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Integrating Seaport Infrastructure Monitoring Approaches to Improve Smartness and Climate Adaptive Capacity

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Abstract. Seaport infrastructure monitoring promotes the development of an effective management system that ensures functionality, structural capacity and safety. Monitoring approaches are considered to be a useful tool in an attempt to deal with growing global trends, such as seaport "smartness", or with challenging issues such as climate crisis, while enhancing the financial performance and the capability of a seaport to remain competitive in the trading environment. Therefore, the present paper proposes a framework for integrating monitoring processes and relevant data analyses to improve seaport smartness and adaptive capacity to climate change. The framework is applied at the seaport of Lavrio, located in central-eastern Greece, where in-situ inspection and condition assessment is performed through utilizing modern monitoring techniques. The research outlines the significance of establishing a robust monitoring system such as the one hereto described to minimize the impact of natural hazards, perform suitable maintenance strategies and optimize the required periodic control of seaport facilities.

Keywords: Monitoring, Smart Ports, Climate Change, Climate Adaptive Capacity, Seaport Infrastructure

1. Introduction

Seaports play a crucial role in the global economy not only since more than 90% of global trade is carried by sea (IMO, 2012), but also through job provision and public transportation facilitation. Towards an effective asset management of seaports, infrastructure inspection approaches that constitute an integral part of a monitoring system are of paramount importance to ensure public safety, enhance operations reliability and optimize maintenance (ASCE, 2015).

Infrastructure monitoring seeks to provide expedient feedback for recovery measures, accelerate decision-making for adaptation of built environments and utilize emerging technologies to continuously deliver safer and resilient infrastructure (Achillopoulou et al., 2020). The location of seaports along the coasts and the impacts of climate crisis pose additional challenges for seaports (Ng et al., 2016, Izaguirre et al., 2021). Implementing monitoring approaches of seaport infrastructure is considered an effective measure to reduce seaports' exposure to climate change. Furthermore, monitoring approaches and maintenance strategies constitute a prerequisite for achieving seaports "smartness", referring to their proper reinforcement with modern technologies to allow for both remote access to infrastructure condition and continuous information update for the relevant stakeholders and managers (Rajabi et al., 2018).

A four-step monitoring framework has been developed and implemented by the Laboratory of Harbour Works (LHW) of National Technical University of Athens (NTUA). The framework hereto proposed aims not only to increase seaports' adaptive capacity to climate change, i.e. their ability to adjust to potential damage, take advantage of opportunities and respond to consequences (IPCC, 2014), but also their smartness, through the use of recent technologies that improve port performance (PortTechnology, 2016). The seaport of Lavrio, located in central-eastern Greece was used as a case study to validate part of the proposed framework and acquire preliminary results fundamental for the ongoing research regarding developing a comprehensive monitoring system.

2. Methods and material

2.1. Monitoring framework

The proposed framework consists of four stages, namely Stage 1: Monitoring with modern methods; Stage 2: Analysis of in-situ data; Stage 3: Utilizing geospatial information; and Stage 4: Database generation (Fig. 1). The goal of improving the seaport smartness and climate adaptive capacity (CAC) is achieved through the entire circular mode.

Stage 1 of the framework incorporates modern methods for the implementation of a periodical monitoring of the seaport infrastructure. Such methods include the use of unmanned vehicles (aerial and underwater) as well as 3-D cameras, both used during in-situ inspections performed by LHW, NTUA. For the purposes of this paper the proposed framework is based on implementing monitoring procedures with Unmanned Aerial Vehicles (UAVs). UAVs' efficiency for infrastructure Non Destructive

Testing (NDT) has already attracted significant research interest (Yu et al., 2017; Kim et al., 2018). However, in the seaport context, UAVs have been mostly used for monitoring parameters such as security (Stein, 2018), rather than infrastructure itself. This work illustrates that UAVs' robustness is needed while monitoring seaport infrastructure seeking to improve both seaport smartness and CAC.

