Final publishable summary report

Executive summary

ISTIMES project has designed, assessed and developed a prototypical modular and scalable ICT-based system, exploiting distributed and local sensors, for non-destructive electromagnetic monitoring. The specific application field was the reliability and safety of critical transport infrastructures, even if the modularity of the ISTIMES approach has permitted to extend it successfully to other critical infrastructures, as dams. In addition, ISTIMES system is able to couple current monitoring of infrastructures with a high situational awareness during crisis management, providing updated and detailed real and near real time information about the infrastructure status to improve decision support for emergency and disasters stakeholders.

The system exploits an open network architecture that accommodates a wide range of heterogeneous sensors, static and mobile, and can be easily scaled up to allow the integration of additional sensors and interfaces with other networks. It relies on state-of-the-art in-situ electromagnetic sensors supported by specific satellite and airborne measurements. The integration of electromagnetic technologies with new ICT information and telecommunications systems has enabled remotely controlled monitoring at different temporal and spatial scales, providing indexes and images of the critical transport infrastructures.

The project has exploited, assessed and improved many different non-invasive technologies based on electromagnetic sensing as: Optic Fiber Sensors, Synthetic Aperture; Radar (SAR) satellite platform; Hyperspectral Spectroscopy; Infrared Thermography; Ground Penetrating Radar; low-frequency Geophysical Techniques; ground based SAR and optical cameras for the assessment of the dynamical behaviour of the infrastructure. A great effort has been devoted to “transfer” these novel and state-of art technologies from the laboratory experience to actual on field applications by adapting/improving them and developing prototypes for the specific domain of the monitoring of transport and critical infrastructures. Sensor synergy, data cross correlation and novel concepts of information fusion have permitted to carry out a multi-method, multi-resolution and multi-scale electromagnetic detection and monitoring of the infrastructure, including surface and subsurface aspects.

The project has allowed to develop an ICT architecture based on web sensors and service oriented-technologies that comply with specific end-user requirements, including interoperability, economical convenience, exportability, efficiency and reliability. The efforts have focussed mainly to the creation of web based interfaces able to control “not standard” sensors, as the ones proposed in the project, and to the standardization necessary to have a full interoperability and modularity of the monitoring system. In addition, the system is able to provide a more easily accessible and transparent scheme for use by different end-users and to integrate the monitoring results and images with other kind of information such as GIS layer.

The ISTIMES system has been evaluated at two test sites and two test beds. At the two test sites of Montagnole rock-fall station (Chambery, France) and Hydrogeosite Laboratory (Potenza, Italy), the attention was posed to a thorough analysis of the performances of the in situ sensing techniques, by investigating, with good outcomes, also the possibility to correlate and have a synergy from the different sensors. In particular, it is worth noting that the experiment realized at Montagnole is unique, at least at European level, regarding both the high mechanical impact on a real scale elements of civil engineering structure, and also for the exploitation of all sensor techniques set up in a cooperative way. The effectiveness of the overall monitoring system has been assessed by the experiments at real test beds as Sihlhochstrasse bridge, a 1.5 km bridge representing one of the main entrance road to Zurich city (Switzerland), Varco Izzo railway tunnel and Musmeci motorway bridge located in the area of Potenza city in Basilicata region (Italy) affected by a high seismic risk.

A good dissemination and exploitation activity has been carried out and as proof of the goodness of ISTIMES results, several cases of successful exploitation of the ISTIMES outcomes have been already achieved, as specific monitoring services requested from end-users outside the Consortium.

Summary description of project context and objectives

The aim of the ISTIMES project was to design, assess and promote an ICT-based system, exploiting distributed and local sensors, for non-destructive electromagnetic monitoring of the critical transport infrastructures, by providing updated and detailed information and images of the infrastructure status in order to improve the decision support for emergency and disasters stakeholders.

ISTIMES system exploits an open network architecture, which can accommodate a wide range of sensors, static and mobile/ in-situ and remote, and is scalable so to allow the integration of additional sensors and interfacing with other networks. It relies on heterogeneous state-of-the-art electromagnetic sensors, enabling a networking of terrestrial sensors, supported by specific satellite and airborne measurements. The integration of electromagnetic technologies with new ICT information and telecommunications systems enables remotely controlled monitoring and surveillance and quasi-real time data imaging of the critical transport infrastructures.

The project is based on several independent non-invasive imaging technologies based on electromagnetic sensing (Optic Fiber Sensors, Synthetic Aperture Radar (SAR) satellite platform based, Hyperspectral Spectroscopy, Infrared Thermography, Ground Penetrating Radar, low-frequency geophysical techniques, Ground Based SAR systems and optical systems for displacement monitoring). Sensor cross validation, synergy and new data fusion and correlation schemes permit a multi-method, multi-resolution and multi-scale electromagnetic detection and monitoring of surface and subsurface changes of the infrastructure.

The architecture is based on web sensors and service-oriented-technologies that comply with specific end-user requirements, including economical convenience, exportability, efficiency and reliability. The sensing technologies are tuned at two important test sites located in Montagnole (France) and in Italy (Marsico Nuovo); the demonstration activities is tested on two very challenging test beds such as: a highway-bridge in Switzerland and a railway tunnel plus a motorway bridge in Italy.

The system has been based on clear end-user requirements, coming from representative end-users and technological choices are based on a long term cost-benefit analysis.

In particular, the overall scientific/technological objectives of ISTIMES project were:

- **To design a prototype electromagnetic sensing (ES) monitoring and surveillance system** which could provide a radical different approach to the situational awareness and crisis management to improve safety and security of the transportation infrastructures. The system uses and integrates heterogeneous, state-of-the-art electromagnetic sensors enabling a networking of terrestrial in situ sensors, supported by specific airborne and satellite measurements.

- **To develop a flexible information and communications system** able to control a permanent and non-permanent distributed sensor network, and allow the processing of large amounts of electromagnetic data by means of innovative and efficient inversion algorithms to constrain the models obtained from the different methodologies. The system provides a more easily accessible and transparent scheme for use by different users such as: security stakeholders, non-specialist maintenance engineers, etc. In this framework, the system is able to integrate the monitoring results and images with other kind of information such as GIS information and historical datasets relating to the site.

- **To improve, exploit and integrate, new or emerging electromagnetic sensing techniques** for in-situ and remote electromagnetic monitoring. The proposed integrated system is able to provide 4D tomographic near-continuous monitoring of existing transportation infrastructures at different spatial-temporal scales and resolution.

- **To apply robust reconstruction techniques for data processing and the early detection of anomalous patterns** in space-time dynamics of the Electromagnetic Sensing surface and sub-surface images.

- **To demonstrate the effectiveness of the overall monitoring ISTIMES system** (ICT expert system plus electromagnetic sensing techniques) at several engineered sites such as a highway bridge in Switzerland and a railway tunnel and a motorway bridge in Italy .

- **To disseminate and promote the new technology including the demonstration results** from the test sites. To encourage a wide range of public institutions and private companies to evaluate and adopt our approach for real-time control and distributed monitoring also in the more general framework of critical and civil infrastructure management and protection. To develop an exploitation plan for the commercialization of any derived technology, software, or monitoring concepts and services.

Main S&T results/foregrounds

The activities of ISTIMES project were organised by adopting a Work package (WP) structure according to the following subdivision (fig.1):

- WP1.Users Requirements;
- WP2. System Architecture Design;
- WP3. System Architecture Development;
- WP4. Sensors Technologies;
- WP5. System Implementation;
- WP6. Dissemination and Exploitation;
- WP7. Management.

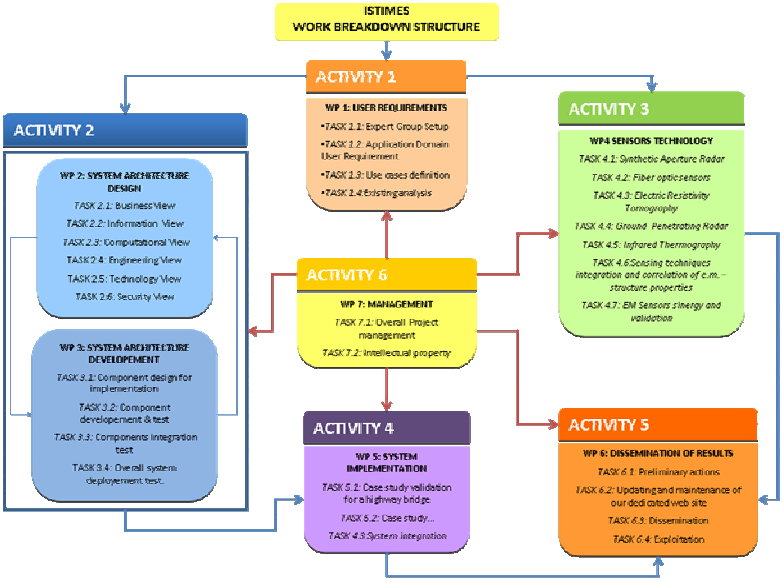

Figure 1. Work package structure of ISTIMES project.

