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ACOUSTIC CAMERAS MEASUREMENTS OF MOVING CARGO SHIPS IN THE PORT OF LIVORNO

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Commercial ports, characterized by intense human activity, are susceptible to elevated noise levels, with ships being significant contributors to the complex acoustic environment. During ship manoeuvres, specific port zones are directly exposed to noise, potentially impacting both workers and nearby residential areas. The CLASTER project, a European research initiative, is dedicated to enhancing the sustainability of commercial ports by contributing to the reduction of acoustic pollution in the Maritime cooperation space. This study, conducted within the CLASTER project context (RUMBLE dataset), presents a case study of Livorno City's port in Italy, employing an innovative approach utilizing Acoustic Camera technology. The implementation of this measurement technique proves beneficial in characterizing and monitoring port noise, especially considering challenges posed by the large dimensions of ships, the sparse location of various noise sources on ships, and the dynamic movement of those sources during ship manoeuvres. We identify and analyse diverse noise sources during the pass-by of various cargo ships, including auxiliary propulsion systems, ventilation, and exhaust. Given the global significance of ports in commerce and the proximity of residential areas in some Mediterranean cities to port zones, understanding and mitigating these noise sources assumes critical importance.

Keywords: acoustic camera, beamforming, noise measurements, port noise, ship noise

1. Introduction

In the context of globalized modern era, freight global shipping plays a pivotal role, with its volume consistently on the rise. Sea shipping, primarily driven by cost considerations, stands out as the dominant mode of freight transportation, accounting for approximately 80% of all global trade [1]. Despite the challenges posed by the COVID-19 pandemic and other global political issues in recent years, the volume of global maritime trade has continued to expand. According to the latest United Nations report [2], in 2021, ships transported 1.95 billion metric tons of freight. This growth in seaborne trade is closely linked to the increasing capacity of the global merchant fleet, which has grown by 43% between 2013 and 2021.

Over the last decade, dry cargo, particularly containers, has been the driving force behind more than 90% of the growth in embarked volumes. The freight journey involves multiple stages, resulting in a wide array of associated activities both at sea and on land. Within terminals and docks, goods undergo frequent handling and shifting for organizational and logistical purposes. Considering that ports do not just accommodate container terminals, but they also handle bulk unloading areas, roll-on/roll-off (RO-RO) operations, and passenger movements, the sheer number of operations, machinery, and vehicles operating day and night within a port is enormous [3].

Consequently, the acoustic landscape within port areas is inherently complex, characterized by a multitude of simultaneous noise sources emitting from various sources, including ships, heavy machinery, trains, and industrial equipment. As expected, noise disturbance and complaints have recently emerged in ports where residential areas are located in close proximity to the port [5-9]. Therefore, increased attention is needed from the scientific community to prevent noise exposure. This includes noise mapping and subsequent mitigation efforts. These targets necessitate a thorough acoustic characterization of port sources, a task that presents its own set of complexities and for which only recently studies emerged, also producing measurements guidelines [10-20].

However, the complexity poses considerable difficulties for traditional acoustical measurement methods, particularly when dealing with large vessels. The dynamic nature of port operations further complicates matters, making it challenging to isolate specific noise sources and accurately assess their impact. Conventional noise monitoring techniques, typically reliant on omnidirectional microphones [21, 22], often fail to provide comprehensive insights due to their inability to discern individual sources amidst the ambient noise. Additionally, accessing certain noise sources for direct measurement is often impractical or unsafe, further limiting the effectiveness of traditional methods. To overcome these limitations, innovative technologies such as Acoustic Cameras, based on beamforming techniques [23], are under investigation as valuable tools for characterizing the intricate soundscape of ports [24]. By harnessing advanced sound analysis algorithms and visual imaging techniques, Acoustic Cameras offer a unique capability to identify, analyse, and visualize noise sources in real-time. Recent applications of Acoustic Cameras have yielded valuable support in investigating the spatial distribution of noise sources and their contribution to overall acoustic pollution for both the arrival/departure of vessels and loading/unloading port activities, or inside ships [25-28].

