The necessities and the perspectives of the monitoring/surveillance systems for multi-risk scenarios of urban areas including COVID-19 pandemic

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Abstract

The present contribution deals with the necessities related to the monitoring and surveillance of the urban areas against multi risk scenarios furtherly worsened by Covid-19 pandemic. In response to these issues, a strategy based on the integration of remote sensing technologies, in-situ and pervasive sensing and advanced data processing and correlation is proposed. This strategy can enable a multi-scale monitoring/surveillance, ranging from the global "city and territory" scale to the single areas, pervasive and having the same positive impact for the richer areas and the periphery of the city inhabited by the more vulnerable population. An "example" of the proposed strategy is presented by referring to the monitoring of transport infrastructures, in particular by focussing on bridges. Finally, a proof of the effectiveness of the remote and in-situ sensing technologies is presented by showing a demonstration activity at Basento Viaduct in Potenza (Basilicata region, Southern Italy).

Keywords: Urban areas; resilience; monitoring and surveillance systems; early warning; quick damage assessment

1. Introduction

COVID-19 pandemic has now revolutionized completely our life and socio-economic relationships at individual and public level. This is particularly true for the urban areas and cities that have tried to manage their immediate response to the COVID-19 pandemic and, at the same time, are rethinking to the planning and managing resources. The aim is not only to protect vulnerable people from immediate threats but also to improve resilience for facing multi-risk scenarios, where the effect of the local specific hazards are combined with worldwide challenges, such as climate change and pandemic events [1].

Therefore, cities are in front of the necessity of rethinking their urban policies to strengthen their risk preparedness and response capabilities and become more resilient, smarter, greener and inclusive. The concept of the inclusivity is becoming crucial since the COVID pandemic event has shown how the most vulnerable population is the one living at the poorly and densely populated areas, where the level of social and physical services is often not adequate. In this frame, liveable city should be shaped in

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future according to the “15-minute city” concept that states how city functions should have core services and functions being within a 15-minute radius, which has clear advantages in terms of liveability [2].

By considering the necessities and perspectives related to the monitoring and surveillance of the urban areas, three aspects to be focused. The first one is that resilience must be addressed as a whole due to the fact that the services and networks are interconnected and interdependent (i.e. health, transport, energy and water distribution, air quality. protection from extreme weather events,..). The main consequence of these interconnections is that the “black swan” crisis may become a realistic possibility. The second aspect is that resilience needs monitoring both of the building/infrastructure and of the site where it is located, and that without monitoring, it is impossible to define correctly the interventions to be done and their prioritizations. The third aspect regards the development of new monitoring systems made possible not only by the improvement of earth observation technologies, positioning and navigation and ICT technologies and their integration, but also by new concepts of operation, such as the citizen as a sensor and “sensors not sensors” (i.e., sensors that give useful information for monitoring even if they were not designed with such an end). As a consequence, the amount of data to be processed increase exponentially taking advantage of ICT (HPC, Big data, IoT, AI) development.

In the just mentioned frame, one of the key elements is the development of strategies able to enable monitoring and surveillance capabilities for the service networks, critical infrastructures and the built environment. At the sight of the above considerations, these capabilities should be multi-scale, ranging from the global “city and territory” scale to the single areas, pervasive and have the same positive impact for the richer areas and the periphery of the city inhabited by the more vulnerable population. Of course, this challenge has to comply also with a social and economic sustainability and demands for strategies based on the smart integration of technological tools, such as remote sensing technology, in-situ and pervasive sensing, big data and AI, just to quote few of them.

2. The main features of a monitoring/early warning/quick damage assessment system

In this contribution, as an application of the above stated concept, we deal with the development of systems for early warning, monitoring and quick damage assessment of the built environment and critical infrastructures and networks [3], where the integration is the key factor for achieving several aims such as;

- The development of a monitoring platform able to integrate different kind of sensing/diagnostics technologies (including new concept of operation, such as the citizen as a sensor and sensors no sensors) with Spatial Data infrastructure and ICT architectures;
- The capability to assimilate monitoring data and indicators coming from the sensing into civil engineering or mobility models with the end to assess the loss of performance of the structure or the transportation system. This is crucial to identify actions and strategies for an effective and economically sustainable management of the infrastructure;
- The possibility to couple current monitoring with early warning and quick damage assessment capabilities, then to follow remedial solutions in crisis situations;
- The use of AI and Big Data for the monitoring and behaviour prediction of the urban areas and embedding territory for the present status and future risk scenarios (climatic, pandemic, hydrogeological, seismic…).

