POLITECNICO DI TORINO

Faculty of Civil Engineering

Master Thesis:

Satellite Data for the Monitoring of Urban Areas - A State of The Art

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Contents

Abstract

This thesis aims to provide an overview of the current state of structural monitoring of urban areas through the use of satellite data, in particular deformation time series and mean velocity deformation associated to specific targets. Once the basic characteristics relating to the operation of the synthetic aperture radar have been described, we continue with the mention of some of the most important missions launched in space in recent years and describe the most important techniques through which it is possible to collect deformation data on the ground and mean velocity deformation, which are the most important results deriving from these techniques, are described.

Thanks to the technological innovation, it is possible to collect a huge amount of deformation data; because of this data is not easy to interpret, especially in the absence of further information about the types of structures existing in a monitored area, one objective is to combine such data in a unique way with structural classes through specific criteria. This field of research is still under development and no examples are currently available from the literature; however, there are additional techniques that allow to extract useful information from amplitude satellite images, without taking into account the deformation data.

Once the points of interest to the ground have been identified, it is necessary to organize a system for the prompt detection of anomalies in the deformation time series associated with each target in order to allow in situ inspection and prevent worse situations. These early warning systems are promising tool to support all existing monitoring techniques.

Introduction

The following thesis focuses on the emerging methodology of monitoring urban areas with the use of satellite data, in particular are evaluated deformation time series and mean velocity deformation associated to specific targets on structures. This methodology has improved considerably in recent years both from a technological point of view with the advent of new missions by the major European states and from the point of view of the fields of application, in fact, several emerging studies of deformative phenomena relative to earthquakes, subsidence, landslides or any natural event capable of causing damage to buildings or structures built by man start to be present in literature. These resources are particularly suitable to be detected with satellite radar techniques because they demonstrate a maintenance of electromagnetic properties over time, fundamental characteristic used by satellites in order to identify ground targets and evaluate historical series of deformation.
This type of data is not in competition with the other more common techniques, in fact in the studies derived from the literature it is possible to see a combined use of several techniques in order to validate the satellite measurements and make the analysis more effective. At the same time, it is important to underline the positive aspects which have led the use of satellite data to an increasing use: satellites are able to acquire data even under unfavorable weather conditions and do not need to install additional equipment in areas considered at risk, this may be considered a considerable advantage in order to avoid accidents of the staff responsible for carrying out the measurements.
In the first chapter of the thesis are described the fundamental characteristics of the monitoring technique to introduce the reader to the basic knowledge and then a series of case studies are presented concerning different fields of application. Then, in the second chapter we focus on the description of the principle interferometric techniques deriving from satellite data, in particular the permanent scatterer InSAR and the Small Baseline Subset InSAR techniques; several examples of application of these techniques are presented. In the third chapter after a research of the existing classification algorithms, few studies which aims to extract some features from the amplitude data derived from satellite data are shown. Finally, in the fourth chapter is presented the concept of early warning and its application using deformation time series data in order to prevent irreparable damage to the monitored building.
The final objective of the thesis is to outline the state of the art about the monitoring of urban areas with satellite interferometric data trying to identify the best technology currently available on engineering application, focusing the attention on the utility of deformation time series and mean deformation velocities.

1.Syntetic Aperture Radar (SAR)

1.1 SAR system generality

In order to introduce the SAR System, we are going to explain some basic concepts. The principle of RADAR operation (RAdio Detecting And Ranging) is a transmitting system which illuminates the earth's surface with an electromagnetic wave which, impacting the surrounding space, allows a scattering phenomenon (Tele-Rilevamento Europa T.R.E. s.r.l., 2009).
Talking about satellite radar system, we specifically refer to Syntetic Aperture Radar in the field monitoring of urban areas. This system allows to solve the compromise between resolution and extension of the observed area, combining coherently (considering the amplitude and phase values) data acquired by the sensor in successive positions. With this method a large, fictitious synthetic aperture antenna is synthesized (Ferretti , et al., 2007).
Satellite radar systems provide electromagnetic images of the Earth's surface with spatial resolution of a few meters. Compared to the most famous optical systems operate with continuity, being able to acquire data in presence of cloud cover and both day and night, this is an important advantage introduce this type of technology in the monitoring field of urban areas.
A part of the diffused field returns to the transmitting station, where its characteristics are measured (phase and amplitude); in fact, the station is also able to receive the signal. With the phase data it is possible to evaluate the target sensor distance while with the amplitude data you gain information regarding the reflection properties (how much bright an object is in a SAR image). The device can detect the electromagnetic target and, by measuring the time delay between the moment of transmission and the time of reception, evaluate the distance between the target and the antenna, locating it precisely along the pointing direction of the antenna (range direction). The directivity of the antenna used to transmit and receive the radar signal, that is the selectivity in the lighting of the surrounding space allows to locate the object also along the other dimension (called azimuth). In order to give an example of how this type of system works in Figure 1 is shown the acquisition geometry of the European Remote-Sensing satellite, ERS-1 launched by the European Space Agency: the direction parallel to the orbit is called azimuth and approximately coincides with the North-South direction. The resolution (the ability to recognize two distinct targets) in azimuth is about 5 m. The direction of the sensor-target joint (perpendicular to the orbit and inclined of an angle ϑ - called off-nadir - with respect to the vertical equal average to 23°) is called slant range (or more simply range) or Line Of sight (LOS). The resolution in range is about 8 m, its projection on the plane (ground range) about 20 m. It is worth to say that the news SAR missions with improved sensors can guarantee resolutions in both directions even better than the previous ones. The radar images are therefore developed along the directions of range and azimuth, usually called SAR coordinates.