The present work introduces a case study performed in the Port of Livorno within the framework of the Claster project. A pair of different Acoustic Cameras and a sound level meter were simultaneously used to measure pass-by of cargo ships in Livorno Port, Italy. This preliminary analysis is aimed at underlying the difficulties and actual criticalities in such innovative measurements. The results would be a starting point for future deeper studies that will boost ship's airborne sound characterization and beamforming applicability. Moreover, the work reports additional data on the noise sources associated with a common ship pass-by, that would support the community and decision makers in targeting mitigation strategies to minimize the impact of port noise on surrounding communities.

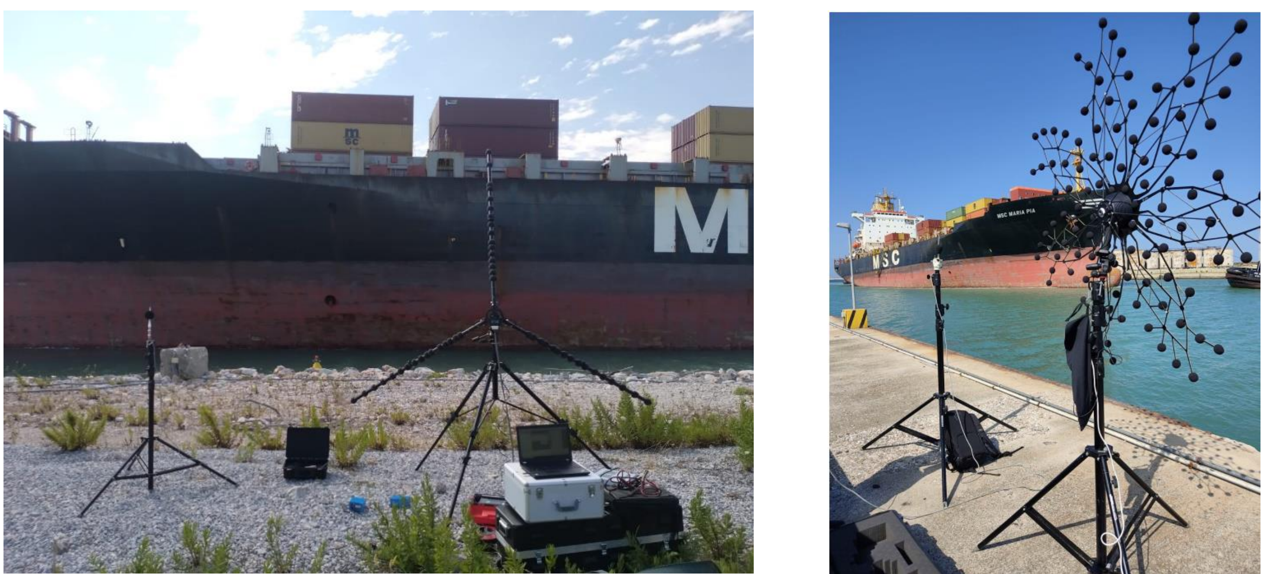
2. Methods

The pass-by of the cargo ship (MSC Maria Pia) when arriving to the Livorno's port was the main measurement scenario studied. An auxiliary carrier ship is used to move the big cargo ship through the channel. Two measurement stations were located at each side of the main channel in the Livorno port. Each station with an acoustic camera registering simultaneously the passage of a cargo ship, see figure 1.

Figure 1: Livorno port's map. (a) Channel; (b) Measurement stations P1 and P2.

Measurement station 1 (P1): The Acoustic Camera has a 48-microphone array, Fig. 2(a). Signals sampled at 48 kHz in a frequency range from 66 to 13 kHz.