In particular, monitoring and understanding connection between public transportation mobility during a sanitary crisis versus pandemic propagation models could pave the way to more resilient urban areas toward sanitary crisis such as COVID-19 one. It could favour new strategies to help in the optimisation of the public transportation service to minimize pandemic influence. Furthermore, arrival of different automated vehicles in urban areas could provide additional and frequently updated information about their health status.

The sustainability is not only ensured by a smart use of all the technological tools but also, more important, by the economic savings related to the prioritization and efficient planning of the maintenance interventions and the feeling of the most vulnerable population to be included in the social life.

From a technological point of view, the conceptual scheme to be adopted can be devised to deal with the following challenges:

(i) Definition of the most suitable sensing strategy for each area of the city, depending on type, localization, extension and severity of hazard and degradation/damage scenario;
(ii) Exploitation and integration of different non-invasive sensing techniques and sensor set-ups, to monitor the areas and single structures during their life cycle. In this context, the adoption of simple (cost effective) but pervasive sensing systems directly in the houses of the population might be important also for improving the feeling of protection and inclusivity;
(iii) Selection of the most suitable data processing technique, modelling approach and method of analysis, included AI and Big Data, for the different defect/degradation/damage effects in multi-risk present and future scenario. This is important to plan the maintenance interventions and provide support in shaping the urban planning;
(iv) Real-time assessment of the levels of risk of the structure regarding the attainment of different performance levels under service and ultimate conditions.

In the implementation of this system/approach, several critical aspects have to be considered to ensure the performance optimisation. First, the exploitation of non-redundant sensing configurations and set–ups is fundamental to acquire data ready to be used. Secondly, results derived from data processing should be presented via web, using an adequate and easy to read graphical representation, in an integrated common framework to achieve a rapid and comprehensive evaluation of the health status of the area and of the single structures. Thirdly, different sensing techniques and/or sensor set-ups should be used for both monitoring the long-term degradation and performing quick damage assessment after crisis events. Furthermore, the possibility to embed the sensors directly in the design of the structure should be considered as a tool to follow the behaviour of the structure from the "time zero" of its lifecycle, thus monitoring the entire life cycle of the structure (included its response to extreme events).

Finally, such a system of systems could help in identifying mitigation solutions during crisis period. For instance, by acting at infrastructures level and adding to them new functionalities, as depollution capabilities (already tested for certain chemical species emitted by vehicles), is relevant to fight biological contaminants in pandemic situation.

3. An example of use of the integrated approach: the bridge monitoring

This section concerns with an example of specialization of the integrated approach/strategy for monitoring and diagnostics of transport infrastructures, in particular a bridge. According to the considerations of the above section, the system is modular and its degree of economic sustainability is managed through a series of protocols, which are articulated by levels of complexity for the observational capabilities. In this case, the technologies / analysis methodologies typical of civil engineering are coupled with remote sensing technologies for prompt and non-invasive investigation (also in terms of minimum traffic interruption).

A crucial aspect is the assimilation of monitoring results not only for the purpose of continuous assessment of the state of health (damage detection), but also for the aim of calibrating structural models to be used for assessing the vulnerability of the structure.

In addition, the system has to monitor also the territory in which the infrastructures are located in order to control the extent and characteristics of the forcing (seismic, hydrogeological, ...) that affect the infrastructures. Basically, site forcings play a key role in determining any critical issues and can have slow dynamics (subsidence, differential subsidence, slow sliding landslides) and fast dynamics (such as earthquakes). In the case of buildings / infrastructures located in seismic areas, the resilience depends not only on the seismic forcing but also on the local seismic response (amplification factor): two buildings located in the same seismic area, but one built on the rock and the other on ground flood will have completely different damage after a seismic event.