For the design of ISTIMES system, as first activity, a survey of the real necessities of the stakeholders involved in the management of transport infrastructures was necessary to identify the users requirements. This survey was complemented by the analysis aiming at identifying the key factors describing the possible interactions between users (humans or machines) and the system to be developed. In addition, a description of existing solutions, in terms of technologies and processes, was performed for the field of the transport infrastructures monitoring; in this way it was possible to define, in a general frame, the technological and organization constraints affecting the functional and non-functional requirements. These activities were performed under the WP1 and the related outcomes represented a relevant input to the activities of the WP2 and WP3, regarding the system architecture design and implementation, and WP4 concerned with sensor technologies development and performance assessment.

The technological pillars at the basis of the ISTIMES systems were two: the ICT System Architecture and the Electromagnetic Sensing Technologies. Therefore, WP2, WP3 and WP4 were specifically devoted to the development of new tools and improvement of the existing ones for these two technological areas.

In fact, WP2 and WP3 were devoted to design and implement the ISTIMES system architecture; such an architecture is able to comply with the two needs: the first one is the control and data acquisition for the large suite of ISTIMES sensors; the second one is concerned with the “friendly” presentation of the monitoring/diagnostics results to experts (Decision Support System) and non-experts (Presentation System) end-users (fig.2).

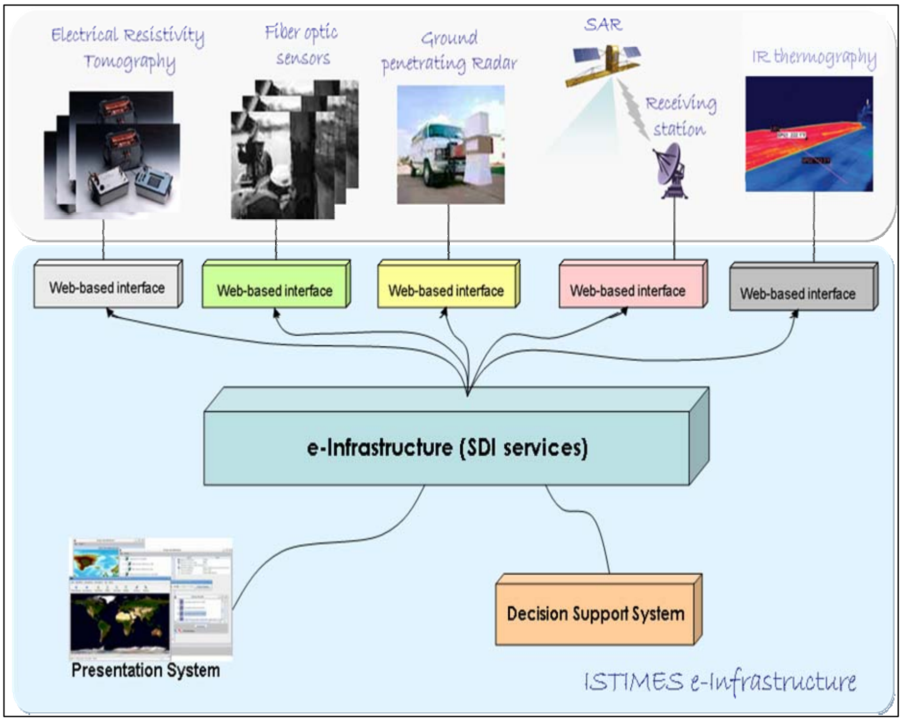

Figure 2.ISTIMES system architecture.

In particular, WP2 was devoted to design the system architecture on the basis of inputs coming from WP1 (Users Requirements) and WP4 (Sensors technologies); WP3 and WP2 worked in a very strict relation and in a cyclic way, so that the outputs of one WP became an input to the other one. The system was preliminary sketched at month 18 and after fully designed. After, WP3 implemented the system architecture, starting from the design achieved in WP2; this was performed through a successive refinement procedure based on two releases (first and final) of the system architecture.

The actions of WP4 were specifically devoted the second technological pillar, at the basis of ISTIMES project, i.e., the electromagnetic sensing technologies. The first phase was concerned with the analysis of the potentialities of the sensing technologies with respect to the domain of the monitoring and diagnostics of the transport infrastructures. This analysis was preliminary to the scientific/technical activities aiming at turning laboratory instrumentations to sensor operating “on field” and to the development and validation in operative conditions of a number of prototypical instrumentations developed in the ISTIMES context.

A significant attention was due not only to the data processing but even the development of data correlation and information fusion approaches able to exploit in a synergic way the observations from different sensors.

In WP4 a crucial role was played by the experimental activity carried out at the two test sites of Montagnole (France) and Hydrogeosite (Marsico Nuovo, Italy) (fig.3). The effectiveness and the synergy of the ISTIMES technologies were demonstrated at the two test sites in experiments carried out at an intermediate level between the laboratory controlled conditions and full “on-field” tests.

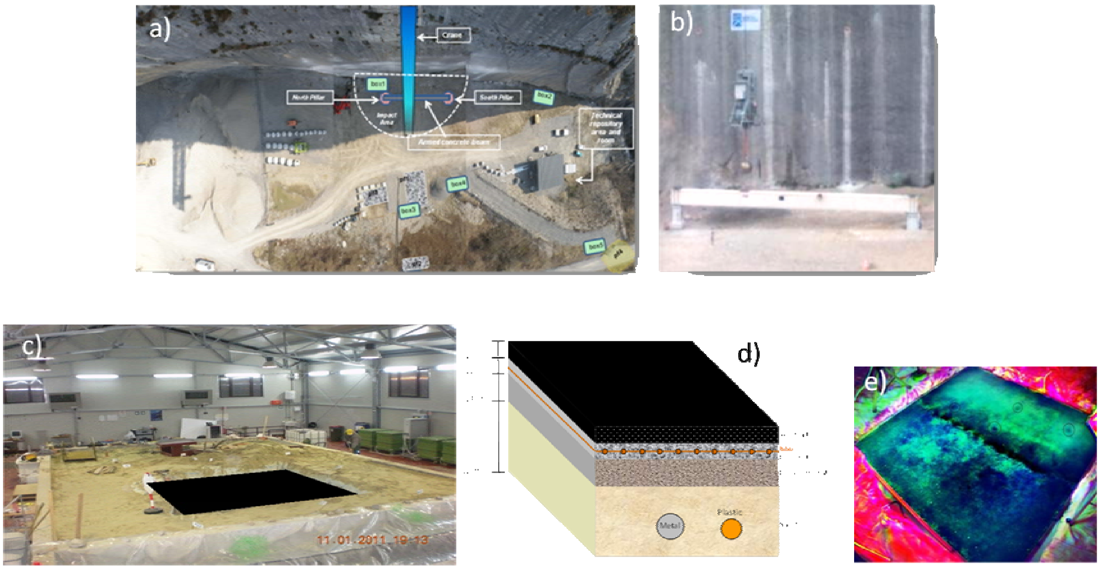

Figure 3. Test sites of ISTIMES: a) Montagnole falling block station (owned by IFSTTAR); b) Montagnole site: detail of the reinforced concrete beam used during the experiments; c) Hydrogeosite Laboratory (Marsico Nuovo, Italy); d) Hydrogeosite Laboratory: asphalt-concrete layered body used for testing electromagnetic techniques; e) Hydrogeosite Laboratory: example of RGB composition of PC bands 4, 8, 12 of the layered body.

The experimental activities at the two test sites were decisive to perform a critical analysis of the effectiveness of the sensors, when they passed from the status of “laboratory instrumentation” to sensors operating in “on field”; this activity was also important, since it provided “learnt lessons” useful to design and implement in a reliable way the demonstration activities of WP5.

Furthermore, actions of WP4 were strictly related to WP2 and WP3 ones in order to provide information and feedback for the design of the System architecture, specifically for the activity regarding the set-up of web based interfaces for the control and the data acquisition of the sensors. These interactions represented one of the first successful examples of knowledge/information exchange between the two “worlds” of ICT developers and providers and sensor owners, with a specific focus to the state of art and novel electromagnetic sensing techniques.

The demonstration activities were carried out under WP5, at challenging test beds as two bridges in Switzerland and Italy (Sihlhochstrasse and Musmeci bridges, respectively) and a railway tunnel (Varco d'Izzo Railway Tunnel) (fig.4). The demonstration activities aimed at performing a critical analysis of the sensing technologies in really operative fields and for different situations. Preliminarily to the effective implementation of the sensors, an accurate survey was carried out at the test beds with the aim to choose the sensors to be installed at the different test beds. This choice was motivated also by logistic constraints about the installation of the sensors; in fact, one of the main issues of the demonstration activity was the identification of the problems affecting the fully operative implementation of the technologies.