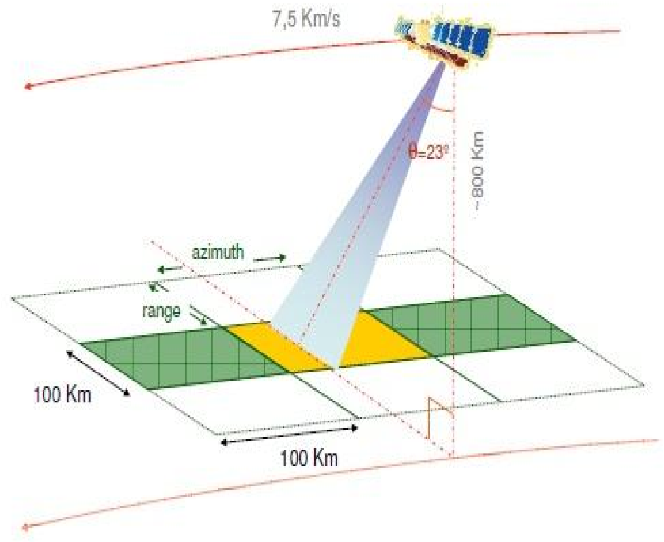

Figure 1: Acquisition geometry of the SAR ERS-1 system, (Tele-Rilevamento Europa T.R.E. s.r.l., 2009).

Where:

- ϑ: is the off nadir angle, which is the look angle between the Line of Sight respect the perpendicular to the orbit.
- Azimuth: is the orbit satellite direction and it’s approximately the same of the North-South direction.
- Range: is the direction perpendicular to Azimuth direction.

It is this process that guarantees high resolution even in the azimuth direction. Because the system illuminates the surrounding space with its own electromagnetic radiation it is called “active system”, solar illumination is not required and the frequencies used by the radar penetrate through the clouds, thus avoiding the problems of acquisition of optical systems.
In the SAR image it is possible to recognize the amplitude value, which is the quantity of backscattered radiation from the targets on the Earth surface to the satellite, these values go in each SAR resolution cells in other to build the SAR image. The amplitude value depends of the physics composition of the target. Generally, buildings in urban areas show strong amplitude value, whereas objects like water of vegetal areas show low amplitudes, because the radiation is for a big amount scattered away from the satellite. Taking in to account a stack of SAR images it is possible to generate an image as shown in Figure 2. In the image it is possible to see how the urban areas are more visible and more illuminated, while the other targets appear dimmer.

Figure 2: ERS SAR detected multi-image of Milan (Italy), (Ferretti , et al., 2007).

1.2 SAR images

SAR images are matrices of complex numbers defined by amplitude and phase quantities. The amplitude detects the amount of electromagnetic field retrodiffused towards the satellite, while the phase depends on several factors, including the sensor-target distance. Precisely the phase constitutes the key information for interferometric applications aimed at identifying areas subject to surface movement phenomena. During the acquisition phase each target on the ground is hit by more electromagnetic pulses emitted by the sensor along its orbit. Radar images proper born only downstream of a focusing algorithm, which allows to associate to the various cells of resolution (pixels) the relative contribution of retrodiffused energy. Taking as example ERS satellite, each element of the matrix corresponds an area of earth of 20 for 5 meters approximately (on flat ground). Each image contains a quantity of data for an area of 100 x 100 km (10000 km^2). During the various passages along the same orbit the satellites deviate slightly from the nominal trajectory, in fact there are variations of the order of the hundreds of meters described by the parameter geometric baseline (or normal); consequently the capture geometry for the same area it's not the same during different detections from slightly different angles ϑ creating pixel matrices not corresponding to the same ground resolution cell.

To perform the analysis, it is necessary to match the same pixel in different images resolution cell, a data processing step called re sampling. Between all acquisitions it is chosen one image as referring system (master image) and all the remaining ones, called slaves, are embroidered on the geometry of the master, thanks to an appropriate model, so as to have the same grid of reference for all the passages of the satellite. The model allows to compensate both a rotation and a translation induced on the images because of the different angle of view. The choice of the master image is mainly dictated by the need to minimize the so-called temporal and geometric decoration phenomena. For such reason, in the initial phase the historical series of each target has zero value of displacement in correspondence of the date of acquisition of the master image.

1.3 Perspective deformations

The mode of acquisition, not perpendicular to the ground but according to an angle of view ϑ, described before, gives rise in the focused images to some prospective deformations due to the topography of the ground. According to the slope of the ground are distinguished three different types of deformation phenomena Figure 3:

- Foreshortening: occurs when the slope of the ground tends to be perpendicular to the sensor-target joint (positive slope equal to the angle of off-nadir q); in these cases the contribution of more points is concentrated in a few cells producing very bright pixels in the image of amplitude.

- Layover: it is possible to see this phenomenon when ground slope is greater than the angle q; this produces a strong distortion of the image that prevents the correct interpretation of the signal and any quantitative analysis.

- Shadowing: occurs when some areas cannot be illuminated by the radar pulse because they are shielded by other objects; therefore, very dark areas (in the shade) are produced in the image of width.