Measurement station 2 (P2): The Acoustic Camera has a 112-microphone array, Fig. 2(b). Signals sampled at 48 kHz from 150 Hz. Both Acoustic Cameras (P1 and P2) were placed within view of the sources at a minimum distance of 60 m, 2 m height, and oriented directly to the channel.



(a) (b)

Figure 2: Measurement stations. (a) P1; (b) P2.

3. Results

The evolution of the perceived sound level, some coloured acoustic picture, frequency spectra and spectrograms for each measurement stations are presented in separated.

3.1 Measurements from P1

The time history of the perceived sound levels in the measurement station P1 is presented in Figure 3. During the measurement the mean perceived sound level was 83.2 dB (64.5 dB(A)). The perceived level on the station is directly related to the distance to the ship.

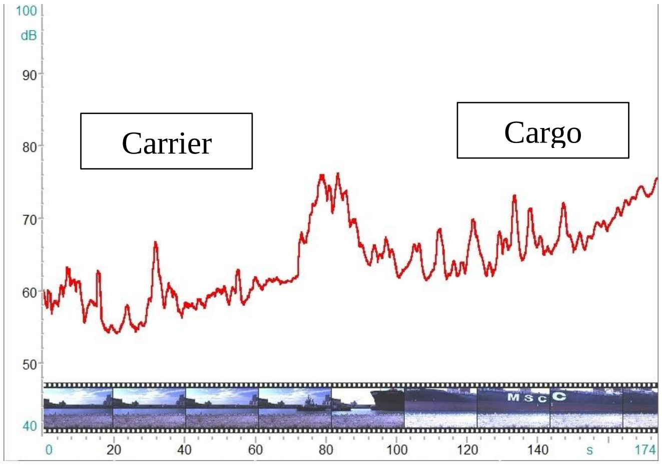


Figure 3: Time history, data in dB(A). Measurement station P1.

The location of the main sources could be obtained by using the acoustic beamforming algorithms. Some coloured acoustic pictures are presented in Fig. 4, frequency range: 66 Hz -13 kHz (the ship is moving from right to left side). One relevant source is detected in the auxiliary carrier ship that becomes the primary source while the carrier is near to the station, see Fig. 4(a). When the big cargo ship comes closer some additional sources can be detected for example noise coming from the main board is presented in Fig. 4(b).

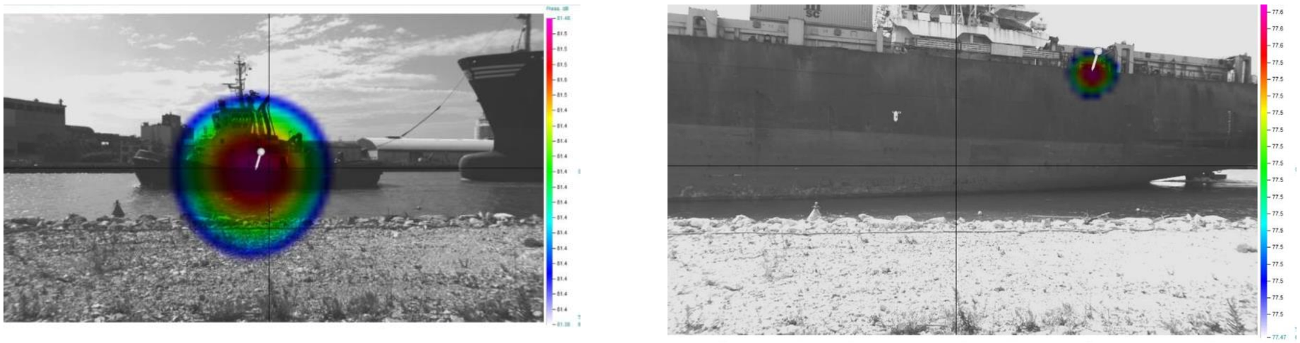


Figure 4: Coloured acoustic pictures. (a) Auxiliary carrier; (b) activity on the main board. Measurement station P1.