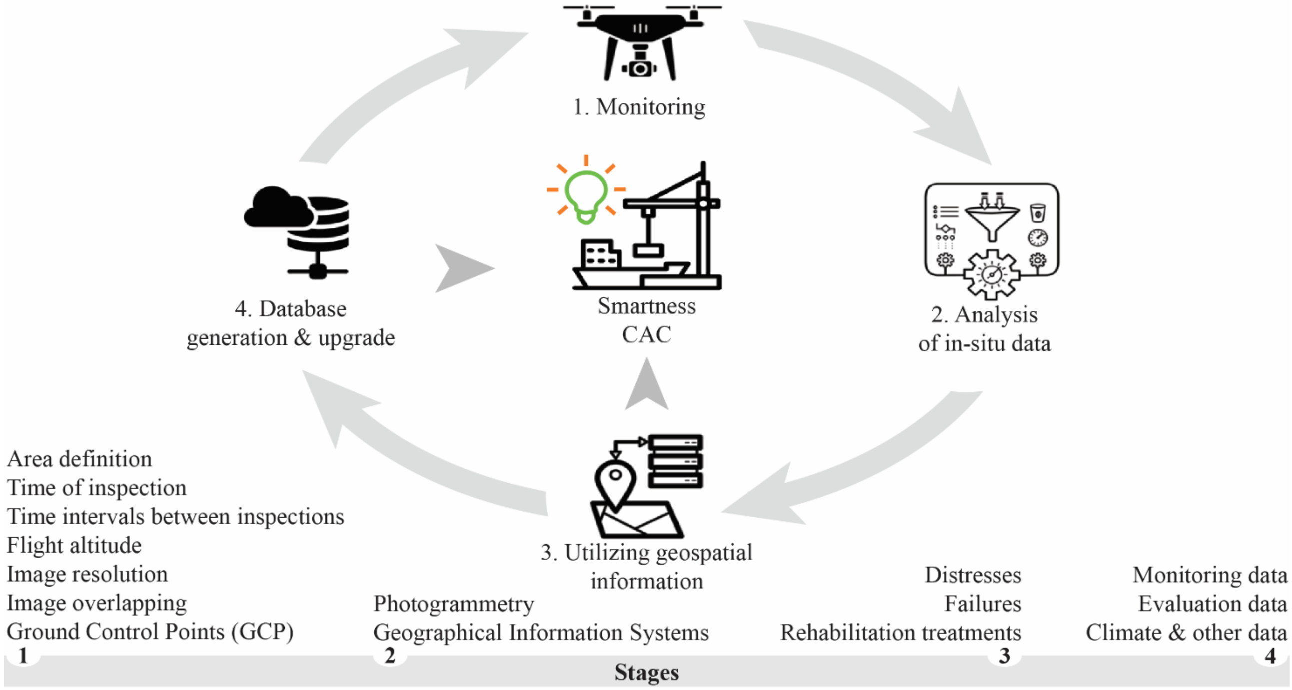

Figure 1. The framework of integrating monitoring to improve seaports' smartness and CAC.

Stage 2 entails the analysis of data collected during in-situ inspections. Following the monitoring procedure described in Stage 1 including a UAV system implementation, data analysis is achieved through image processing and photogrammetry (McGlone & Lee G., 2013) resulting in the generation of orthophotos which include all geospatial information of images acquired during the previous stage. It should be noted that Stages 1 and 2 of the proposed framework are inherently connected since analysis requirements (e.g. desired image quality) affect in-situ inspection characteristics (e.g. flight altitude). Orthophotos are included in Geographical Information Systems (GIS) software to acquire the full spectrum of the seaport's geospatial analysis.

Processing orthophotos with GIS tools is useful for a more detailed analysis of the seaport's condition (Stage 3, Fig. 1). In particular, distresses and failures are determined in a georeferenced manner, while periodical implementation of Stages 1 and 2 allows for the identification of any rehabilitation treatments examined during Stage 3.