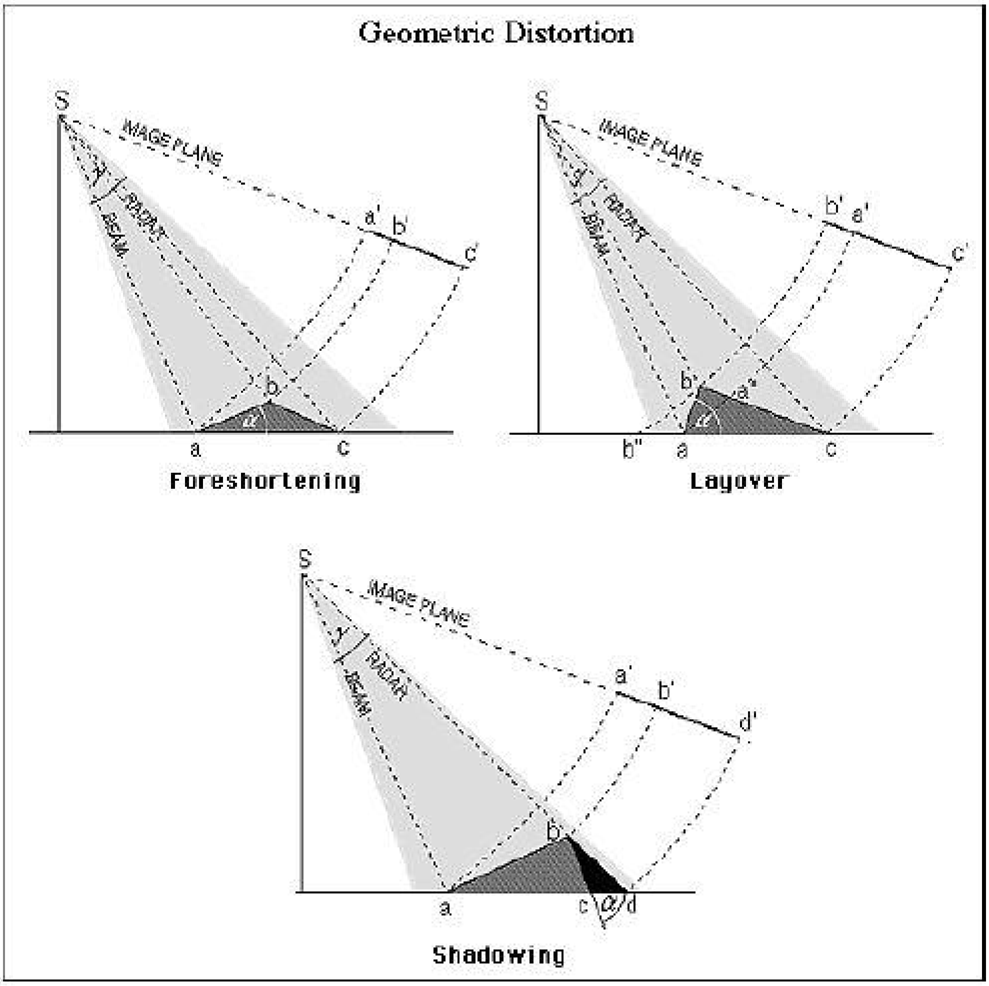

Figure 3: Perspective deformations in SAR image, (Tele-Rilevamento Europa T.R.E. s.r.l., 2009).

1.4 SAR differential interferometry

The traditional technique for SAR data study is differential interferometry, which is based on the analysis of the evolution of the phase value between two different acquisitions in order to identify differences due to deformation, topography or atmospheric disturbances. The interferogram is the data matrix obtained by comparing the two distinct acquisitions of the same area and contains information about the various contributions that generate the phase value.
As mentioned, the relative radar signal referred to a target is characterized by two values: the amplitude and the phase. The phase contains the most important information for interferometric applications: the sensor-target distance. The terms that contribute to the phase of a single SAR image are multiple and can be summarized in the following equation:

$$\phi = \psi + \frac{4\pi}{\lambda} \cdot r + \alpha + n \tag{1}$$

where:
- Φ: is the total phase recorded by the sensor.
- ψ: is the phase term due to the reflectivity of the target (depending on the material and its geometry).
- α: is a phase contribution due to the atmosphere.
- r: is the sensor-target distance (this value, multiplied by the constant factor in the equation, is indicated by the term propagator).
- n: is an unavoidable noise of the acquisition system.

The phase of a single SAR image in fact is not useful, because it is impossible to discriminate one contribution from the other. If are available at least two acquisitions related to the same area, accurately recorded on the same reference grid, it is possible to use the information contained in them. In this case an interferogram is generated by subtracting the phase of one image from the other image. The objective of the interferometric technique is to isolate the actual phase contributions due to the movement of the target and not referred to noise and accurately estimate the difference in optical path of the electromagnetic wave transmitted in two successive acquisitions and backscattered by the target on the ground.
In order to isolate the contribution due to the displacement of the target it is necessary to make a simplification, it is assumed to be in ideal conditions: within a sufficiently narrow time interval between two successive acquisitions the term due to the reflectivity of the target and that related to the atmospheric disturbance can be considered constant and therefore eliminated in creating the interferogram. The differential equation between two acquisitions which generate the interferogram becomes:

$$\Delta\phi = \Delta\psi + \frac{4\pi}{\lambda} \cdot r + \Delta\alpha + n = \frac{4\pi}{\lambda} \cdot r \tag{2}$$

In this equation the phase value depends only to the target-sensor distance (r) and a constant term which depends from the characteristic wavelength of the signal (λ).
In order to understand the physical aspect of the problem, the interferogram is done with a series of colored fringes which represent a cycle of variation of the interferometric phase in the selected area. As mentioned before, if no particular changes occur in the period between the two acquisitions, reflectivity contributions are eliminated and the phase of the interferogram depends, with good approximation, only on the sensor-target distance and thus from any movement between the two acquisitions. Under ideal condition, therefore the interferogram can be assimilated to a map of movements.
The quality of a specific interferogram is referred to phenomena of temporal decorrelation caused by the variation of the electromagnetic properties (reflectivity) of radar targets over time. These phenomena are more relevant to the increase of the interval of time between the two acquisitions used, defined temporal baseline. Areas covered by vegetation, easily influenced by wind and of different appearance to according to the season, they are a source of decorrelationship, while urban centers and exposed rocks remain more stable over time. The quality of the interferogram also depends on the distance between the two orbits traveled by the sensor during the acquisition of the two images (called normal or geometric baseline). It can be shown that the greater the absolute value of the baseline, the smaller the common band between the two signals and therefore the lower the signal-noise ratio relative to the interferogram generated by them. This noise is called: geometric decorrelationship. As an example, the result of an interferometric analysis of the city of L'Aquila in Italy is given in Figure 4:

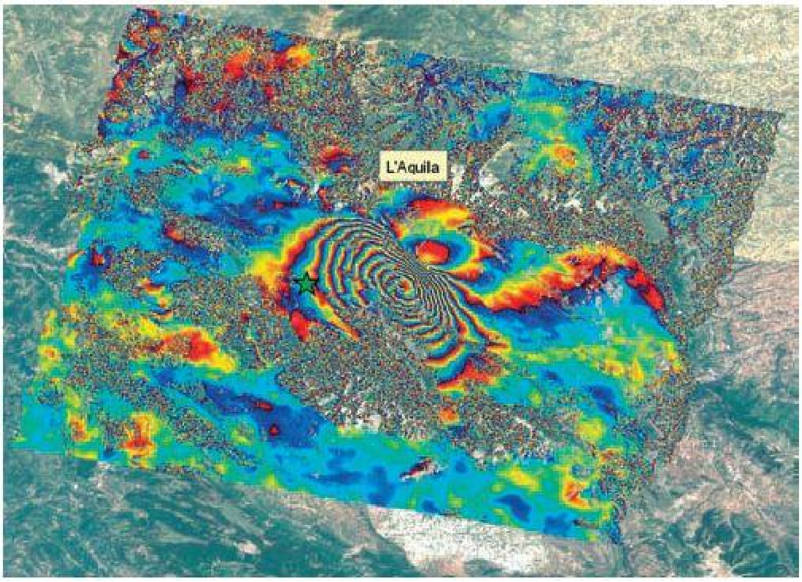

Figure 4: Interferogram generated from two different SAR Images in the city of L'Aquila, (Reg. Liguria, Reg. Piemonte, Reg. Valle D'Aosta, 2009).