In addition, it is useful to monitor slow site dynamics (such as subsidence, slow-flowing landslides, differential settlements), because they can cause serious damage to the infrastructure even to its collapse. Therefore, the rapid diagnosis of the criticalities is necessary to start a quick extraordinary maintenance intervention. By summarising, an efficient monitoring strategy requires the monitoring not only of the building / infrastructure but also of the embedding territory.

Compared to the state of the art, the proposed system has the following advantages:

- The system is able to act a comprehensive monitoring of all the structure, unlike most systems operating today, which mainly look to local zones;
- The system monitors not only the infrastructure, but also the surrounding area to obtain information on forcing that can damage the infrastructure (especially if coupled with aging phenomena) such as loads and / or deformations caused by possible landslides, phenomena of local amplification of seismic waves; subsidence, differential settlements, etc.
- The system exploits inexpensive technologies at the first stages (levels) of diagnostics followed by more sophisticated technologies only in the advanced stages of monitoring.

The different levels of the observation and related technologies are detailed below.

LEVEL 0

The integration of the technologies shown in the table 1 allows to activate an almost entirely automated long-term monitoring and early warning strategy. This strategy is able to follow the life of an infrastructure continuously over time, by limiting at minimum the exploitation of personnel, just only to periodic inspections, and traffic interruptions. Therefore, this level is characterized by the use of technologies that require an extremely simplified logistics (minimum personnel intervention).

Level 0 provides information about: the deformation status of the structure and of the surrounding soil; the frequencies of structural vibration and on their possible variation over time (this parameter is an indicator of the damage of the structure); the status of damage/deterioration of the surfaces.

At this level, the interruption of the operation of the structure has almost zero probability.

Table 1. Technologies operating at Level 0

Technology	*Purpose*	*Observation scale*	*Notes*
Synthetic aperture radar on satellite platforms	Monitoring of deformations of infrastructures and of the territory (e.g. landslide areas) but also of the differential subsidence. Provides information on global forcing (territory and infrastructure).	Global (territory and infrastructure). Continuous over time.	Two types of observation: *Sentinel-1* with medium resolution scale; in this case the data is free and open. *COSMO SKYMED* with high resolution (tens of centimetres) and a cost for the acquisition and processing of images. *Satellite technologies are able to detect and follow subsidence phenomena, differential subsidence over time.*
Force balance triaxial accelerometer (single or very limited number of sensors) permanently installed on the structure	Vibration frequency of the bridge monitored continuously over time. When installed in sufficient numbers, it is possible to achieve information about	Single infrastructure. Continuous over time.	Solution with low cost and impact on the operations of the structure. It allows continuous monitoring of the state of the infrastructure. Particularly useful solution in the case of diagnostics of a large number of structures. *Accelerometer allows to record the trend of vibration frequencies over*

	the modal behaviour.		*time, which is an indicator of damage.*
Interferometric Radar	Determination of the vibration frequency and possibly info on the modal behaviour Provides information on the overall behaviour of the infrastructure	Single infrastructure Periodic or on demand inspection	Portable instrumentation capable of providing information in real-time. Of particular interest in crisis situations. It is a fast technology for measurements of many infrastructures in a short time *It has the same function as the accelerometer but allows measurement with portable instrumentation capable of operating remotely from the infrastructure.* *It is of interest when access to the infrastructure is not convenient or possible.*
Optical and infrared cameras on drones.	Analysis of the surfaces of the bridge (deck).	Single infrastructure Periodic or on demand inspection	In line with what are visual inspections, here we aim at the automation of this procedure that could be optimized with data processing strategies for the change detection of the bridge surfaces (for example variations in density and opening surface fractures, surface concrete alterations, bar oxidation, etc.) *Technologies capable of providing information on the surface state of the structure. They are an automated evolution of visual inspections.*

LEVEL 1

Based on the info achieved by Level 0, or also on request, Level 1 can be activated to deepen the information of level 0 and improving the spatial detail and knowledge of the structural elements.
Level 1 is activated when level 0 indicates the presence of criticality. This level is characterized by a more complex logistics. In few cases, the installation of accelerometers may require direct access to the structure with a consequent short interruption of traffic. The use of sensors on mobile vehicles does not require the interruption of traffic.
This level provides information on the modal behavior of the structure and therefore is able to detect, quantify and possibly localize the damage at the structural elements. The use of Ground Penetrating Radar (mainly at deck) allows at evaluating the damage and characterizing its type (oxidation of the reinforcement bars, alteration of the mechanical characteristics of the concrete, breakage of pre-stressing strands). Table 2 reports the technologies exploited in Level 1.