The outputs of Stages 1-3 (i.e. raw and analyzed data) are included in an integrated database (Stage 4, Fig. 1). Taking into account that temporally evolved factors, such as aging and environmental conditions, affect seaport functional and structural performance (U.S. Department of Homeland Security, 2010), this database should be continuously updated. The update shall include not only data obtained during Stages 1-3, but also climate data that enables investigating seaport infrastructure behavior in relation to climate change, as well as building relationships for the connection between infrastructure condition evolution and climate conditions. Indeed, the database constitutes a promising tool for acting proactively to climate challenges based on existing failures, while simultaneously enhancing its smartness by guiding targeted "smart" maintenance practices (Molavi et al., 2020). Furthermore, emerging technologies, including the concept of producing Digital Twins for ports (Yao et al., 2021) can also incorporate the proposed monitoring framework as the main basis for their development.

2.2. Case study

The Greek seaport of Lavrio is located in south-eastern Attica, Greece (37º42´44″N, 24º3´25″E) and is a seaport of international interest (Government Gazette, 2007). Lavrio seaport serves a wide range of activities (https://oll.gr/en/). Due to its favorable configuration (i.e. well protected seaport very close to Cyclades), its proximity to both the Athens International Airport "Eleftherios Venizelos" and critical nodes of the national supply chain (e.g. "Thriasio" logistic hub), as well as its very good road access from / to Athens, Lavrio seaport has been explicitly proposed as an alternative to Piraeus and Rafina seaports for domestic ferry traffic. However, the undisrupted operation of the seaport led to its infrastructure deterioration, mainly due to loading forces and the effect of climatic phenomena.

Therefore, the combination of the seaport's strategic position along with the functional and structural degradation of its infrastructure constitutes a suitable basis for applying infrastructure monitoring techniques and validating Stages 1 and 2 of the framework described above (Fig. 1). Three in-situ inspections (ISI) were undertaken until the drafting of the current paper at Lavrio seaport (Table 1), since the ongoing research towards a holistic and effective monitoring system for seaports developed by LHW includes field monitoring performed twice-a-year.

Table 1. In-situ inspections' program.

ISI-no	ISI - Date
ISI-1	2020-02-10
ISI-2	2020-09-04
ISI-3	2021-02-10

Field measurements were conducted at the ferry-domestic and cruise domain including the windward breakwater through the use of a UAV (DJI series) with an integrated camera (model L1D-20c) of 5472x3648 resolution. Eight Ground Control Points (GCP) were determined within the area under investigation to ensure accuracy for the georeferencing process. The altitude of the flight was approximately 50 m for the first two inspections (ISI-1 and ISI-2) and approximately 75 m for the last one (ISI-3) due to flight limitations imposed by vessels' and buildings' height. In-situ data was analyzed with the Agisoft Metashape software (Professional edition, version 1.6) (Agisoft LCC, 2020).

3. Results

The three inspections (ISI-1, ISI-2 and ISI-3) presented in the present paper (Table 1) include data collection with UAV image capturing, as well as video recording as a pilot testing of UAVs' capabilities. Fig. 2 shows the results of the photogrammetry processing for the inspection ISI-2 in September 2020, illustrated with the use of GIS tools. The produced orthophoto of the seaport includes data stored in a raster format that represents surface infrastructure condition. In this context, every element on the orthophoto is georeferenced.

Figure 2. Orthophoto of the domestic ferry and cruise domain including the windward breakwater of Lavrio port (ISI-2).

The information obtained by each in-situ inspection is both spatial and temporal (Fig. 3). Spatial information refers to surface distresses, such as concrete cracking or joints defects (Fig. 3A), as well as to rusty elements of the structure and/or crack depth (Fig. 3B). This information is necessary to adopt CAC approaches, since climate change affects existing infrastructure condition. Fig. 3B demonstrates a screenshot of the video recorded during a pilot UAV flight along the windward breakwater, performed close to the vertical quay wall. The outcome of this flight showed that video recording was proved to be a promising process for condition investigation of the non-surface structure elements that are above the sea level, however without providing georeferenced information.

