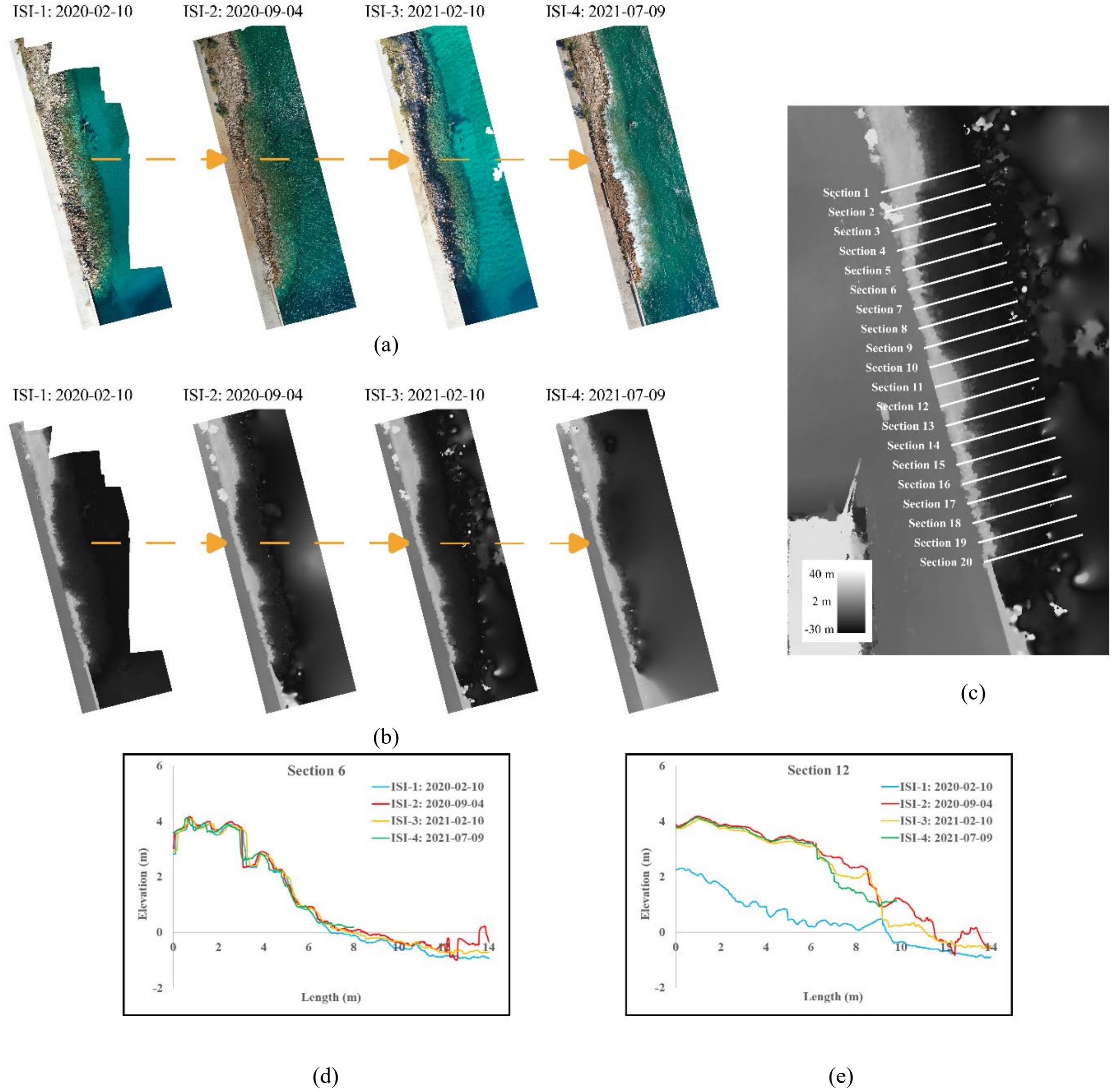


Fig. 6. Elevation changes of the armour layer of the rubble mound structure of the domestic ferry domain at Lavrio port: (a) change detection in the orthophotos of the four (4) UAV-based in situ inspections, (b) change detection in the DEMs of the four (4) UAV-based in situ inspections, (c) section definition for producing the transverse profiles, (d) transverse profile of Section 6, and e) transverse profile of Section 12