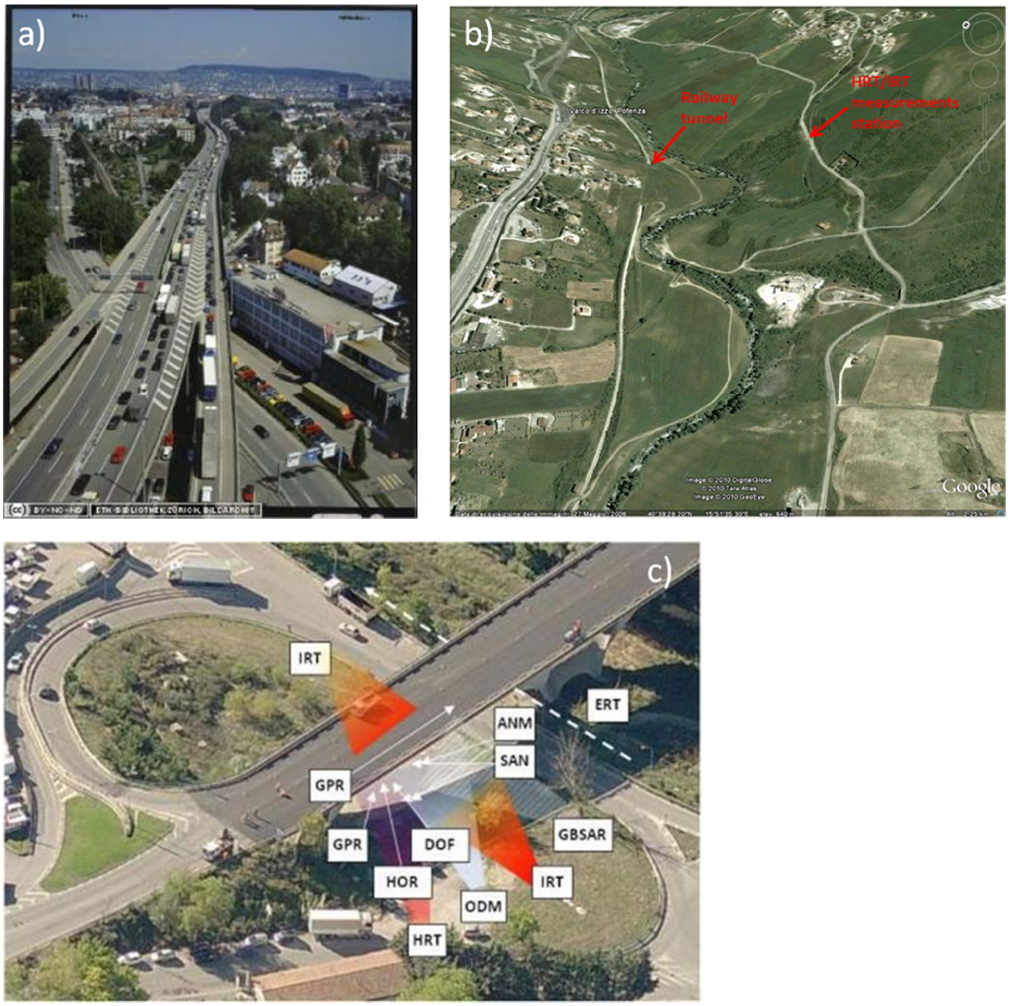

Figure 4. Test beds of ISTIMES: a) Sihlhochstrasse Bridge (Zurich, Switzerland); b) Varco d'Izzo Railway Tunnel (Potenza, Italy); c) Musmeci Bridge (Potenza, Italy).

Successful demonstration activities were performed for each test bed. Moreover, as a not originally expected activity, the involvement of structural engineers was very important to have a feedback about the effectiveness and usefulness of the ISTIMES approach. The other main aim of the WP5 was the support to the development of the software components for the integration of the system architecture with sensors; this action was performed for all the sensors, by considering specifically the remote control of two sensors as the distributed optic fiber and the uncooled infrared camera.

During all duration of the project a significant activity of dissemination and exploitation was carried out in the framework of WP6. Finally, administrative and financial management of the project was ensured in the framework of WP7 (Management).

The project achieved all the expected objectives about the development and improvement of the System Architecture and of the sensing technologies; a full integration of the ICT architecture and the suite of sensing technologies was finalised; demonstration activities testified the effectiveness and the usefulness of the ISTIMES approach in fully operative conditions.

Furthermore, the ISTIMES project achieved results beyond the expected ones, in fact, ISTIMES partners were requested by end users outside the Consortium to perform specific monitoring services, even in sectors different from the transportation one (dam monitoring).

The following paragraphs reported in detail the main technical/scientific results of the project, which are regrouped in terms of four main classes as:

- User requirements Analysis and Definition;
- System Architecture Design and Implementation;
- Analysis, Development and Validation of the Sensing Technologies;
- System Implementation.

Users Requirements Analysis and Definition

A survey of the necessities of the significant European end-users in transportation sector was carried out thanks to the actions of an Expert (Core) Group, made up of of one representative by each Consortium partner. In this way, it was possible to have a first general identification of the end-users requirements.

The identification and definition of relevant use-cases was carried out thanks to different actions such as:

- the examination of the basic issues, also thanks to the feedback of the end-users contacted by the Expert (Core) Group;
- the description of the “objects” relevant to the implementation of the monitoring system;
- a detailed description of the infrastructures was combined with the end-users (owners) requirements regarding the desired system output, details of the installation of such a monitoring system and the user-system interface.

A survey of the existing solutions and technologies was performed, also thanks to the review of the literature on Structural Health Monitoring and documented in the related deliverable.

The activities above described were concerned with the first months of the project. After, the identification of the users-needs and the definition of the end-users requirements were completed thanks to the activities carried out during the final part of the project, by means of actions carried out in the frame of the exploitation of the project; in this frame, it is worth stressing the usefulness of actions as the “Exploitation on Demand” , the Steering Committee involvement and the activation of the User Forum.

System Architecture Design and Implementation

A design of the ISTIMES System Architecture was achieved thanks to the strict interrelation between WP2 (System Architecture Design) and WP3 (System Architecture Development).

In this frame, a significant information and knowledge exchange was carried out performed between WP2/WP3 and WP4 (Sensor Technologies), with the aim of defining the sensor network architecture and information model; this work was very challenging and of particular significance , due to the fact that almost all the sensors deployed in the project are at the boundaries of the state of art and/or prototypical.

In the final design of the System Architecture, the following technical objectives and contribution were accounted for:

- designing the system architecture of the ISTIMES e-infrastructure following an approach based on the Reference Model for Open Distributed Processing (RM-ODP);

- providing contribution to existing standardization initiatives in the field of web services for sensor management and access;
- providing a general framework (common functionalities and common interfaces) to implement monitoring services based on sensor networks.

The design of the system architecture was performed by taking care to the following complementary points of view:

- Business view .- use-cases and policy of use;
- Information view – data structure and information flow;
- Computational view: functional modules and interfaces;
- Engineering view: component distribution and communication protocols;
- Technology view: chosen technologies and implementations;
- Security view – identified security solutions.

After, the system architecture was implemented in WP3, by applying the architectural specification worked out by the WP2 System Architecture Design. The specification of the ISTIMES software components was performed by accounting the results of the WP2 activities. The development of the specified components, with unit and the integration tests, was carried out after the specification of the components. The above steps were performed in a "cycle approach" in order to integrate the second revision of the ISTIMES architecture. Finally a map GIS integration in the portal and a test bed session were performed to validate the system.

A significant effort was devoted to the integration of the system architecture with the sensing technologies and a specific focus was addressed to software components allowing this integration. In ISTIMES architecture, the sensors were classified in two main categories: dynamic sensors (online sensors that can be commanded using WEB based interfaces); static Sensors (offline sensors for which it is not possible or useful to command them via WEB).

For the dynamic Sensors Integration, two sensors were specifically considered, also according to the analysis performed in WP4, as:

- the uncooled InfraRed (IR) camera (available at IFSTTAR);
- the distributed optic fiber (DOF) sensor (available at TERN-CNR).

The choice of these two sensors as related both to technical and methodological reasons. In fact, both the sensors are self-assembled prototypes, which could be easily modified and customized. Furthermore, the solution of the specific problem of a web based interface for the infrared camera provide the general guidelines for a more general class of sensors built up of cameras based on different sensing principles (video, microwave,..), where the main problem to be addressed is to manage a large amount of data. For the second case regarding the optic fiber sensor, we are concerned with the concept of a "spatially distributed monitoring", which is s a quite new concept, but, at the same time, the implemented solutions are of interest even for the more traditional case of network of "point-sensors". Two different communication solutions were implemented for the infrared camera and optic fiber sensor. ISTIMES architecture has also homogenized the engine, by extending the logic of OGS SWE to the static sensors. The static sensors were not commanded directly via web, but they inserted the measurement results according to the same modalities of the online sensors.

Therefore, the project achieved the full implementation of a scalable System Architecture able to provide services via WEB and to "reconfigure" the measurement strategy, by means of the addition of new kind of sensors or to change the observation modalities of the existing ones. These capabilities, together with the large availability of ISTIMES sensors, allow to tackle not only the necessities related to the different typologies of infrastructures in transportation sector, but even to extend the approach to other types of critical infrastructures; this second possibility has been already demonstrated during the project, since end-users outside the Consortium required specific request for the monitoring and diagnostics of their infrastructures.