Finally, as far as the temporal information is concerned, comparing the orthophotos of each inspection can provide identification of infrastructure changes. Fig. 3C depicts, with chronological order from left to right, (from ISI-1 to ISI-2 and ISI-3) the downgrade of the armour layer (i.e. orange arrow) occurred during the time interval of the three inspections in position C (Fig. 2). Repetition of the entire process at specific time intervals is necessary for the accuracy of the reported alterations. Therefore, continuous and up-to-date monitoring evaluation is required, to identify the reason of the downgrade, investigate a potential link with climate change issues and propose measures that will enhance seaport CAC.

Therefore, UAV monitoring approaches including both image capturing and video recording hereto presented provide useful information for condition assessment of the surface seaport infrastructure and the sub-structures above the sea level. This information are intended to be combined with and complemented by other modern monitoring techniques and methods (e.g. 3-D camera and Remotely Operated Vehicle - ROV) in order to complete the integrated seaport monitoring system proposed by LHW for smart ports capable to face future challenges of climate change.

4. Conclusions

This paper proposes a comprehensive framework for integrating monitoring approaches of seaport infrastructure that enables addressing challenges related to current issues such as seaport's smartness and CAC. Georeferenced output resulting from in-situ data analysis, along with environmental and climate data can be inserted into coherent and informative databases. Therefore, both spatial and temporal information is obtained for the assessment of surface and above-water condition of the waterfront infrastructure. The results are particularly important for policy-makers who wish to proactively undertake seaport management actions to achieve adaptation to climate change and enhance seaport smartness. Further research is needed to include additional monitoring equipment, smartness indices as well as vulnerability indicators.