The above observations regarding elevation changes for Sections 6 and 12 are summarised in Table 6, where the slopes of the transverse profiles are presented. The estimation of the slope was performed from the crest level to the waterline level for each in situ inspection. Section 6 slopes' comparison implies minor variations, likely due to local movements of armour units. Section 12 slopes' comparison demonstrates the placement of additional armour units, resulting in a slope increase of up to 41.76% from ISI-1 to ISI-2. Slope comparison between ISI-2 and ISI-3, as well as between ISI-3 and ISI-4 reveals an ongoing armour unit movement that may result in armour layer damage as recorded in ISI-1.

Apart from detecting changes in armour units' movement and armour layer slope, the detailed analysis of the extracted profile lines provides useful information for assessing the suitability of maintenance measures by monitoring the structure's behaviour after repairs. Profile results along with additional data acquired by orthophoto analysis and calibrated with field inspections (e.g., size of armour layer units) can be integrated into numerical simulations to assess the performance of the considered structure against pressures including wave loads.

Table 6. Slope estimation for the transverse profiles of Sections 6 and 12 of the rubble mound structure of the domestic ferry domain at Lavrio port

Data collection	Section 6		Section 12	
	Slope (%)	Slope change (%)	Slope (%)	Slope change (%)
ISI-1	-56.39	-	-24.02	-
ISI-2	-58.33	3.44	-34.05	41.76
ISI-3	-57.55	-1.34	-37.19	9.22
ISI-4	-58.67	1.95	-35.16	-5.46

Finally, it is important to note that Figs. 5 and 6 do not include elevation profiles from Worldview-3 imagery due to data unavailability (stereo-pair satellite images) required to build DEM from satellite images. However, if transverse and longitudinal profiles could be created, important information about the armour layer damage before the implementation of the in situ monitoring approaches could be obtained. This information includes material regarding ongoing or unexpected damage due to extreme events, as well as knowledge about previous maintenance actions that have failed.

4. Discussion

The implementation of the multimodal RS monitoring framework at Lavrio port provides crucial information regarding the condition of the windward rubble mound structure not only during the time intervals of the in situ inspections but also before the initiation of the monitoring program. Further analysis of this data enables assessment of the performance and the integrity of the structure.

The structural integrity of the rubble mound structure can be expressed in terms of the damage factor S_d (Eq. 2) described by Van der Meer (1988):

$$S_d = \frac{A_e}{D_{n50}^2} \tag{2}$$

where A_e is the eroded area and D_{n50} is the nominal diameter of the stone class.

The area of erosion A_e can be obtained by monitoring data, while the determination of the nominal diameter D_{n50} requires design data and field measurements. Estimation of the damage factor S_d allows for understanding and managing the life-cycle of the structure.