Table 2. Technologies operating at Level 1

Technology	Purpose	Observation scale	Notes
Use of accelerometers in their complete configuration (longitudinal and transverse arrays)	Modal analysis of the structure	Single infrastructure Periodic inspection	Instrumentation capable of providing information on the frequencies and modes of vibration of the structure. This measure is the evolution of the measure of the resonant frequency made at Level 0. In presence of critical cases or in cases of rapidly evolving situations, a continuous monitoring system can be envisaged consisting of several wired accelerometric sensors.
Seismic microtremor measurement sensors (seismometers / velocimeters)	Information on soil / infrastructure interaction	Single infrastructure Periodic inspection	In this way, it will be possible to obtain useful information on the soil / structure interaction and predict seismic amplification phenomena determined by the particular type of the soil.
Ground Penetrating Radar on mobile vehicle	Information on the internal state of the structure (asphalt layers, state of the rebars, internal fractures, carbonation of the surface layer, detachment of the concrete cover)	Single infrastructure Periodic Inspection	The analysis is focussed on the deck and does not require traffic interruption.
Optical and infrared cameras located on drones or mobile vehicle	Analysis of the state of the bridge surfaces.	Single infrastructure Periodic or on-demand inspection	Technologies capable of providing information on the surface state of the structure and on the degree of deterioration of the first layers of the structure due to water infiltrations.

LEVEL 2

This level is activated only on the basis of a critical situation detected at the two above levels. It consists of a detailed analysis of the state of the infrastructure for its individual structural elements. In this case, the logistical needs are significant, requiring the presence of staff and most likely the interruption of traffic. This level involves the use of technologies such as ground penetrating radar, electrical resistivity tomography, ultrasound to be operated with manual interventions and able to make a detailed investigation of single elements of the structure.

4. A proof of the effectiveness of the sensing technologies at the Basento Viaduct

A practical demonstration of the effectiveness of the integrated approach and of the technological effectiveness of the sensing technologies was carried at the test bed of the Basento Viaduct, which links

the Town of Potenza (at NW) to the Basentana highway (at SE) (figure 1 left). The bridge is formed by a reinforced-concrete shell lifting a reinforced box deck; the bridge is an infrastructure of high architectural value, which was designed and built under the supervision of the engineer Sergio Musmeci [4]. At Basento Viaduct, a large suite of sensors have been exploited /installed for the diagnostics and monitoring: Synthetic Aperture Radar(SAR); Distributed Optical Fiber (DOF) sensor; Infrared Termography by using cooled camera (COOLED IRT); Hyperspectral Spectroscopy; Infrared Termography by using uncooled camera (UNCOOLED IRT); Ground Penetrating Radar by using a mobile system (Mobile GPR); Ground Penetrating Radar by using a manual system (Manual GPR); Electrical Resistivity Tomography; Optical Displacement camera (ODM); Ground Based SAR (GB-SAR): Seismic Ambient Noise (SAN); Accelerometric Noise Measurements. (ANM); Holographic Radar by using the RASCAN-4/4000.
Sensor location (see figure 1 right), installation and measurements have been designed also with the aim to enable a data correlation.

Fig. 1. (left) Location of Musmeci bridge - aerial view; (right) Locations of sensors on the Musmeci Bridge - upper view.

Figure 2 depicts very briefly the richness of the sensing techniques exploited at Basento Viaduct with several related diagnostics outcomes.

SAR observation were carried out at very high resolution and permitted to point out that the bridge deformations are mainly associated to seasonal thermal dilations. The correlation of the *SAR* time series with temperature distribution is 0.99 whereas the standard deviation of the difference is 1.3mm [5].