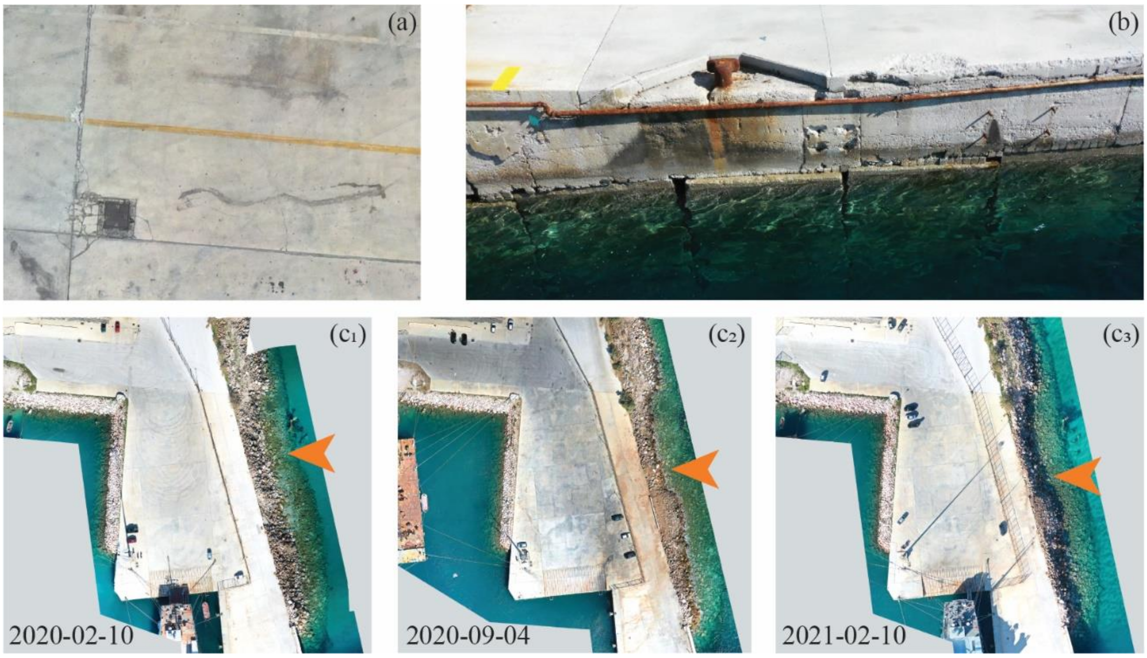

Figure 3. Information obtained by UAV monitoring approaches: (a) surface distresses (e.g. concrete cracking, joints defects - *location A of Fig.2*), (b) rusty elements of the structure and crack depth - *location B of Fig.2*, (c) armour layer downgrade during the time interval of the three inspections (c_1:ISI-1, c_2:ISI-2, and c_3: ISI-3) - *location C of Fig.2* .

References

Achillopoulou D.V., Mitoulis S.A., Argyroudi, S.A. and Wang Y. (2020), Monitoring of Transport Infrastructure Exposed to Multiple Hazards: A Roadmap for Building Resilience, *Science of The Total Environment*, **746**.

Agisoft LLC (2020), Agisoft Metashape User Manual Professional Edition, Version 1.6.

ASCE (2015), *Waterfront Facilities Inspection and Assessment*, Reston, Virginia: American Society of Civil Engineers.

Government Gazette (2007), Ports Classification, No. 8315.2/02/07, **B** (202) (in Greek).

IMO (2012), International Shipping Facts and Figures – Information Resources on Trade, Safety, Security, Environment, International Marine Organization, IMO Maritime Knowledge Center.

IPCC (2014), Summary for Policymakers, In *Climate Change 2014: Impacts, Adaptation and Vulnerability*, Cambridge University Press.

Izaguirre C., Losada I.J., Camus P., Vigh J.L. and Stenek V. (2021), Climate Change Risk to Global Port Operations. *Nature Climate Change*, **11**, pp. 14–20.

Kim I.H., Jeon H., Baek S.C., Hong W.H. and Jung H.J. (2018), Application of Crack Identification Techniques for an Aging Concrete Bridge Inspection Using an Unmanned Aerial Vehicle, *Sensors*, **18** (1881).

McGlone J.C. and Lee G.Y.G. (2013). *Manual of Photogrammetry* (6th ed.), Bethesda, Md.: American Society for Photogrammetry and Remote Sensing.

Molavi A., Lim G.J. and Race B. (2020), A Framework for Building a Smart Port and Smart Port Index, *International Journal of Sustainable Transportation*, **14** (9), 686-700.

Ng A.K.Y., Becker A., Cahoon S., Chen S.L., Earl P. and Yang Z. (2016), *Climate Change and Adaptation Planning for Ports* (1st ed.), London and New York: Routlege, Taylor & Francis Group.

PortTechnology (2016), What is a Smart Port? Retrieved from https://www.porttechnology.org/news/what_is_a_smart_port.

Rajabi A., Saryazdi A.K., Belfkih A. and Duvallet, C. (2018), Towards Smart Port: An Application of AIS Data, *IEEE 16th International Conference on Smart City*, 28-30 June, United Kingdom, 1414-1421.

Stein M. (2018), Integrating Unmanned Vehicles in Port Security Operations: An Introductory Analysis and First Applicable Frameworks, Ocean Yearbook, pp. 556-582.

U.S. Department of Homeland Security. (2010), *Aging Infrastructure: Issues, Research, and Technology*, Buildings and Infrastructure Protection Series.

Yao H., Wang D., Su M. and Qi Y. (2021), Application of Digital Twins in Port System, Journal of Physics: Conference Series, **1846**.

Yu H., Yang W., Zhang H. and He W. (2017), A UAV-based Crack Inspection System for Concrete Bridge Monitoring, *2017 IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, TX, USA, pp. 3305-3308.