In order to evaluate the real deformation occurred between two acquisitions is necessary to depurate the phase value from the topography value, this is possible with the Three Pass Interferometry or the DTM elimination method (Massonet & Feigl, 1998).
The phase assume the same values with a multiple integer of 2π (correspondent colour fringe in the interferogram) and it is not useful in absolute value; to solve this problem it is necessary to use the unwrapped phase which is important to extract useful information from the interferogram.

The phase unwrapping is in fact similar to start from a series of curves level map (it is known simply the variation of altitude between one and the other curve) to a real elevation map in which each point is associated with an altitude all a from a known altitude measurement point.

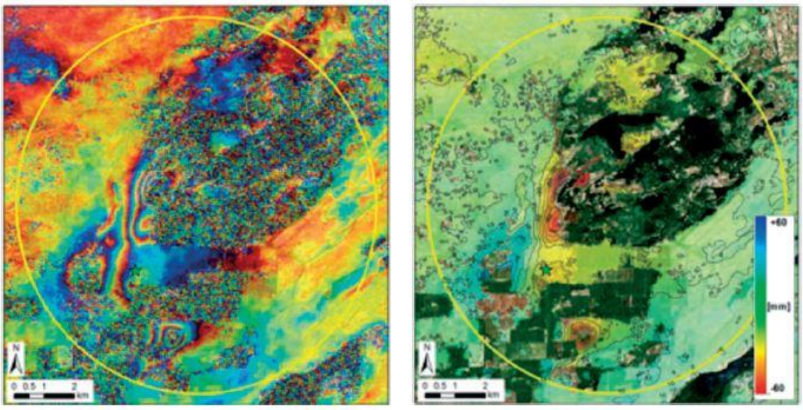

Figure 5: Deformation map generated from an interferogram, (Reg. Piemonte, Reg. Liguria, Reg. Valle D'aosta, 2012)

Through the interferometric analysis it is possible to create maps of displacement and velocity of displacement of the investigated points in a determined area; at the same time it is possible to derive a digital model of elevation that associates to each point its altitude Figure 5.
A fundamental aspect to emphasize is that all the measures of dimension and displacement obtained in the analysis are differentials in space and time, that is they are referred to a specific point called reference point. This point belongs to the master image to which all surrounding points are docked. The parameters of dimension, displacement and speed of displacement referred to the reference point are placed conventionally equal to zero, without knowing a priori the dynamics in existence in the examined territory.

1.5 Georeferencing

In general terms, georeferencing is a procedure for assigning coordinates standard (according to a given projection) at the points of an image, using control points (Ground Control Point or GCP) of a topographic map or of an already georeferenced image. It is made by applying a deformation to the image (conforming transformation, related, etc.) that has the purpose to bring the control points to the right place in order to adapt the original image to the geographical/cartographic coordinates assigned to him GCP and to return the objects the size real on the scale. Originally, each target belongs to a single SAR system sampling cell defined by two coordinate values called ranges and azimuth. Thanks to the geo-referencing process, that is to the connection to the coordinate system taken as reference for the representation of the study area, the whole of the PS acquires a real cartographic meaning.

Geo-referencing can be divided in two steps:

- Transition from coordinates in the SAR system to geographical coordinates in the GCS WGS84.
- Alignment of PS on the cartographic support available through rigid translation.

1.6 SAR missions in the world

1.6.1 RADARSTAT Constellation mission

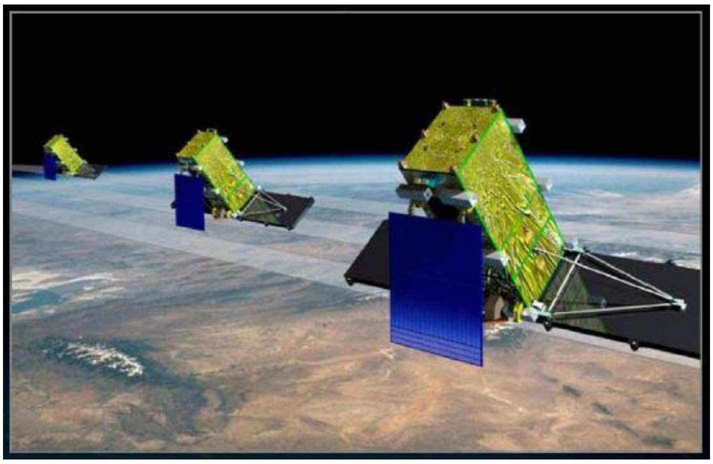

Figure 6: RADARSAT Constellation Mission, (Canadian Space Agency, s.d.).

On June 2019 Canadian Space Agency launched the RADARSAT Constellation Mission (RCM) which was the evolution of the previous RADARSAT Figure 6. The RADARSAT was a joint Canada (Canadian Space Agency/Canada Center for Remote Sensing) and United States (NASA) project (NASA, 2016).
The focus of RADARSAT Constellation Mission is Synthetic Aperture Radar and it is used for the following fields of expertise (Boucher, 2019):

- Sea monitoring: (the ice's state conservation, disasters deriving from pollution and ship monitoring).
- Catastrophe monitoring: (prevention, early warning, immediat recovery).
- Ecosystem's health: (agriculture, wetlands, forestry and coastal change monitoring)

Generally, the satellites stay operative for seven years but it is possible to consider even a longer life in some case scenarios.