Analysis, Development and Validation of the sensing technologies

As first result, an accurate analysis of the state of art sensing technologies exploited in the project was performed together with the investigation and definition of strategies for data integration and information fusion. After, activities were performed with the aim of developing and testing prototypical sensing instrumentations and improving the state of art instrumentations, by taking care to both the hardware and data processing aspects.

The following six sensor prototypes were developed and validated:

1. **Distributed optic fiber (DOF) system (by TERN-CNR);**
2. **Portable Electrical Resistivity tomography (ERT) for structures (by TERN-CNR);**
3. **Mobile Ground Penetrating Radar (GPR) system (by EMPA);**
4. **Electrical Capacity Tomography (TDR) tested in lab and at a real bridge for the external tendon diagnostics (by IFSTTAR);**
5. **Optical Displacement Monitoring (ODM) prototype developed for real site application (by NEO);**
6. **Uncooled Infrared Thermography (IR) prototype system for long term monitoring of infrastructure temperature, with embedded GPU card for real time thermal radiation corrections on measurement and with wire or wireless remote control (by IFSTTAR).**

For the other sensing techniques, an effort was made to turn them from the use in laboratory conditions to the deployment in operative e condition, mainly during the activities at the two test-sites and, after in WP5, at the test beds.

The effectiveness and the synergy of the exploitation of the different sensing technologies was first tested in October 2010 at a Montagnole site (France), where, at our knowledge, for the first time a large number of electromagnetic sensing technologies was applied simultaneously and in the same place for the monitoring of a civil engineering structure during an induced crisis event. In particular, at Montagnole, a simplified one-scale civil engineering structure, which consisted in a reinforced concrete beam laid on two piers anchored on foundations, was monitored and diagnosed when affected by indirect and direct impacts of a falling block.

Design of the concrete beam was validated by partners during the second WP4 meeting and building of this structure was completed on September 2010. The week experiment at Montagnole was performed by using all the in-situ ISTIMES sensing techniques in order to investigate and monitor the damage of the concrete beam affected by high mechanical loadings up to 6 MJ. The experiment is, at the best of our knowledge, unique at least at European level; in fact, never before of this experiment, a so large number of electromagnetic sensing techniques, complemented by several usual civil engineering tools and by numerical modeling, were exploited at the same time to monitor a one-scale civil engineering structure (fig.5).

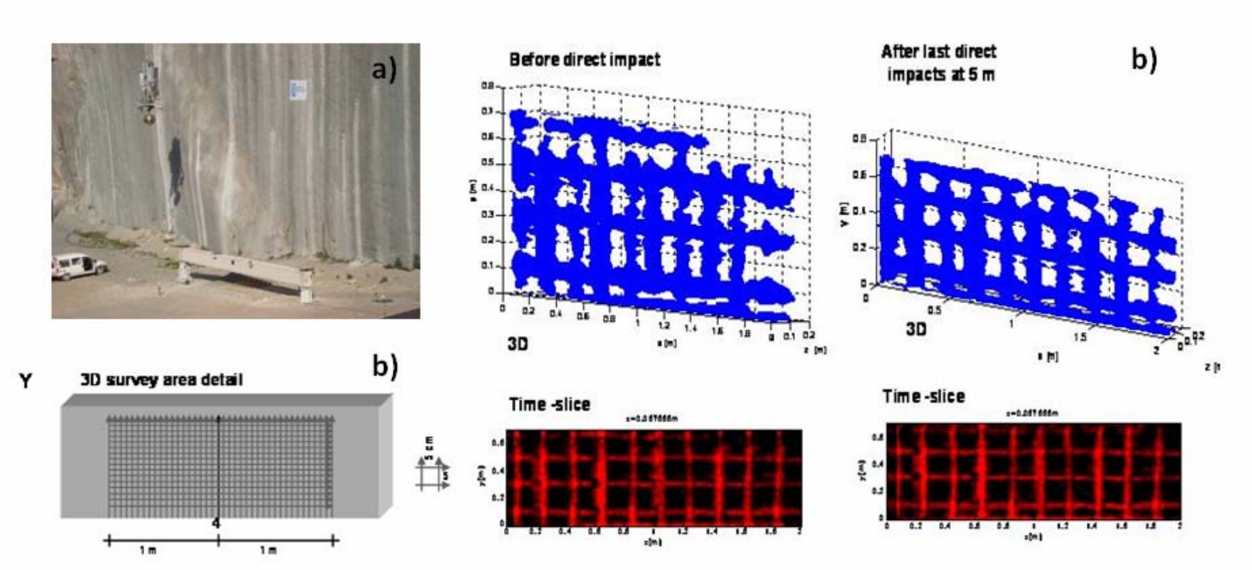

Figure 5. Examples of tomographic reconstruction at Montagnole test bed; a) beam shot by the heavy mass; b) GPR survey design; c) example of reconstruction of the internal rebar cage before and after the impacts.

For Montagnole test site, a significant effort was carried out in data processing and data correlation/integration in order to explore the synergic effect arising from the use of different sensing techniques. In particular, data correlation was carried out with the two aims: to mitigate the ambiguity of interpretation, related to the use of a single technique; to improve the information about the structure under test. In particular, as significant results for the data correlation, we report here two cases. The first one regards the correlation of ERT and GPR in order to evaluate the change of the underground properties before and after the mechanical impacts on the ground. The second case was concerned with the correlation of high-frequency IRT, Ground Based SAR (GBSAR) and ODM to characterize the fast displacements (vibrations) of the beam, when affected by direct impacts.

For the second test site “Hydrogeosite”, (a controlled site in Marsico Nuovo (Southern Italy) available at TeRN) experiments were carried out for the diagnostics and monitoring of a three square meter layered structure with the asphalt layer laid on a concrete layer, which in its turn was leaned on a sand ground affected by different water content. The experiment was carried out on February 2011 and had the aim of monitoring for few days a structure simulating a road (bridge deck) affected by different stresses, such as subsidence and mechanical impact. For this second test site, four in-situ techniques (DOF, GPR, IRT, and ERT) were tested at the end of January / start of February 2011 with the aim to perform a time-continuous and high-resolution diagnostics/monitoring of the structure.

For data integration and correlation, four different approaches were developed and analyzed (two developed by Tel Aviv University and two by Lund University). Some of these approaches were tested for Montagnole data, but also for experiments outside of the scope of ISTIMES project. **The relevance of the approaches developed in ISTIMES for the information fusion was testified by the fact that the paper “Data fusion for reconstruction algorithms via different sensors in geophysical sensing'', by Nordebo S., Gustafsson M., Soldovieri F has been included among**

the "Highlights 2011" papers of Journal of Geophysics and Engineering.

As other main scientific, a prototypical mobile GPR system was designed and realized by EMPA; preliminary tests showed the effectiveness of such a system, which was after tested in operative condition under WP5 activities (due to its field of application that concerns large scale pavement diagnostics).

The effectiveness of the SAR satellite platform based technology was shown in two different cases. The first one was concerned with the exploitation and data processing with a medium spatial resolution SAR satellite (ENVISAT data); the outcome of this processing was used as an initial reference for the Musmeci bridge slow displacement monitoring; this result was then compared with the advanced data processing with TerraSAR-X carried out in WP5. In addition, high spatial resolution SAR data (1m spatial resolution), thanks to the exploitation of the state-of art TERRASAR-X system over Las Vegas city (USA), was used to validate the whole new processing chain studied and developed, which has been after used in WP5 for Musmeci Bridge investigation. **As significant outcome of the SAR activity, with the focus to Las Vegas data, the paper "Tomographic Imaging and Monitoring of Buildings With Very High Resolution SAR Data" by Reale D., *Fornaro G*., Pauciullo A., Zhu X., and Bamler R. was awarded as *the 2011 Best paper published in IEEE Geoscience and Remote Sensing Letters.***

The experimental activities, mostly at the two test sites, were crucial to perform a critical analysis of the effectiveness of the sensing techniques when they passed from the status of "laboratory instrumentation" to sensors operating in "on field activities"; this activity was also important since it provided "learnt lessons" useful to design and implement in a reliable way the demonstration activities of WP5.

In particular, it was demonstrated how sensing techniques of different costs and complexities provide coherent diagnostics results; this is a necessary condition for the identification of operative protocols, based on the use of the technologies in a "cascade mode", where the simpler and cheaper technologies give indication if or not to activate the subsequent measurement chain through the use of the more sophisticated technologies.

Finally, it is worth noting that the richness of the trials carried out in Montagnole and Hydrogeosite motivated many complementary research activities, in addition to the initial research works planned in the ISTIMES WP4.

System Implementation

One of the main aims of the project was to show the potentiality and the effectiveness of the proposed ICT/EM based system by carrying out demonstration activities at several test beds with significant end-users requirements in terms of spatial extent and structural complexity. The test beds were a highway bridge in Switzerland and a railway tunnel and an motorway bridge in Italy.
The sensors and related signal processing techniques, developed during the project in the WP4, were validated through demonstration activities at test beds. The demonstration activities regarded the analysis of the feasibility and effectiveness of the sensing techniques, when deployed for a non-invasive monitoring and diagnostics in realistic and challenging conditions at test beds as: an highway bridge in Switzerland (Sihlhochstrasse bridge, fig. 6); a railway tunnel in Italy (Varco Izzo, fig. 7) and a city bridge in Italy (Musmeci bridge, fig. 8).