Figure 5 presents spectral information. As can be figure out high levels reaching 80 dB in the low frequencies characterize the pass-by of those big cargos, a kind of *rumble* noise. The spectrogram shows the acoustical fingerprint of the carrier near the 80 s of the measurement, after that becomes masked by the noise coming from different sources in the cargo from this side on the main board.

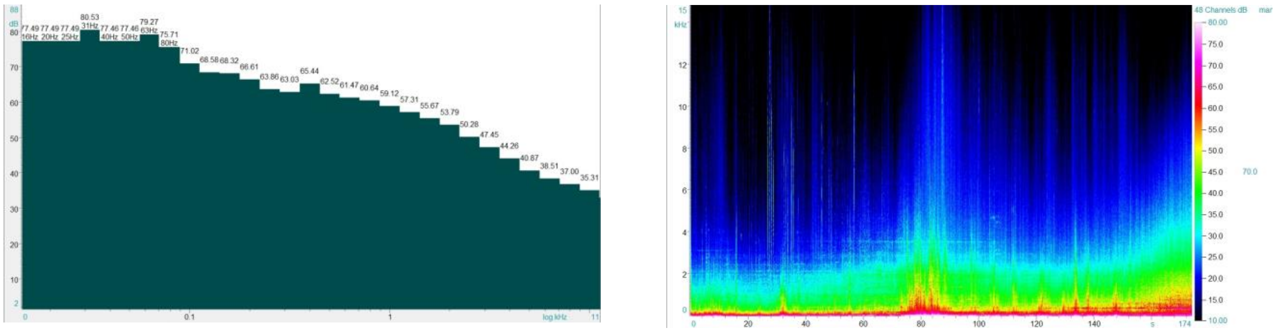


Figure 5: (a) Spectrum; (b) linear spectrogram. Measurement station P1.

3.2 Measurements from P2

The time history of the perceived sound level in the measurement station P2 is presented in Figure 6. During the measurement the mean perceived sound level was 62.9 dB(A).

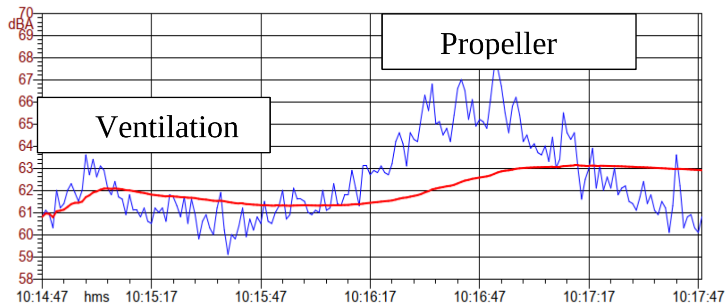
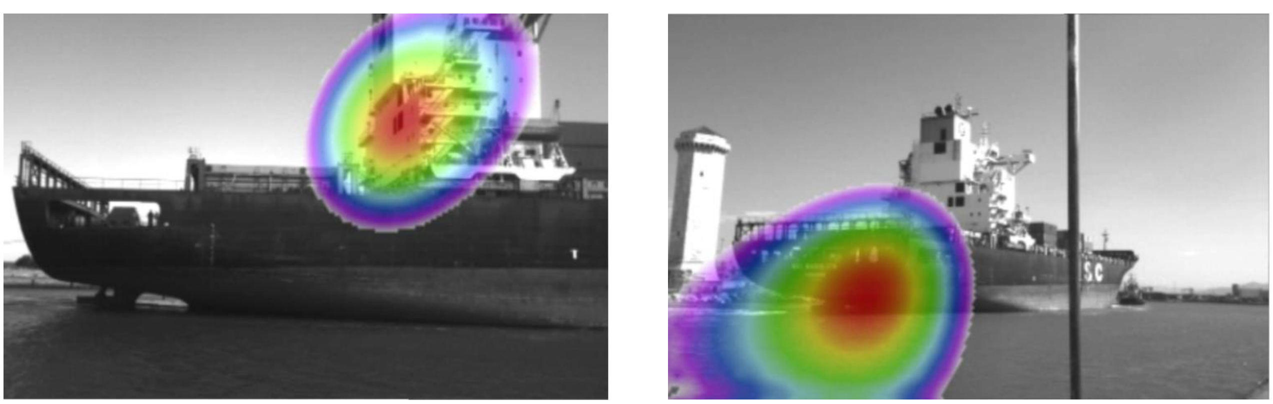


Figure 6: Time history, data in dB(A). Measurement station P2.