Table 1: RADARSAT satellite properties.

RADARSAT Constellation Mission (RCM) characteristics	
Revisiting time	12 days/satellite
Radar center frequency	C-Band
Spatial resolution	5-50 m

1.6.2 NISAR mission

Figure 7: NISAR satellite, (NASA, 2016).

NISAR is a mission in cooperation between two organizations: the National Aeronautics and Space Administration (NASA) and the Indian Space Research Organization (ISRO), its launch is planned for December 2021 (NASA, 2018).
This project is the first NASA mission, before that NASA used the RADARSAT constellation in cooperation with the Canadian Space Agency, which has the responsibility to monitor the heart surface considering every aspects (ecosystems, deformation of built/no built areas and finally the state of health of the seas). This mission is studied to include systems with L and S band, which is an important advantage respect the previous global missions; this is important in order to satisfy every request deriving from the previous listed aspects.
It is important to notice that the NISAR mission will help also the monitoring of urban areas susceptible to natural disasters like earthquakes, landslides and subsidence phenomena. The data deriving from the analysis of the NISAR satellite will be available to the public in order to help the global society in the easiest way possible. It is known that the synthetic aperture radar is able to work also with cloud conditions and considering the high spatial resolution this will be and important instrument to give time series data displacements of the urban areas. The hope is that this type of monitoring will increasingly be used.

Table 2: NISAR Properties.

NASA-ISRO SAR (NISAR) characteristics	
Revisiting time	12 days
Radar center frequency	L/S-Band
Spatial resolution	3-10 m

1.6.3 COSMO-SkyMed Second Generation mission

Figure 8: COSMO-SkyMed satellite, (Maday, s.d.).

The Italian Space Agency has launched the Second-Generation constellation of satellites on December 2019, this is the evolution of the COSMO SkyMed previous mission (Planetek Italia s.r.l., s.d.), which is already active with its four satellites. On that data it was launched the first satellite and the second one could be launched in 2021.

The purpose of this mission is the same of the NISAR and RADARSAT projects, so it will be very important for monitoring the Earth Surface in general and particularly the habituated areas of the planet in order to reduce the loss of resources. The aim of this mission is to improve the quality of the SAR imaging of the previous first generation of satellites and maintaining the compatibility between the two missions.

Differently from the NISAR mission, it has only the X-Band on board and a revisiting time of 16 days for each satellite; this time could seem big, but considering the entire constellation this time is reduced between each satellite. The Second Generation has the same orbit of the first generation of 4 satellite, this means that considering all the satellites it is possible to reduce the revisiting time to 12 hours.

Table 3: COSMO SkyMed properties.

COSMO SkyMed characteristics	
Revisiting time	16 days
Radar center frequency	X-Band
Spatial resolution	1-100 m

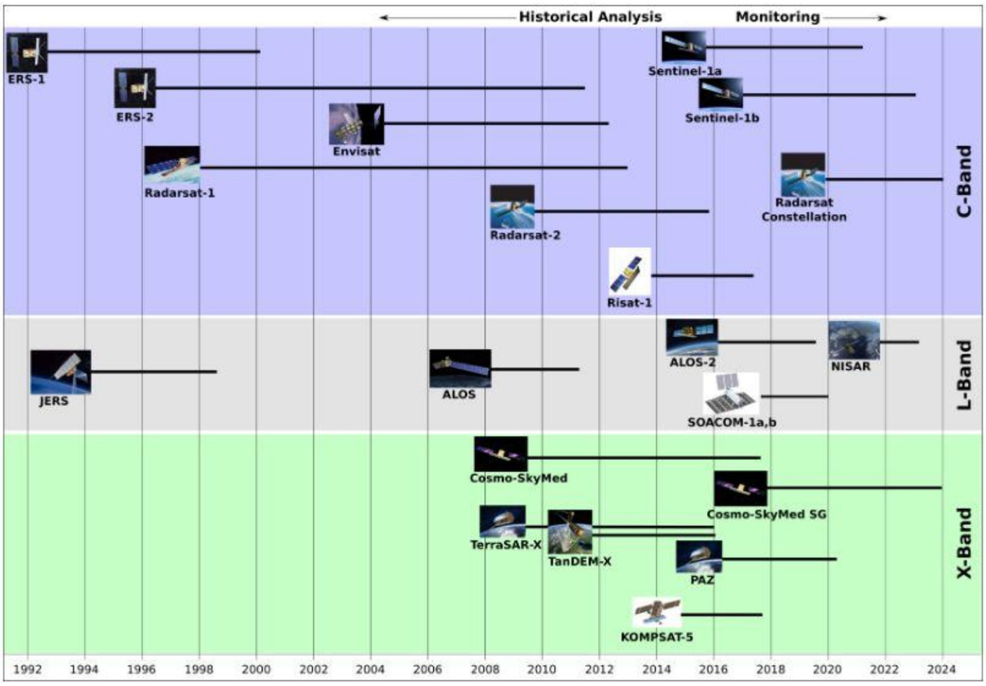

Figure 9: historical evolution of SAR missions

2. SAR Techniques

One of the upcoming techniques for monitoring deformations phenomena of the earth surface is the Differential synthetic aperture radar interferometry (DInSAR), which can guarantee millimetric precision on the deformation time series, which are the most important results of the technique for building monitoring. The key of these techniques is the evaluation of the phase differences between a stack of SAR images of a certain monitored area, thus let the researcher to extract the deformation along the Line Of Sight direction (LOS), which is the conjunction between the satellite and the target. (Tele-Rilevamento Europa T.R.E. s.r.l., 2009). The negative aspects of this technique are the decorrelation phenomena, both in time and in space and terms related to topography/atmosphere.
A new tipology of Advanced DInSAR (A-DInSAR) techniques are born in order to overcome these problems, which have the peculiarity to use a stack of SAR images instead two images; this is an important aspect because this method allows to build a interferogram with more accuracy and also to remove the previous negative aspects. In this work we mention two techniques which depends on the choice of the targets on the Earth surface: the first one is the Permanent Scatterer InSAR technique, which considers targets characterized by a stable amplitude value direction (Tele-Rilevamento Europa T.R.E. s.r.l., 2009) ; the second one is the Small Baseline approach, which refers to distributed targets characterized by a spatial coherence (Berardino, et al., 2002) (Lanari R., 2004).
In the following paragraph we focus on Advanced DInSAR approaches which are the most used in several applications like the studying of deformations phenomena due to landslides, subsidence, and monitoring heritage archeological sites.