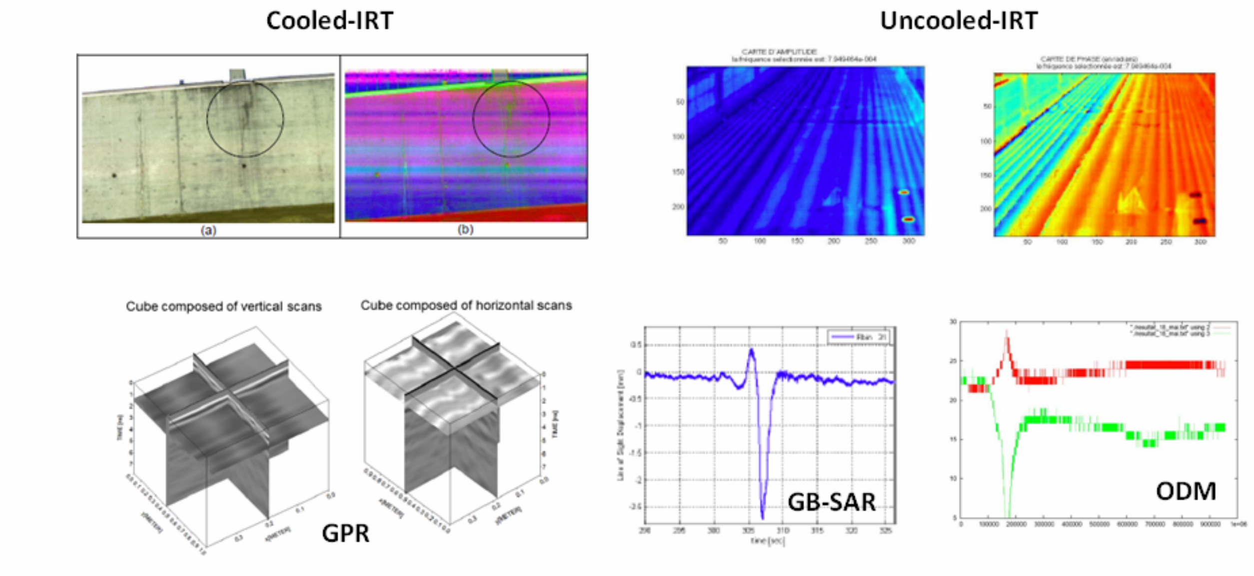

Figure 6. Examples of the results obtained at Sihlhochstrasse bridge for each used technique. Cooled-IRT: thermal image of the bridge; Uncooled-IRT: thermal image of a lane of the bridge; GPR: 3D reconstruction of the inner structure of the bridge; GB-SAR: bridge displacement; ODM: bridge displacement.

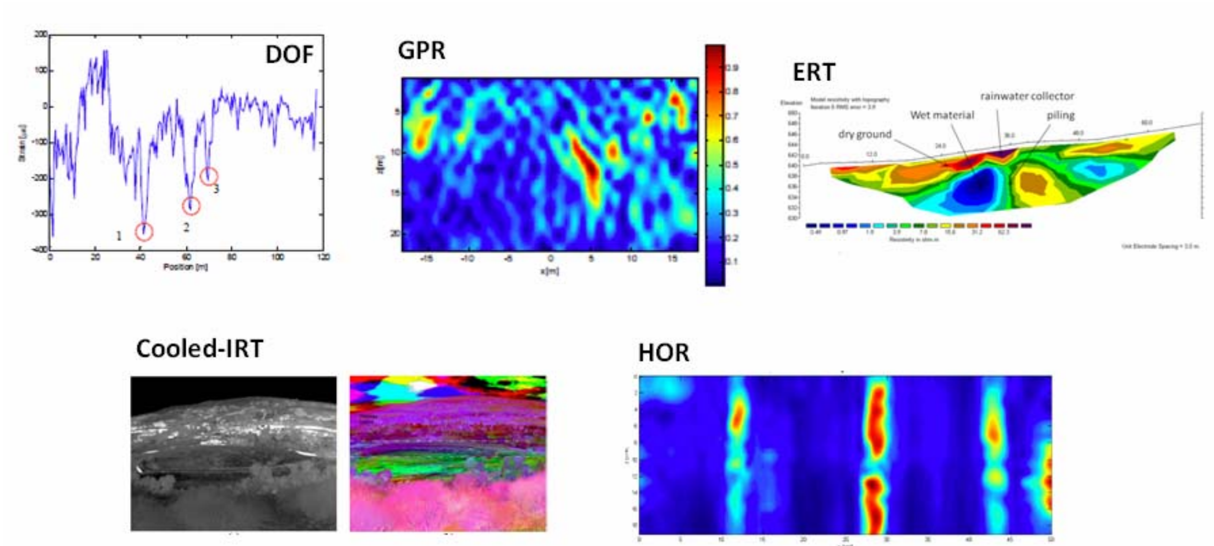

Figure 7. Examples of the results obtained at Varco d'Izzo site for each used technique. DOF: strain of the ground; GPR: tomographic image of the subsoil; ERT: tomographic image of the subsoil; cooled-IRT: thermal image of the studied area; HOR: holographyc radar image of the rebars of a reinforced concrete structure.

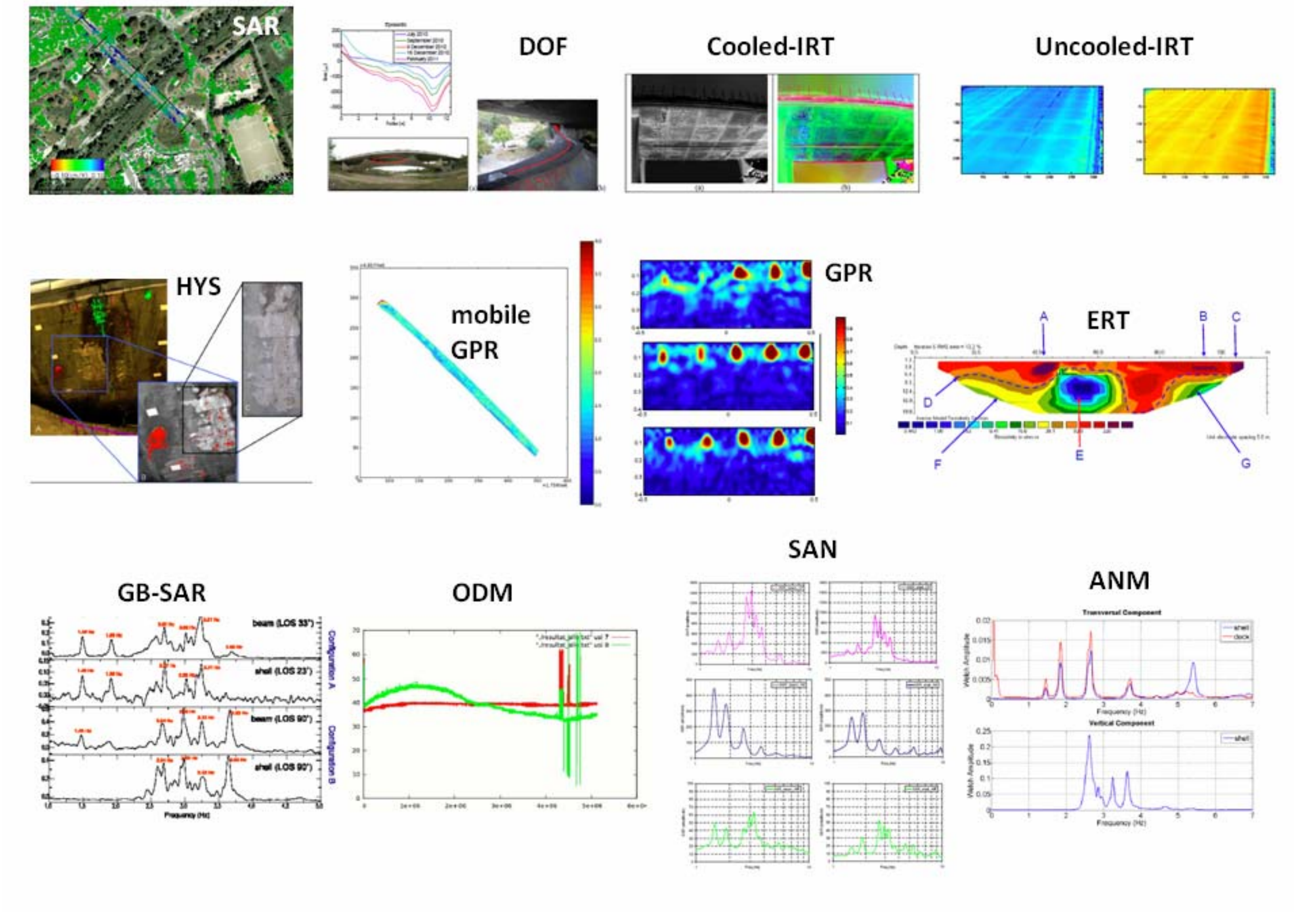

Figure 8. Examples of the results obtained on the Musmeci bridge for each used technique. SAR: thermal dilatation coefficient mapping; DOF: strain distribution along the optical fiber; Cooled-IRT: thermal images of the bridge deck; Uncooled-IRT: thermal images of a bridge lane; HYS: Hyperspectral images of the bridge surface; mobile-GPR: depth-slice of the bridge asphalt layer; GPR: tomography of some reinforced concrete rebars; 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: foundamental frequencies of the bridge

The choice of the technologies to be deployed for the specific test-bed was carried out by taking into account not only the technological and logistic constraints but also on the basis of suggestions and requirements of the end-users.
For each test bed, a detailed description of construction parameters, access to the structures and limitations concerning monitoring activities was carried out; the planned monitoring activities and the requirements for the different methods were portrayed. An accurate picture of the sensor location during the test bed and a detailed description of the sensor installation procedure were discussed and assessed. The approaches, to be used for processing sensor data collected during the monitoring activities, were identified, described and developed.