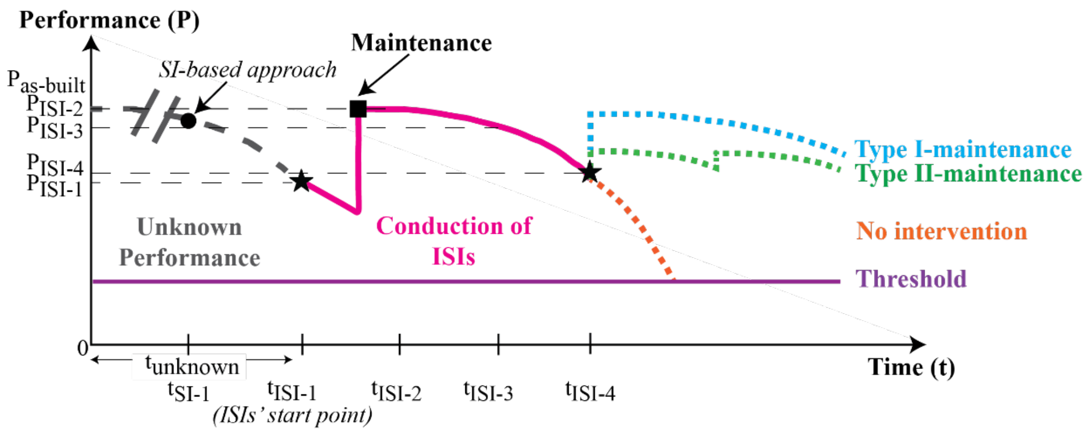


Fig. 7. Life-Cycle Performance for the rubble mound structure at the domestic ferry domain of Lavrio port considering the applied RS monitoring framework

Fig. 7 presents the theoretical life-cycle curve of the performance of the rubble mound structure of Lavrio port based on the data acquired by the applied multimodal RS monitoring program. Before the in situ inspections ($t<t_{ISI\text{-}1}$) were conducted, limited information was available for the performance of the structure, except satellite imagery data. After introducing field applications, it is observed that between ISI-1 and ISI-2 the structural integrity of the considered structure was enhanced, while during the time intervals of ISI-2 and ISI-3, as well as ISI-3 and ISI-4 an ongoing performance decrease was taking

place. Following this, port managers are tasked to decide if repair measures should be scheduled, including major or continuously applied minor interventions (Type I-maintenance and Type II-maintenance, respectively). In the case where no maintenance treatments will take place (no intervention), the performance of the structure will reach a defined threshold that refers to failure.

5. Conclusions

The present paper is focused on enhancing monitoring practices of port infrastructure by investigating the potential of exploiting two (2) RS types of data, i.e., satellite imagery and UAV aerial imagery. To achieve this, the windward rubble mound structure of Lavrio port in Greece was examined by applying a periodical monitoring program. During the implementation of the monitoring program, changes in the armour layer of the structure were detected. The combination of the specific RS approaches facilitated the procedure of visualising, mapping, and quantifying the elevation alterations at the armour layer. The analyses performed included the extraction of the waterline, the toe line, as well as the transverse and the longitudinal profile lines to determine slope variations, and monitor the structural integrity of the rubble mound structure. The above analysis also identified the maintenance treatments that had been conducted to improve structural integrity by placing additional armour units.

The analysis indicated that the proposed multimodal RS framework eliminates some of the limitations of applying the satellite imagery approach or the UAV-based one independently of each other (e.g., data availability, resolution and quality of data, frequency of in situ inspections, inventory data regarding previous maintenance or rehabilitation actions, etc). Both RS approaches proved to be promising in terms of collecting required data for detailed assessment of infrastructure condition. The periodical implementation of the monitoring program enables the detection of defects within the structures, thus enhancing life-cycle management strategies.

The proposed RS monitoring framework can be further strengthened by acquiring historic images from satellite collections. This would enhance an integrated database that contains comprehensive knowledge of the structure's behaviour and performance, as well as important information regarding previous maintenance or repairs.

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Author Contributions

Christina N. Tsaimou contributes to conceptualization, methodology, software, validation, analysis, investigation, data collection, draft preparation, manuscript editing, and visualization. Dimitrios Georgios N. Kagkelis contributes to methodology, software, and analysis. Konstantinos Karantzalos contributes to methodology, software, validation, and manuscript editing. Panagiotis Sartampakos contributes to field data collection and validation. Vasiliki K. Tsoukala contributes to conceptualization, methodology, analysis, investigation, data collection, validation, manuscript editing, review, visualization, supervision, project administration, and funding acquisition. All authors have read and agreed with the manuscript before its submission and publication.

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