2.1 PSInSAR Technique

2.1.1 Description of the method

The Persistent Scatterer Interferometric SAR technique was developed by a team of Politecnico of Milan in 1999 (Tele-Rilevamento Europa T.R.E. s.r.l., 2009), it is born to improve the DInSAR traditional approach, which has many critical aspects as mentioned in the previous paragraph.
This technique is based on the observation that a small subset of radar targets (Persistent Scatterer) which have not effects of geometric correlation (PS are targets much smaller than the resolution cell) and they are stable over time. These targets have a stable phase over the time and are used to overcome and solve the atmospheric noise on the entire SAR image, taking advantage on the fact that atmospheric conditions have small difference in space and are not correlated over time. The elaboration of the PS derived from a statistical study of the radar images and marks a transition from an analysis of a pair of images, typical of the traditional Differential Interferometry, to a multi-image analysis of the entire data set available of the area of interest for selected set of PS.

The basic idea is to focus the analysis on some targets which show stable electromagnetic characteristics over the time, suitable to interferometric measurements (Permanent Scatterer). Once these points are defined, characterized by extremely low phase noise values, it is possible to apply appropriate algorithms that allow to reduce the impact of atmospheric disturbances and derive the historical series deformation of the PS (with millimetric precisions) and estimate accurately the altitude from a reference point (with metric precision). In order to identify the radar measuring points available and successfully filter the atmospheric contribution, it is necessary to consider a high number of images captured on the same area, typically it is necessary to use at least 12-15 acquisitions, but the best results are obtained with more than 25-30 acquisitions. Several objects can turn out to be PS, both of natural origin, both of anthropic origin. The first ones are essentially rocks exposed, uncrowded surfaces, debris heaps. Artificial PS could be: buildings, lampposts, pylons and in general any structure metal oriented to reflect the radar signal to the satellite antenna.
Figure 10 shows a typical result of an analysis PSInSAR. The points colored correspond to the Permanent Scatterers identified in the area of interest: their color means the average speed of long displacement the sensor-target combination (Line Of Sight), positive if approaching the satellite, negative if it moves away. The PS were superimposed on an image optical reference to simplify the interpretation.

The informations related to each PS, collected in digital files are:
- The target position on the ground or its spatial coordinates (latitude/east, longitude/north, altitude).
- The average annual velocity of displacement (measured along the Line Of Sight), reported in mm/year, calculated in the acquisition range of images processed and in relation to the reference point.
- The displacement time history, which represents the evolution of displacement from each PS, evaluated in mm and measured in the systems view direction.

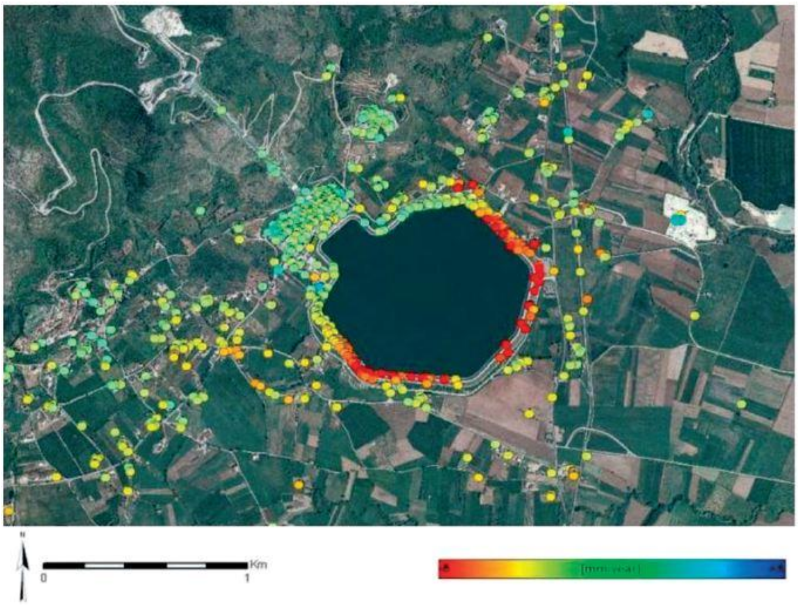

Figure 10: Permanent Scatterer analysis superimposed to an optical photo, (Reg. Liguria, Reg. Piemonte, Reg. Valle D'Aosta, 2009)

2.1.2 Displacements data format

The results derived from the PSInSAR technique can be opened with Microsoft Excel and are divided in three different databases:

- REF: spatial coordinates of the Reference Point, which is the point used as referring systems for all the PS points in the analysis.
- MET: information about each PS in terms of velocity, positions and stability.
- TSR: time series deformations related to each PS.

The REF file shows the spatial coordinates of the referens point (LAT/NORTH, LON/EST). The velocity values of PS are differential and are referred to this point, it is very important to define these coordinates with the high degree of precision as possible.

CODE	LAT	LON
REF	43,9134506	11,4457217

Figure 11: REF coordinates, (Tele-Rilevamento Europa T.R.E. s.r.l., 2009).

The MET file instead gives information about PS, are described geographic properties (LAT/LON) and the quality of the datas (COHERENCE) and finally the mean value velocity (VEL) is referred to the monitored period. In particular, there are the following informations:

- Code: is the code which describes the measured point.
- Lat/North: PS position in North/South direction in geographic/cartographic coordinates.
- Lon/East: PS position in East/West direction in geographic/cartographic coordinates.
- Coherence: identify the quality of the PS data.
- Height: altitude of the PS points referred to WGS84 ellipsoid.
- Vel: mean value velocity in mm/year in the LOS direction.
- V_stdev: dispersion value around the mean value velocity.