Hyperspectral Spectroscopy (HYS),Ground Penetrating Radar (GPR), Infrared Thermography (IRT), Ground Based SAR (GBSAR) and Optical Displacement monitoring (ODM) measurements were performed at Sihlhochstrasse bridge (one of the main entrance to the Zurich city). The activity demonstrated that the proposed sensors can give important information on different spatial scale about pavement status and main structural elements of a part of the bridge as well as about the “dynamic behaviour” (fast displacements). It is

worth noting that the sensing techniques were deployed without affecting the normal functionality of the infrastructure affected by a significant car traffic.

As concerned with the Varco Izzo railway tunnel the activity was focussed to the monitoring of the surrounding area and to monitor the possible landslide features affecting the railway structure.

The following technologies were deployed:

- Distributed Fiber Optic sensors (DOF);
- Infrared Thermography (Cooled IRT);
- Ground Penetrating Radar (GPR);
- Electrical Resistivity Tomography (ERT).

Moreover, the Holographic Radar (HOR), an initially not foreseen imaging technique by using the RASCAN4/4000 system, was carried out on a reinforced concrete structure present in the test bed.

As expected according to the DOW, at Musmeci bridge test bed all the ISTIMES sensors were exploited/installed for the diagnostics and monitoring. In addition, thanks to the strong interest of the scientific community, further measurements were performed with several techniques not originally foreseen in the ISTIMES project as:

- **Seismic Ambient Noise (SAN);**
- **Accelerometric Noise Measurements (ANM);**
- **Holographic Radar by using the RASCAN-4/4000 (HOR).**

It must be stressed the joint use of all the ISTIMES sensing technologies at Musmeci bridge and the possibility to validate the ISTIMES diagnostics results with both the outcomes of structural engineering measurements/expectations and the available information about the construction modalities of the bridge. This was a not originally expected aim.

Finally, about the integration of the ICT system architecture with the sensing technologies, a specific focus was addressed to the software components development. In ISTIMES ICT architecture, the sensors were classified in two main categories: dynamic sensors (online sensors that can be commanded using WEB); static Sensors(offline sensors).

For the dynamic sensors integration, two sensors have been specifically considered, also according to the analysis performed in WP4, as:

- the uncooled InfraRed (IR) camera (available at IFSTTAR);
- the distributed optic fiber (DOF) sensor (available at TERN-CNR).

The choice of these two sensors is related both to technical and methodological reasons. In fact, both the sensors are self-assembled prototype that could be easily modified and customized. Furthermore, to find a solution to the specific problem of web based interface for the infrared camera allowed to provide the general guidelines for a more general class of sensors as cameras, based on different sensing principles (video, microwave,..); in this case, the main problem is to manage a large amount of data. For the second case regarding the distributed optic fiber sensor, we were concerned with the concept of a "spatially distributed monitoring" , which is a quite new concept, but, at the same time, the implemented solutions are of interest even for the more traditional case of network of "point-sensors". Two different communication solution have been implemented for the infrared camera and fiber optic sensor. ISTIMES architecture has homogenized the engine, by extending the logic of OGS SWE even to the static sensors. The static sensors were not commanded directly via web, but they inserted the measurement results according to the same modalities of the online sensors.

In the following, we summarise the main scientific and technical results achieved during the project.

- Definition of the end-users requirements for the ISTIMES system through a feedback from relevant European stakeholders in the field of the transportation infrastructure and civil protection.
- Design of the ISTIMES system architecture.
- Complete implementation of the ISTIMES system architecture based on the definition and the integration of its main component.
- Improvement of the state of art sensing technologies of interest for the project and development, testing and validation of six sensor prototypes listed below:
  1. Distributed optic fiber (DOF) system (by TERN-CNR);
  2. Portable Electrical Resistivity tomography (ERT) for structures (by TERN-CNR);
  3. Mobile Ground Penetrating Radar (GPR) system (by EMPA);
  4. Electrical Capacity Tomography (TDR) tested in lab and at a real bridge for the external tendon diagnostics (by IFSTTAR);
  5. Optical Displacement Monitoring (ODM) prototype developed for real site application (by NEO);
  6. Uncooled Infrared Thermography (IR) prototype system for long term monitoring of infrastructure temperature, with embedded GPU card for real time thermal radiation corrections on measurement and with wire or wireless remote control (by IFSTTAR).
- Development, assessment and implementation of several strategies for data correlation and approaches of information fusion to improve the synergy related to the use of different sensing techniques.
- High challenging and unique experiment implementation at European level in Montagnole (France) test site: at our knowledge, Montagnole experiments realized is unique, at least at European level, regarding both the high mechanical impact realized on a real scale elements of civil engineering structure, the exploitation of all sensor techniques set up in a cooperative way.
- Finalization of the Montagnole week experiment, where the damage of the one scale civil engineering structure was monitored by means of almost ISTIMES sensing technologies (with the exception of SAR).
- For Montagnole experiment, data correlation was carried out between GPR and ERT to monitor the change of the properties of the underground when affected by high mechanical

impacts. In addition, ODM, IRT and GBSAR outcomes were correlated to improve the interpretability of the diagnostics of the fast displacements of the concrete beam affected by direct impacts.

- Complete definition of the other experiment at Hydrogeosite (Laboratory in the availability of TERN) for the validation of the sensing technologies in controlled conditions on a simulated civil engineering structure built on the purpose.
- The execution and related data processing of the experiment at Hydrogeosite for the validation of some in-situ sensing technologies (DOF, ERT, IRT, GPR) in controlled conditions on a simulated civil engineering structure built on the purpose.
- Complete analysis of the effectiveness, performances and synergy of the ISTIMES sensing technologies event by means of the activities at the two test-sites of Montagnole and Hydrogeosite.
- Demonstration of the effectiveness of the Synthetic Aperture Radar (SAR) technology, with medium and high resolution systems, as a tool for a long term monitoring of slow displacements affecting civil engineering structures.
- Finalization of the passage of the ISTIMES sensing technologies from the status of laboratory instrumentation to their use in “on-field” conditions.
- Integration of the system architecture with the sensing technologies by accounting specifically the constraints and features dictated by the “dynamic sensors (online sensors)” and “static sensors (offline sensors)”.
- Complete design and definition of the demonstration activities at the test beds in terms of location and installation definition and requirements of the sensors as well as the detailed time-line of the monitoring activities.
- Installation of static sensors for the long term monitoring by in-situ techniques at the Italian test beds (Varco Izzo railway tunnel and Musmeci motorway bridge).
- Demonstration activities at Sihlhochstrasse bridge (Zurich city, Switzerland), where some in-situ sensing techniques were exploited for inspection and monitoring of the bridge under challenging operative conditions.
- Demonstration activities in Basilicata region at the two test sites as Musmeci bridge in Potenza and Varco Izzo where a large landslide affects both the Basentana highway and the Potenza-Taranto railway (WP5).
- Critical of the ISTIMES approach through a deep reconsideration of the demonstration activities.
- Definition of a high level protocol for the deployment of the ISTIMES strategy in monitoring of critical transport infrastructures.

Potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and exploitation of results.

In the last years, the European Community has experienced earthquakes, industrial accidents, and power blackouts leading to the damage or destruction of infrastructures. In addition, the threat of terrorism has arisen new challenges for the European critical infrastructure protection. The social and economic necessity to ensure a proper transportation infrastructure protection is still more clear if one thinks to the strong interdependency between transportation and nearly every other sector of the economy. The above considerations allow to point out how, whereas the surface transportation infrastructure is robust and redundant, the consequences of a crisis event can be very significant in terms of economic and social costs. In this framework, infrastructures such as major bridges and tunnels are imperative to be protected since they play essential connecting roles and serve unique transportation and economic roles, and, in some cases, have a high symbolic value that make them particularly attractive for terrorist attacks. In addition, to ensure the surface transportation infrastructure protection is important not just from the perspective of maintaining its normal important functions but also for its emergency response importance and usefulness in the context of a terrorist incident on or off the transportation system.