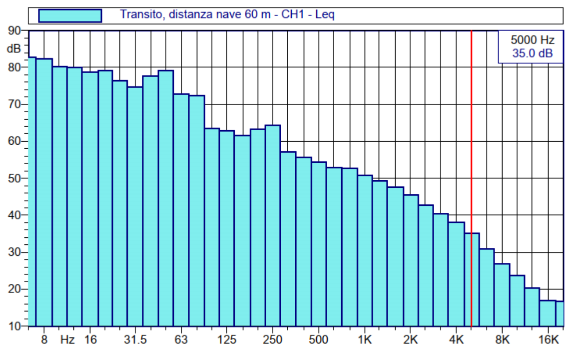
The location of the main sources could be obtained by using the acoustic beamforming algorithms. Some coloured acoustic pictures are presented in Fig. 7, frequency range: 400 - 630 Hz. (the ship is moving from left to right side). One relevant source is detected near the main exhaust, consist of ventilation outlets, see Fig. 7(a). When the big cargo ship has passed the main propeller/motor is detected as an additional source, see Fig. 7(b).



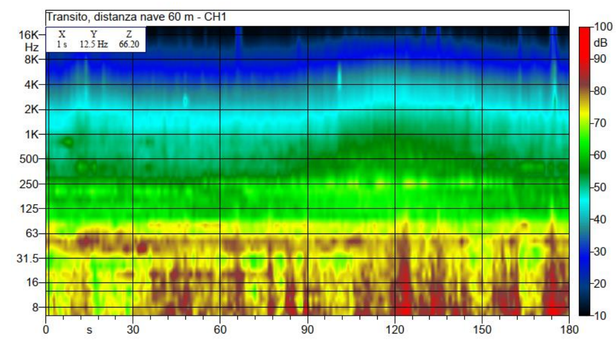
(a) (b)

Figure 7: Coloured acoustic pictures. (a) Ventilation system; (b) main propeller-motor. Measurement station P2

The spectral characteristics of the noise are presented in Fig. 8. As can be seen also from this side high sound Levels (>dB) at low frequency has been observed. The Sound coming from the motor has a higher content of low frequencies than the noise coming from the ventilation system, as can be seen in the spectrogram shown in fig. 8(b).



(a)



(b)

Figure 8: (a) Spectrum; (b) linear spectrogram. Measurement station P2.

4. Conclusions

In this study, a case study of the pass-by of cargo ships in Livorno Port was conducted using Acoustic Camera technology within the framework of the Claster project. The analysis aimed to characterize and monitor port noise, considering the challenges posed by large ships, the sparse distribution of noise sources, and their dynamic movements during manoeuvres. The main observations from this study are as follows:

- Through the utilization of the Acoustic Camera, various noise sources were identified during the pass-by of a cargo ship, including auxiliary carriers, main propulsion systems, and ventilation outlets.
- The analysis revealed high sound levels, particularly in low-frequency bands. This "rumble" sound poses potential challenges for noise mitigation strategies in port areas.

Application of Acoustic Camera as a measurement technology proved its value in enhancing our understanding of port noise dynamics and identifying areas for intervention to mitigate its effects. However the present analysis was mainly qualitative, addressing a complete quantitative approach using the Acoustic Camera is an open problem and the subject of ongoing research. This study provides valuable insights for the development of effective mitigation strategies aimed at reducing the impact of ship noise on the port's soundscape and surrounding areas. Considering the global significance of ports in commerce and their proximity to residential areas, addressing port noise pollution is of critical importance for sustainable development of port cities.