CODE	LAT	LON	COHERENCE	VEL	V_STDEV	HEIGHT
A076N	43,6437385	11,1721541	0,81	-1,75	1,17	156,70
A077T	43,6438608	11,1723888	0,77	-2,15	1,18	150,20
A077U	43,6485441	11,2060593	0,79	-1,41	1,09	155,20
A0789	43,6420717	11,1585834	0,68	-1,09	1,25	151,90
A079A	43,6440493	11,1727766	0,89	-2,49	1,14	147,30
A079X	43,6440896	11,1727440	0,73	-0,92	1,19	153,70

Figure 12: Structure of the MET file, (Tele-Rilevamento Europa T.R.E. s.r.l., 2009).

The last one is the TSR file which contains information about the time of acquisition of the data and the number of images detected. With this file it is possible to build the time series displacements of each PS:

CODE	LAT	LON	V_STDEV	COHERENCE	VEL	D20030407	D20030501	D20030525
A4XNS	43,9615964	11,0486399	1,29	0,76	0,82	0,00	-1,27	-5,72
A4XBX	43,9598439	11,0502158	1,25	0,92	0,29	0,00	0,76	-0,39
A4RKQ	43,9292916	11,0534296	1,26	0,94	-1,05	0,00	6,41	2,72
A4X18	43,9651565	11,0539591	1,28	0,92	-0,10	0,00	1,51	-0,62
A4XVZ	43,9639921	11,0536339	1,29	0,81	0,87	0,00	-2,95	-1,06
A4R62	43,9361723	11,0539562	1,21	0,94	1,18	0,00	0,04	-2,85

Figure 13: Structure of the TSR file, (Tele-Rilevamento Europa T.R.E. s.r.l., 2009).

2.1.3 PSInSAR compared to other techniques

Compared to conventional monitoring techniques, the PSInSAR technique offers some advantages, including:

- Acquire information on a network of extremely dense radar heads, especially in urban areas, where the density of permanent scatterer (PS) can reach significantly higher values than can be achieved with conventional geodetic networks; moreover, it must be considered that the targets are already present on the ground and, unlike the traditional measuring instruments (such as geodetic and GPS bench mark, strain gauges, inclinometers), they do not require any production, installation and subsequent maintenance by the operator;

- Reconstruct for each radar target the historical series of movements with a high precision, higher than that of the GPS in vertical direction, and with a high temporal frequency in comparison to the optical levelling;

- Study large portions of land or areas which are difficult to access (since no ground work is required), thus optimising survey costs and time;

- High accuracy of both displacement and annual average speed measurements (up to 0.5 mm/y);

- To compile the historical archive of the European Space Agency (ESA) with the possibility of investigating the evolution of the deformation phenomenon since 1992 (the date on which ERS radar images were acquired), which may prove to be a decisive element, especially where the speeds involved (mm/a) are extremely low and conventional techniques would take years before significant measures can be taken.

It should be pointed out that the PS technique is not in competition with other techniques but, on the contrary, it is in complete synergy with them. The integration of PS data with traditional geodetic measurements and GPS allows to take advantage from techniques mentioned, increasing the number of information available, in favour of a more complete vision of the evolution of the phenomena studied.
With optical levelling a high degree of accuracy can be achieved (0.1 mm on levelling lines with bench marks 100 m one from the other) and arbitrarily fix the position of the balances and the time interval between one survey campaign and the next (unfortunately the campaigns are rarely carried out regularly over time). By virtue of accuracy reachable and of its versatility, this method is absolutely irreplaceable for the study of localized phenomena with high criticality. The GPS, while showing a density of measuring points extremely lower than the PS data and an accuracy in vertical (in the order of cm) lower than both the PSInSAR technique and the optical levelling, is the only tool currently able to offer three-dimensional data and thus the orientation of the vector displacement in space 3-D. This property allows therefore to give indications on the motion also in direction N-S, where the SAR systems cannot appreciably appreciate the movement. Moreover, having information about the ground motion upstream of the processing of SAR data, and in particular the reference point (reference point, REF) used in the analysis PSInSAR, would have the great advantage of obtaining absolute and no longer differential speeds.

2.2 SBAS-InSAR Technique

2.2.1 Description of the method

The first attempt to show the potentiality of the SBAS technique was shown by (Berardino, et al., 2002). As mentioned before, the important aspect of the technique is the choice to consider a stack of SAR image and making a combination of a series of multilook interferograms; these allow to reconstruct mean deformation maps and deformation time series of the monitored area. Even more important is the meaning of the name of the technique, which consider a small spatial difference between two different satellite acquisitions (this allow to reduce spatial decorrelation phenomena).
An important improvement of the technique was proposed by (Lanari R., 2004), allowing to detect displacements at two different scales, local scale and global scale. In order to give an idea of the resolutions available the global scale offers a ground resolution of 100x100 meters and regarding a monitored urban area it is possible to build the deformation time series of the target; considering the local scale the resolution available is 5x20 meters and allows to study deformation phenomena with more accuracy.

The SBAS approach can be divided in main steps as described in (Casu, et al., 2006):

- The choice of the SAR data which allow to create interferograms are selected in order to reduce decorrelation phenomena. In particular this selection consists to consider only data with a sufficient low spatial and temporal baseline between two SAR images (referred to the satellite orbit). The purpose of this choice is to maximize the coherence of pixels in the SAR image, obviously more coherent pixels correspond to a better quality of the image.

- The second step of the technique consists in the phase unwrapping because the interferogram is composed by a repetition of colored fringes and it is necessary to convert this into a deformation map. This phase is related only to the pixels which have a sufficient level of coherence.

- The next step consists on the Singular Value Decomposition (SVD) method in order to combine all the interferograms used in the analysis. This aspect is very important because the restrictions applied both in space bot in time to a SAR image pass on to the generation of interferograms deriving from an independent subset, which creates a problem with infinite solutions. With this method it is possible to overcome the problem and solve the system.

- The final step consists to apply a filter both in space both in time in order to reduce artifacts deriving from atmosphere differences.