To give an answer to these issues, the ISTIMES project aimed at developing and implementing an innovative system for the monitoring of critical transport infrastructure. The system is based on new ICT technologies and electromagnetic sensor synergy. In particular, it benefits of the integration of remote and in situ electromagnetic observation technologies for a flexibility in terms of spatial resolution/coverage, wave penetration and temporal acquisition rates. In addition, the system exploits an infrastructure management that requires information, pushing the monitoring system to incorporate data fusion and diagnosis procedures together with a presentation system. The final result is the development of a system able to tackle the main issue of the structural health monitoring regarding how to measure, acquire, process, integrate and analyse unprecedented and massive volumes of data coming from terrestrial and satellite sensors, in order to achieve detailed information about the condition and status of the structures under investigation. In conclusion, ISTIMES enables long-term monitoring and a quick damage assessment of the infrastructures by means of a scalable ICT architecture able to provide services via WEB and to "reconfigure" the monitoring strategy on the basis of the specific use-case.

Therefore, the main contributions of the ISTIMES system to the EU necessities in the monitoring of critical transport infrastructure is manifold.

- It makes it possible to achieve monitoring of the transport infrastructures not only in their normal operative conditions but also during and after that the crisis has occurred.
- The first modality of operation is associated to a long-term monitoring, which has the following features: it is distributed to have a global vision of the infrastructure both in operative and crisis conditions; it is able to give a detailed local information on more sensitive and damaged part of the infrastructure; it is able to perform the diagnosis on a time scale from quasi real-time to a long term.
- The second modality of use of the system aims at performing a quick damage assessment; this is possible thanks to the use and integration of in situ and remote sensing techniques able to give fast and reliable information about the dynamical behaviour of the structure and to perform diagnostics of more important structural elements of the

infrastructure.

Therefore, the ISTIMES system allows to overcome the conventional, and rather limiting, vision of damage detection, since it will be able to give an answer also to the needs of:

- Assessing of structural integrity after the risk phenomenon;
- Validating modifications to an existing structure;
- Assessing safety and performance of structures affected by external works;
- Tracking long term movement or degradation of materials in critical structures;
- Providing a feedback loop to design;
- Assessing fatigue life;
- Checking novel systems of construction and new structural forms;
- Assessing of structural integrity after the risk event;
- Enhancing effectiveness of resources as construction declines and maintenance needs increase;
- Catering for the move towards performance-based design philosophy.

In addition, the outcomes of ISTIMES are of relevant interest for the Civil Protection Community Action Program for early warning and crisis management in the case of attacks and hazards and for the prevention of the risks due to the ageing of the infrastructure with a particular interest in the soft risk, the latter being the slow degradation of the structure leading to eventual catastrophe. The “ageing” problem is particularly felt not only in Europe and this opens a potentially large market to the exploitation of ISTIMES,

The strategic impact of the ISTIMES results can be summarized as:

- Implementing a multi-hazard and risk management monitoring system with a special regard to transport infrastructure protection and maintenance.
- Harmonizing and integrating different sensing techniques for the non-invasive multiple hazards and risk assessment.
- Facing the objectives with a multidisciplinary approach and promoting the interaction and cooperation between scientific experts, end-users, industry, decision makers.

In addition, the project permits to capitalize on dual use benefits such as:

- Highway emergency management systems for evacuation and emergency access, including detection, surveillance, and traveler information applications, are needed to improve the operational efficiency of congested metropolitan areas, as well as to serve natural and non-terrorist technological disaster evacuation purposes.
- Improved terrorism-responsive emergency management facilities and procedures, such as integrated and interoperable interagency communications, provide the basis for augmented incident and non-terrorism-related emergency management.

Main dissemination activities

A detailed description of the main actions for the dissemination of the project is provided in Del 6.6 “Final dissemination report listing all activities with measures of success”. Here. We report a rief synthesis of these actions.

The ISTIMES dissemination activities were mainly addressed through two different modalities:

- Internal dissemination;
- Large scale dissemination.

Both dissemination modalities were considered of the same significance. In fact, an effective dissemination addressed outward is possible only if a significant degree of harmonisation and knowledge exchange among ISTIMES partners, having different technical and scientific background and expertise, is achieved.

It is worth noting that a significant effort has been made for the internal dissemination among ISTIMES partners thanks to a good number of scientific meetings, also involving partners from different work-packages, a continuous and day-by day knowledge and information exchange/transfer from scientific and administrative management to partners, and a FPT tool necessary to share all the data collected during the project. At the end of the project, a strong exchange of information/knowledge was achieved non only in the same scientific area but also between different areas.

Large scale dissemination

The large scale dissemination has been structured in several sub-activities:

- Scientific dissemination;
- Steering Committee;
- Web site;
- Dissemination towards end-users with the direct involvement of the partners, especially the DPC, TERN, IFSTTAR, TDE and TERN;
- User Forum;
- Dissemination “on demand”;
- Other dissemination actions performed through several media (newspapers, magazines, broadcasting TV or radio stations, video, brochures..) accessible from not specialist audience.

Scientific dissemination

The outputs of this activity were: publications of papers on international scientific journals; organization of special issues on critical infrastructure diagnostics and monitoring in international scientific journals; attendance and presentation of the ISTIMES results at scientific meetings/conferences/workshops; organization of dedicated sessions on critical infrastructure diagnostics and monitoring at International Conferences. At the end of the project, we achieved the following results:

29 papers published on international journals;

66 published and presented conference proceedings and abstracts;

Four special issues on International Journals;

Two sessions and a mini-symposium organised and chaired at International Conferences.

The high quality of the scientific production is tested by the award recognised to two papers as below:

- Reale D., Fornaro G., Pauciullo A., Zhu X., and Bamler R. (2011), "Tomographic Imaging and Monitoring of Buildings With Very High Resolution SAR Data.", IEEE GEOSCIENCE AND REMOTE SENSING LETTERS, VOL. 8, NO. 4, JULY *2011 has been awarded as the 2011 Best paper published in IEEE Geoscience and Remote Sensing Letters;*
- Nordebo S., Gustafsson M., Soldovieri F., ``Data fusion for reconstruction algorithms via different sensors in geophysical sensing", Journal of Geophysics and Engineering, vol. 8, pp. S54-S60, 2011, *has been included among the "Highlights 2011" papers of Journal of Geophysics and Engineering Highlights 2011 is a special collection of papers that represents the breadth and excellence of the work published in JGE on 2011. The articles were selected for their significance in the field, multidisciplinary interest, scientific impact and highest number of downloads.*

Figure 9 – EGU 2011 about ISTIMES project

Steering Committee

Since the redaction of the proposal, a Steering Committee was foreseen with the aim of identifying key-actions to be performed and improved and critical points of the project and promoting the key-actions for the dissemination and exploitation of the results. The Steering Committee was also an important tool to disseminate the ISTIMES outcomes among the communities of the Committee members as: ICT services implementers and providers; assessment, monitoring and control of structures of relevant civil and industrial interest, in particular the transportation infrastructure; security field with particular attention to GMES initiative.

Web site

The website was periodically and continuously updated by TERN thanks to the contributions (publications, meetings, documents, news, etc) and suggestions from all the other ISTIMES partners.

End-users involvement

ISTIMES project has particularly benefited of the direct involvement in the project of a significant End-User such as Italian Civil Protection Department ensuring a threefold advantage: 1) a strong and assessed link with different typologies of End-users such as: Defence, Local and Regional Authorities, major infrastructure manager boards, etc.; 2) a well branched diffusion on the Italian national territory; 3) a link with National Civil Protection of other European Countries. A dissemination effort was made towards the "European Construction Technology platform (ECTP)" and NEREUS, Network of European Regions Using Space Technologies. Strictly related to the NEREUS activities was the participation and the presentation of ISTIMES strategy and activities at Toulouse Space Show 2012 in the "4th International Conference on Space Applications". Another main dissemination activity was towards SERIT (SEcurity Research in ITaly), which is the Italian Technological Platform, formally recognized by the Minister of Education, University and Research, which deals with the Security thematic in Italy.

About fifty bilateral meetings and presentations were finalised towards significant members of the end-users community.

User Forum

An embryonic user forum including ISTIMES partners and relevant End-users made it possible the dissemination of the ISTIMES concepts to End-users, also by benefiting of the willing and skills of expert End-Users in providing suggestions and driving the ISTIMES strategies and technologies. This first nucleus of end-users together with the GMES experience pointed out the necessity to implement, during the second part of the project, a virtual and physical space where to establish a continuous debate between expert and non-expert End-users and between the End-users and the ISTIMES team. The User Forum, which in principle was planned as an extension of the ISTIMES website, has been redesigned in order to exploit the existing professional social networking websites such as LinkedIn. Therefore, a discussion group on Linkedin named ISTIMES FALL-OUT (http://www.linkedin.com/groups/ISTIMES-FALLOUT-4499762) has been created and tested amongst the ISTIMES partners. End users and partners are and will be involved in discussions about the most significant outcomes of ISTIMES project.