DOF measurements were performed during several months and the results showed a strain peek at a distance of about two meter from the concrete pillar [6]. A detailed visual inspection have shown that at this position a small crack, not detected during the installation, was present in the concrete. The large extent of the peak measured by the optical fiber sensor can be explained by considering that the sensor has a spatial resolution of ≈ 1 m, so the highly localized strains consequent to crack opening are spatially averaged. Further analysis, thanks to environmental complementary measurements, have shown that the measured strain exhibits a very linear correlation with the temperature in the interval between 14-30°C.

GPR and IRT techniques coupled with adapted processing analysis were used to retrieve inner structure information [7, 8].

GB-SAR, ODM, ANM and SAN were exploited for frequency analysis of the vibration of the bridge and a good agreement between results was found. In particular, ANM, consisting in a suite of three 3-directional accelerometers, and SAN, consisting in a three-directional velocimeters, were placed on the shell and on the deck so to have a reliable benchmark for the other vibrational techniques, such as *GBSAR* [9] and *ODM*. The overall arrangement of sensors allowed at focusing on the observational effort on the three main elements of the bridge such as: the shell, the deck and the asphalt layer.

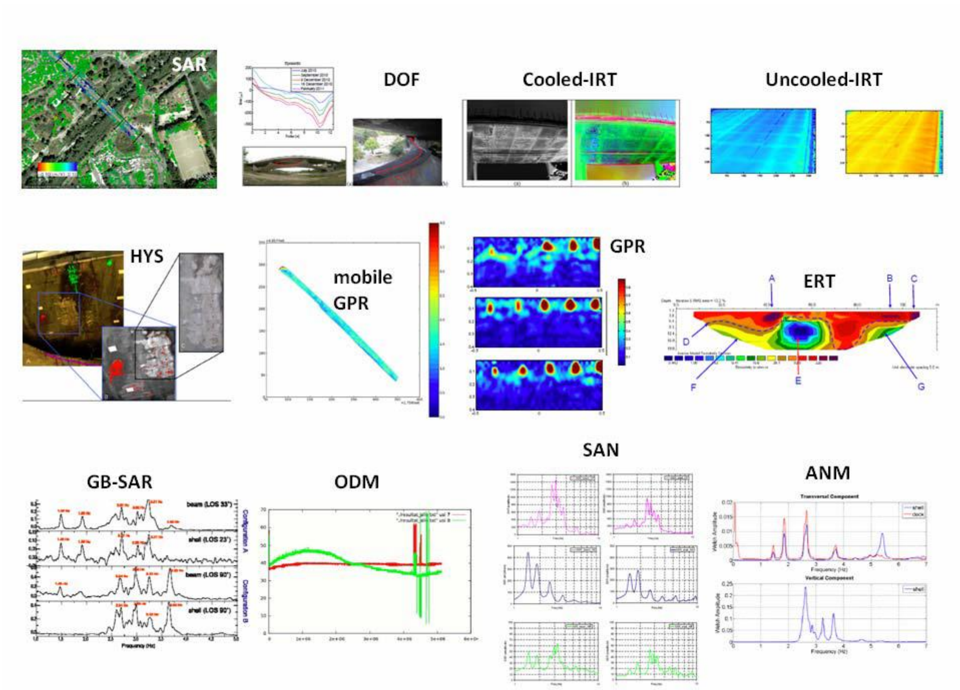

Fig. 2. Examples of the results obtained on the Basento Viaduct for each used technique. SAR: thermal dilatation coefficient mapping; DOF: strain distribution along the optical fiber; Cooled-IRT: thermal images of the bridge deck; Uncooled-IRT: thermal images of a bridge lane; HYS: Hyperspectral images of the bridge surface; mobile-GPR: depth-slice of the bridge asphalt layer; GPR: tomography of some reinforced concrete rebar; ERT:tomography of the foundation soil; GB-SAR: proper frequencies of vibration of single parts of the bridge; ODM: displacement of the bridge (red=sideways movement, green=up and down); SAN: vibrational mode of the bridge in terms of spectral ratio; ANM: fundamental frequencies of the bridge.

ANM provided information on the dynamic characteristics of the bridge (first 5 eigenfrequencies and corresponding damping) that well fitted the results of modal analyses carried out using finite elements simulation [10]. From numerical analyses, a main 1.45Hz transversal mode shape has been detected (see Figure 3).