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REFERENCES

1 Ocean shipping worldwide - statistics & facts. [online] https://www.statista.com/topics/1728/ocean-shipping/#topicOverview

2 United Nations. Review of Maritime Transport-2023; *United Nations Conf. Trade Develop*, New York, NY, USA, (2023).

3 Steenken, D., Voß, S., and Stahlbock, R. Container terminal operation and operations research-a classification and literature review, *OR spectrum*, **26**, 3-49, (2004). https://doi.org/10.1007/s00291-003-0157-z

4 Licitra, G.; Bolognese, M.; Palazzuoli, D.; Fredianelli, L.; Fidecaro, F. Port noise impact and citizens' complaints evaluation in RUMBLE and MON ACUMEN INTERREG projects, *Proceedings of the 26th International Congress on Sound and Vibration*, Montreal, QC, Canada, 7–11 July (2019).

5 Murphy, E.; King, E.A. An assessment of residential exposure to environmental noise at a shipping port, *Environ. Int.*, **63**, 207–215 (2014). https://doi.org/10.1016/j.envint.2013.11.001

6 Bakogiannis, K., Argyropoulos, D., Dagres, P., Fotiou, N., and Cambourakis, G. Residential exposure to port noise, mapping and sources identifications: a case study of Pireaus, Greece, *Proceedings of the 22nd International Congress on Sound and Vibration*, Florence, Italy, (2015).

7 Paschalidou, A.K.; Kassomenos, P.; Chonianaki, F. Strategic Noise Maps and Action Plans for the reduction of population exposure in a Mediterranean port city, *Sci. Total Environ.*, **654**, 144–153, (2019). https://doi.org/10.1016/j.scitotenv.2018.11.04

8 Čurović, L., Jeram, S., Murovec, J., Novaković, T., Rupnik, K., and Prezelj, J. Impact of COVID-19 on environmental noise emitted from the port, *Sci. Total Environ.*, **756**, 144147, (2021). https://doi.org/10.1016/j.scitotenv.2020.144147

9 Vukić, L., Peronja, I., and Glavinović, R. Multi-Faceted Analysis of Airborne Noise Impact in the Port of Split (I), *Journal of Marine Science and Engineering*, **10**(10), 1564, (2022). https://doi.org/10.3390/jmse10101564

10 Fredianelli, L., Bolognese, M., Fidecaro, F., and Licitra, G. Classification of Noise Sources for Port Area Noise Mapping, *Environments*, **8**(2), 12, (2021). https://doi.org/10.3390/environments8020012

11 Fredianelli, L., Gaggero, T., Bolognese, M., Borelli, D., Fidecaro, F., Schenone, C., and Licitra, G. Source characterization guidelines for noise mapping of port areas. *Heliyon*, **8**(3), (2022). https://doi.org/10.1016/j.heliyon.2022.e09021

12 Witte, J. Noise from moored ships. *INTER-NOISE and NOISE-CON Congress and Conference Proceedings*; Institute of Noise Control Engineering: Reston, VA, USA, (2010).

13 Di Bella, A., and Remigi, F. Prediction of noise of moored ships, *Proceedings of Meetings on Acoustics ICA2013* (Vol. 19, No. 1, p. 010053). Acoustical Society of America, June, (2013)

14 Badino, A., Borelli, D., Gaggero, T., Rizzuto, E., and Schenone, C. Acoustical impact of the ship source, *Proceedings of the 21st International Congress on Sound and Vibration*, Beijing, China, 13–17 July (2014).

15 Badino, A., Borelli, D., Gaggero, T., Rizzuto, E., and Schenone, C. Noise emitted from ships: Impact inside and outside the vessels, *Procedia-Soc. Behav. Sci.*, **48**, 868–879, (2012). https://doi.org/10.1016/j.sbspro.2012.06.1064

16 Di Bella, A., Remigi, F., Fausti, P., and Tombolato, A. Measurement methods for the assessment of noise impact of large vessels, *Proceedings of the 23rd International Congress on Sound and Vibration*, Athens, Greece, 10–14 July (2016).