Dissemination "on demand"

The dissemination on demand was not foreseen at the time of proposal writing and has been achieved during the project as a proof of the significant interest of the end-user community towards ISTIMES results and outcomes. In particular, the dissemination on demand has been performed thanks to the steps summarized below:

- The first step was the organization and finalization of bilateral formal and informal meetings towards end-users where the ISTIMES strategy, activities and results were presented (a list of the main meetings has been reported in the subsection 4.4 of present report);
- The relationships with some end-users have been assessed thanks also to the user forum;
- Several end-users have considered the ISTIMES approach and technologies relevant for their institutional aims and missions;
- The final step, at the boundary between dissemination and exploitation, regards the requests to use the ISTIMES technologies to face real problems.

Dissemination on demand was activated towards significant end-users in the field of the critical infrastructures monitoring and ,more generally, civil engineering. The details of this activity are reported in the Del. 6.6.

Other dissemination actions

Other dissemination actions: promotion and dissemination of ISTIMES concepts and technologies was encouraged at every scale and for every kind of non-specialised audience. Concerning this, the publication of newspaper and/or magazines articles at several scales, such as interviews given during programmes on local/regional/national TV broadcasting stations or publication of ISTIMES profile on European specialized magazine, have been promoted. A brief documentary about demonstration activities performed at Musmeci Bridge has been realized in Italian language. The movie has been projected during workshops such as FUTURO REMOTO and during meetings at local and national scale. On the basis of this experience a new documentary in English language regarding overall ISTIMES activities has been prepared.

Main Exploitation actions

Exploitation and promotion of ISTIMES results were carried out according to the first actions expected by the exploitation plan, which were addressed to involve the following potential users, grouped as: enterprises within the ISTIMES Consortium; end-users within the ISTIMES Consortium; scientific partners inside ISTIMES Consortium; end-user, industry and scientific communities outside ISTIMES Consortium.

In order to involve the end users typologies, the following actions were performed.

- The promotion of the results by the ISTIMES end-users to the main European operators in infrastructures management by exploiting existing collaborations between ISTIMES end-user partners and the European community and usual tools such as participation to workshops and other dedicated specific events.
- The improvement of the existing products and commercialization in the market both of the system architecture and sensor technologies by exploiting contacts with high technologies companies.
- The support to SMEs consortium for the development of new “services” in the market of the environmental and infrastructure monitoring, in the European framework.
- Moreover, ISTIMES exploitation strategy was updated in order to push the exploitation beyond the end of the project.

Main actions of this new strategy were:

- Exploitation actions towards SMEs and enterprises producing and improving sensors technologies based on the development of new hardware and advanced software components to command sensors and acquire and process data.
- Exploitation actions towards SMEs and enterprises delivering surveillance and monitoring services in the more general fields of the critical infrastructures protection and environmental monitoring.
- Widespread Exploitation actions addressed to all possible End-Users.
- Exploitation towards to the scientific community for mid- and long term improvements by novel scientific outcomes in the fields of the sensors and ICT architectures.

Therefore, the ISTIMES Exploitation strategy was articulated through the steps below:

- Direct involvement of end-users as partners in the project.
- Exploitation of the technological results from the industrial and SME partners involved in the project.
- Non-commercial exploitation of the ISTIMES results in terms of scientific outcomes.
- Promotion of the ISTIMES concepts and results to the end-user community.
- Promotion of the technological results in terms of advanced electromagnetic sensing techniques and ICT based solutions for the control and command of advanced sensors and sensor networks.
- Promotion of advanced services, related to the ISTIMES results, in the field of the environmental and critical infrastructure monitoring.
- Promotion of the ISTIMES results as a “substrate” for future actions in the field of the research and innovation (new projects, new scientific areas,..).

The ISTIMES exploitation activities was mainly addressed through two main modalities:

- Exploitation of the ISTIMES results carried out directly by the partners of the project.
- Promotion and Exploitation of the ISTIMES outcomes outside of the Consortium, towards the different platforms as: end-users, service providers and high technological industry and SME, scientific communities.

The main outcomes of the exploitation and promotion actions are detailed in the updated version of the Del. 6.5 “Exploitation Plan” (version 1.2). Here, we stress the significant “Exploitation on demand” activity, where the ISTIMES Consortium was required to provide specific diagnostics and monitoring services from end-users in the fields of the control not only of the transportation infrastructures, but also of other kinds of critical infrastructures. Therefore, the “exploitation on demand” is the first attempt to transform the scientific outcomes into operational services which can be easily used and adopted by non-expert users.

Also, attention was made to the non-commercial exploitation of the results, not only in terms of new research activities, start-up and assessment of scientific cooperation inside and outside the ISTIMES Consortium, but also in terms of identification of mid-term scientific and technical challenges for an improvement and an extension of the use of ISTIMES approach in operative conditions for the general frames of safety and environmental monitoring.

Photographs illustrating and promoting the work of the project

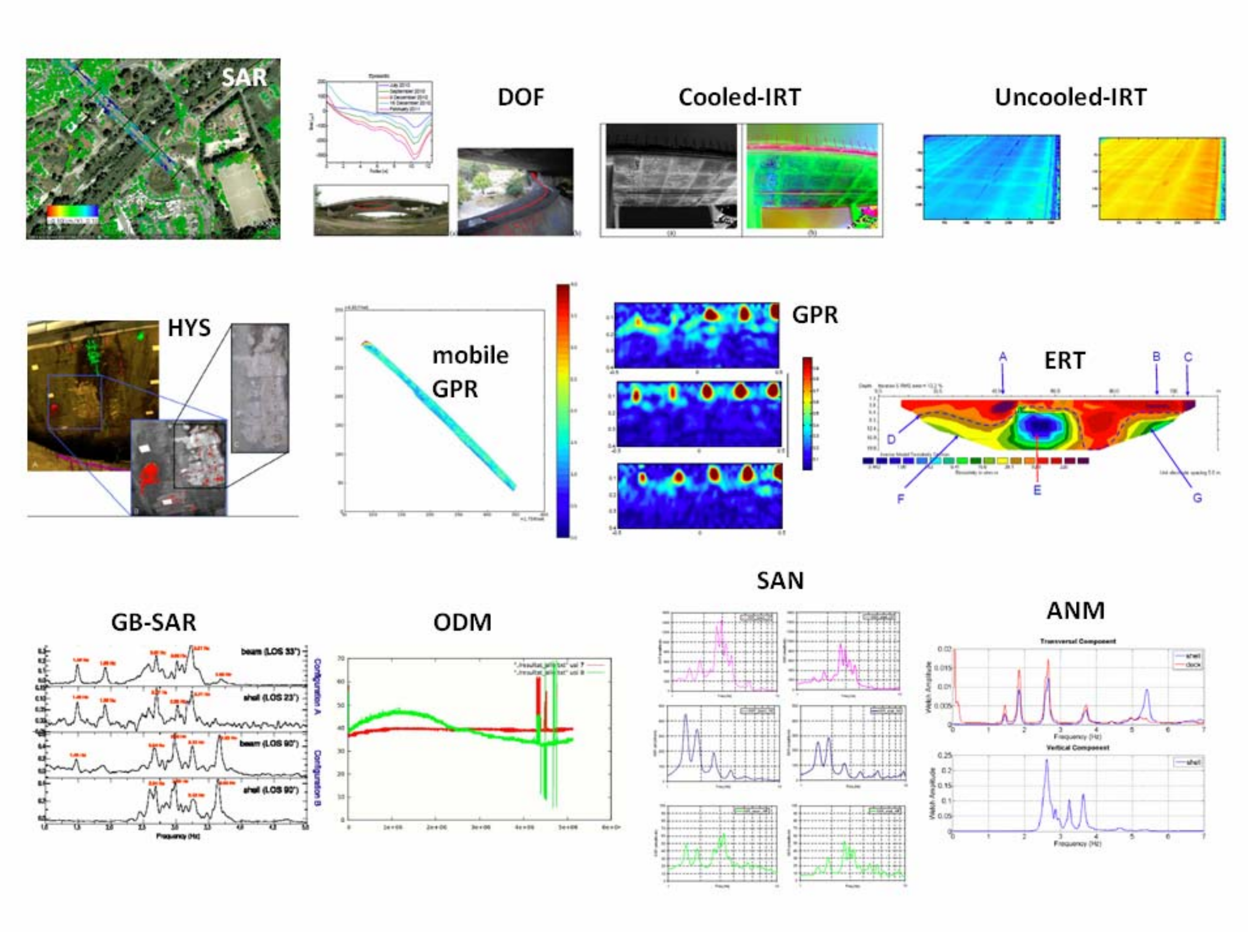

Figure 10 - Examples of the results obtained on the Musmeci bridge for each used technique

Figure 11 - ISTIMES people at EGU 2011

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The address of the project public website

www.istimes.eu

The project logo