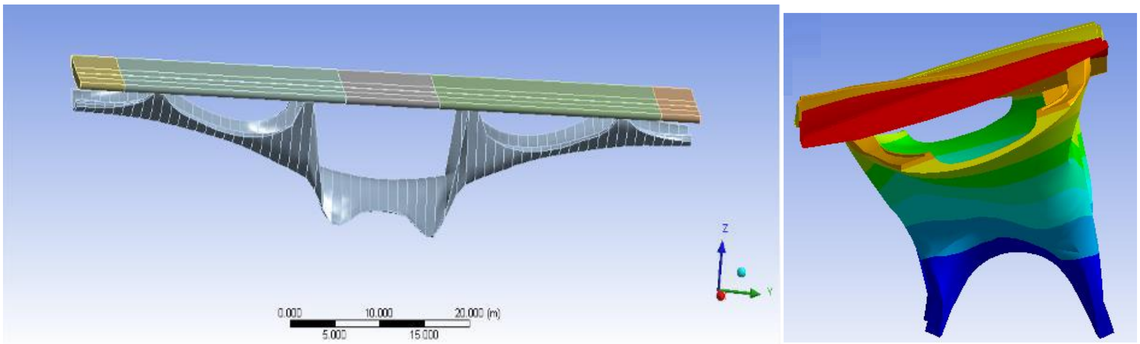

Figure 3 – Right) Finite element numerical model ; Left) fundamental mode shape – transversal direction

Finally, the equivalent viscous damping factor at the fundamental frequency characterizing the deck and the shell of the Basento Viaduct, was evaluated by applying the half-power bandwidth method [11]. The method consists on the estimation of the structural eigenfrequencies (in this case, we use only the fundamental one) and after evaluates a specified fraction of the maximum amplitude (bandwidth frequencies) corresponding to each natural frequency. The equivalent damping evaluated using the *ANM* and *GB-SAR* data showed similar values ranging around ξ=4.1.

All the above presented results were the main outcomes of the FP7 project "Integrated System for Transport Infrastructures surveillance and Monitoring by Electromagnetic Sensing" (ISITIMES), which has represented one of the first projects regarding the investigation of the applicability of new electromagnetic sensing technologies to transport infrastructures monitoring [12-14].

5. Conclusions

The fight against the COVID 19 pandemic passes not only through strictly medical aspects but also through the ability to take advantage of a lot of knowledge that is apparently very distant from that of health. For example, a targeted management of the transport system plays an important role in limiting the transmission of the infection.

In Europe, in recent years, large attention has been paid to sustainable, green and intelligent development that has to face the problem of the "safety" in a unified way. There is surely a need to improve health infrastructures, but this aspect is part of a larger context, where the issue of the safety has to be faced by considering a systematic approach addressing urban areas, energy, air quality, water, transport infrastructures, health infrastructures, ICT facilities under a unified frame.

By summarising, it is necessary to develop a holistic approach that looks to the resilience improvement of the built environment in all its facets. In fact, the resilience of a territory consists precisely in the ability to react to critical issues and to make the existing interconnections in the system an element of strength to minimize the damage.

This means that it is necessary to develop a long-term strategy whose cornerstones are the always updated situational awareness and the prevention. In this context, one of the pillars is the monitoring not only of the building / infrastructure, but even of the site where the infrastructure is located. In fact, such a comprehensive information is necessary to know what structures are in critical conditions and support the planning/definition of the extraordinary maintenance strategies and prioritization of interventions. To this end, one of the current research priorities is the assimilation of data / information deriving from monitoring into structural models typical of structural engineering in order to determine the performance losses.

In recent years, there has been a dramatic improvement in monitoring technologies in numerous fields of knowledge: physics, engineering, chemistry, geology and geophysics. New frontiers are now opened up thanks to the development of navigation and positioning technologies and ICT technologies (HPC, Big data, IoT, AI, etc.) and their integration with the ones of Earth Observation. Furthermore, there has also been a remarkable increase of observational platforms: while until a few years ago, the observation platforms were typically ground-based, now satellite platforms have been added, airborne systems (including remotely piloted systems), stratospheric platforms. Finally, new concepts of operation have been developed, such as clouds of low cost sensors, the citizen as a sensor, sensors not sensors, the use of robotics, the constellations of mini and micro satellites.