17 Bernardini, M., Fredianelli, L., Fidecaro, F., Gagliardi, P., Nastasi, M., and Licitra, G. Noise assessment of small vessels for action planning in canal cities, *Environments*, **6**(3), 31(2019). https://doi.org/10.3390/environments6030031

18 Fredianelli, L., Nastasi, M., Bernardini, M., Fidecaro, F., and Licitra, G. Pass-by characterization of noise emitted by different categories of seagoing ships in ports, *Sustainability*, **12**(5), 1740, (2020). https://doi.org/10.3390/su12051740

19 Nastasi, M., Fredianelli, L., Bernardini, M., Teti, L., Fidecaro, F., and Licitra, G. Parameters Affecting Noise Emitted by Ships Moving in Port Areas, *Sustainability*, **12**(20), 8742, (2020). https://doi.org/10.3390/su12208742

20 Schiavoni, S., Baldinelli, G., Presciutti, A., and D'Alessandro, F. Acoustic mitigation of noise in ports: an original methodology for the identification of intervention priorities, *Noise Mapping*, (2022). https://doi.org/10.1515/noise-2022-0159

21 Bolognese, M., Carpita, S., Fredianelli, L., and Licitra, G. Definition of key performance indicators for noise monitoring networks, *Environments*, **10**(4), 61, (2023). https://doi.org/10.3390/environments10040061

22 Borelli, D., Gaggero, T., Pallavidino, E., Schenone, C., Waffo Kamdem, E. L., and Yousseu Njiotang, C. A. Possible solutions for port noise monitoring, *Proceedings of the 26th International Congress on Sound and Vibration*, Montréal, QC, Canada, July (2019).

23 Licitra, G., Artuso, F., Bernardini, M., Moro, A., Fidecaro, F., and Fredianelli, L. Acoustic beamforming algorithms and their applications in environmental noise, *Current Pollution Reports*, **9**(3), 486-509, (2023). https://doi.org/10.1007/s40726-023-00264-9

24 Bocanegra, J. A., Borelli, D., Gaggero, T., Rizzuto, E., and Schenone, C. A novel approach to port noise characterization using an acoustic camera, *Science of The Total Environment*, 808, p. 151903, (2022). https://doi.org/10.1016/j.scitotenv.2021.151903.

25 Fredianelli, L., Bernardini, M., Del Pizzo, L. G., Tonetti, F., Fidecaro, F., and Licitra, G. Acoustic source localization in ports with different beamforming algorithms, Proceedings of Internoise, **265**(5), 2702–2711, Feb. (2023), doi: 10.3397/IN_2022_0377.

26 Kanka, S., Fredianelli, L., Artuso, F., Fidecaro, F., and Licitra, G. Evaluation of Acoustic Comfort and Sound Energy Transmission in a Yacht, *Energies*, **16**(2), 808, (2023). doi: 10.3390/en16020808.

27 Bocanegra, J. A., Borelli, D., and Schenone, C. Acoustic Camera Ship Noise Measurements During Docking Operations: A Case Study in Genoa, *Proceedings of the 28th International Congress on Sound and Vibration*, (2022). [Online]. Available: https://iiav.org/content/archives_icsv_last/2022_icsv28/indexbd58.html?va=viewpage&vaid=410

28 Bocanegra, J. A., Borelli, D., Pallavidino, E., and Schenone, C. Noise Sources Evaluation Of A Ro-Pax Ship By Means Of An Acoustic Camera: A Case Study In The French City Of Nice, *Proceedings of the 29th International Congress on Sound and Vibration*, (2023). [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85170650499&partnerID=40&md5=40e12c888fb81b1fe781fa9a09b61dff