In perspective, the integration of technologies from various scientificdisciplines and operating on various observational platforms and enhancing ICT tools becomes the starting point of a disruptive evolution of monitoring systems, whose full exploitation is far from being achieved.

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References

[1] UNESCO (2019). https://en.unesco.org/news/urban-solutions-learning-cities-responses-covid-19-meeting-25-june

[2] MORENO (2020) https://www.ted.com/talks/carlos_moreno_the_15_minute_city#t-460735

[3] Cuomo V., Soldovieri F., Ponzo F.C., Ditommaso R. (2018). A holistic approach to long term SHM of transport infrastructures. The International Emergency Management Society (TIEMS) Newsletter 33, pp. 67-84.

[4] Soldovieri F., Dumoulin J. (2017). Integrated Monitoring at a Modern Architectural Masterpiece: The Case of Viaduct Basento in Potenza. In: Masini N., Soldovieri F. (eds) Sensing the Past. Geotechnologies and the Environment, vol 16. Springer, Cham. doi.org/10.1007/978-3-319-50518-3_25

[5] G. Fornaro, D. Reale and S. Verde (2013). Bridge Thermal Dilation Monitoring With Millimeter Sensitivity via Multidimensional SAR Imaging. IEEE Geoscience and Remote Sensing Letters, vol. 10, no. 4, pp. 677-681, doi: 10.1109/LGRS.2012.2218214

[6] A. Minardo, G. Persichetti, G. Testa, L. Zeni, R. Bernini, (2012). Long term structural health monitoring by Brillouin fibre-optic sensing: a real case. Journal of Geophysics and Engineering, Volume 9, Issue 4, pages S64–S69, doi.org/10.1088/1742-2132/9/4/S64

[7] Bavusi M., Soldovieri F., Di Napoli R., Loperte A., Di Cesare A., Ponzo F.C. and Lapenna V. (2011). Ground penetrating radar and microwave tomography 3D applications for the deck evaluation of the Musmeci bridge in Potenza, Italy. Journal of Geophysics and Engineering, vol. 8, pp. S33-S46.

[8] Dumoulin J., Crinière A., Averty R. (2013). Detection and thermal characterization of the inner structure of the “Musmeci” bridge deck by infrared thermography monitoring. Journal of Geophysics and Engineering, Volume 10, Number 2, IOP Science, doi:10.1088/1742-2132/10/6/064003

[9] Stabile T.A., Perrone A., Gallipoli M.R., Ditommaso R., Ponzo F.C. (2013). Dynamic Survey of the Musmeci Bridge by Joint Application of Ground-Based Microwave Radar Interferometry and Ambient Noise Standard Spectral Ratio Techniques. IEEE Geoscience and Remote Sensing Letters. 07/2013; 10(4):870-874. doi:10.1109/LGRS.2012.2226428.

[10] Ponzo F.C., Di Cesare A., Ditommaso R., Auletta G., Nigro D., Dolce M., Moroni C. (2013). Vulnerabilità Sismica dei ponti in c.a.: studio del ponte “Musmeci” a Potenza. PROGETTAZIONE SISMICA, vol. 3, p. 5-26, ISSN: 1973-7432

[11] Chopra A. K. (2007). Dynamics of structures: Theory and Applications to Earthquake Engineering, 3rd ed. Englewood Cliffs, NJ: Prentice-Hall.

[12] Proto M., et al. (2010). Transport Infrastructure surveillance and Monitoring by Electromagnetic Sensing: the ISTIMES project. Sensors, 10(12), 10620-10639.

[13] F. Soldovieri , F. Bourquin, V. Cuomo and J. Dumoulin. (2014). ISTIMES Project: outcomes and perspectives”, TRA 2014 (5th Transportation Research Arena), Paris, France, 14-17 April 2014.

[14] F. Soldovieri, J. Dumoulin, F.C. Ponzo, A. Crinière, F. Bourquin and V. Cuomo. (2014). Association of sensing techniques with a designed ICT architecture in the ISTIMES project: application example with the monitoring of the Musmeci bridge. EWSHM 2014, 7th European Workshop on Structural Health Monitoring, Nantes, France, 8 - 11 July 2014.