Here it is shown a scheme of SBAS DInSAR method Figure 14:

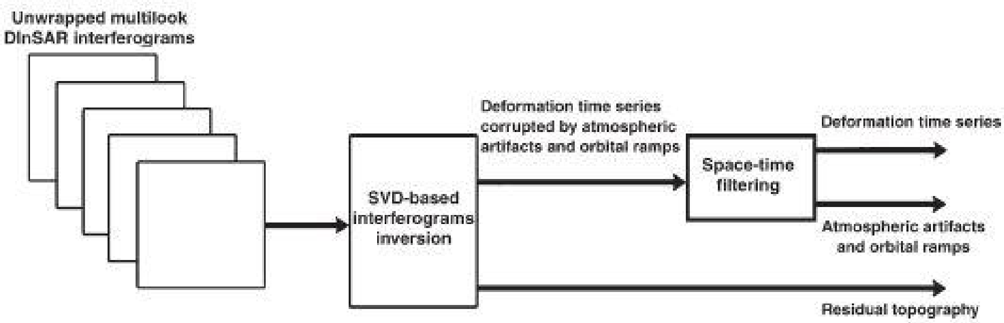

Figure 14: SBAS method steps, (Casu, et al., 2006).

2.2.2 Historical evolution of the technique

The first study using the SBAS approach was carried out in Campi Flegrei area (Italy) (Berardino, et al., 2002). This work proposed a new DIFSAR approach for the evaluation of the earth's surface deformation evolution; it is based on multiple SAR acquisition subsets based on a small baseline value in order to reduce decorrelation phenomena and an effective combination of all the available Small Baseline interferograms. The combination is based on the application of the singular value decomposition (SVD) method.

This technique is able to generate dense spatial deformation maps using data deriving from independent stack of interferograms, which is the most important result used for the monitoring od deformation phenomena.

This study was validated with a successful comparison between time series SAR deformations and geodetic measures proposed by the researchers of Osservatorio Vesuviano, an organization which study deformation phenomena in the Campania region. In order to make the analysis consistent it is necessary to project all the measurements in the same direction which is the Line Of Sight, without this step it isn't possible to detect stack of data deriving from different methods.

Finally, is important to notice that the proposed technique is not already able to give information at the local scale; an example could be the deformation time series located in a target from a small building.

A new approach of the SBAS technique for the evaluation of deformation time series deriving from DIFSAR interferograms was done in (Lanari R., 2004). In order to get this aim they extended the original SBAS approach, which was able to detect deformations only at the large scale (Berardino, et al., 2002). In this case the technique uses different stack of data deriving both at the low resolution both at full resolution (multilook/singlelook respectively). The conventional SBAS technique was used to identify deformation time series at large scale, topographic errors and atmospheric artifacts; this improvement allows to detect targets which present a high level of coherence over the time and estimate height and deformation of buildings in urban areas. This technique was used in the Campania region and later validated using GPS measurements, which is a common procedure to make more consistent the analysis. It is important to notice that the two technique are not in contrast to each other.

In Figure 15 is shown with a white narrow the area with SAR and GPS deformations time series available, in particular it is evident the agreement between these data (triangles SAR data, continuous line GPS data):

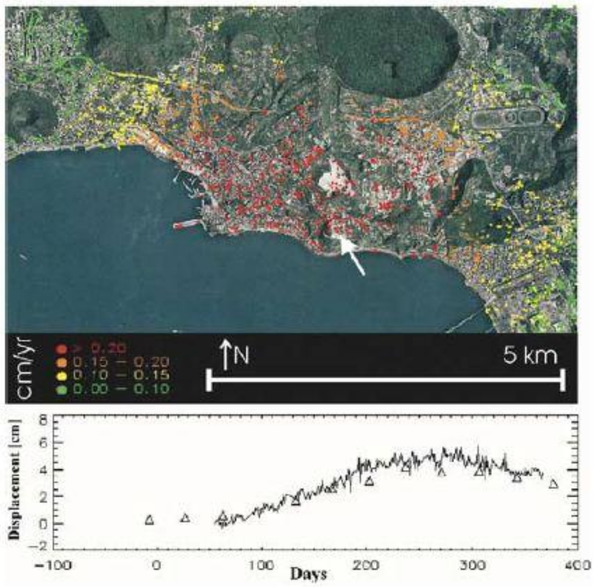

Figure 15: Comparison between GPS and SAR data in Campi Flegrei area, (Berardino, et al., 2002).

An addictional experiment was carried out. In particular they have correlated deformation time series with temperatures data; another time there was an agreement between the two measures and this show how deformations occurred in the urban area have seasonal behavior Figure 16:

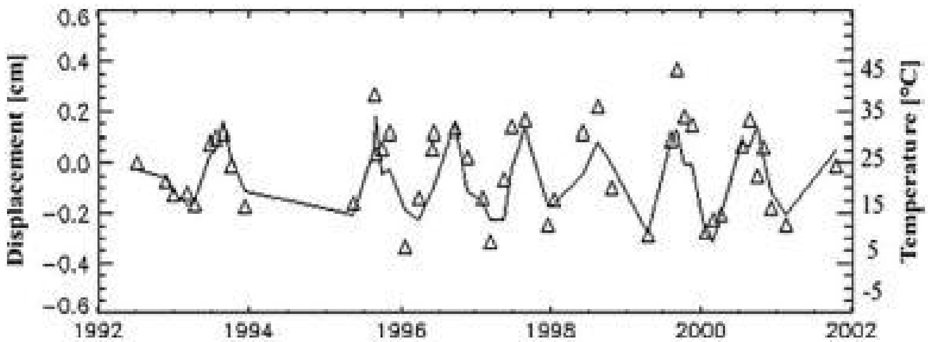

Figure 16: Overview between temperature and displacements data (triangles SAR data, continuous line temperature), (Berardino, et al., 2002).

A new development of the SBAS technique was proposed and validated in the area of Napoli and in the Murge region (Italy)) (Bonano, et al., 2012) in order to create deformation time series deriving from SAR data. Another time it was applied the singular value decomposition method in order to combine interferograms deriving from independent subsets (ERS/ENVISAT). In particular the method proposed by (Manunta M., 2008) which considers a two scale approach was applied to the method proposed by (Pepe, et al., 2005).
The main restriction of the combine technique consists on the superimposition of data sets deriving from independent stack, but at the same time this is not a big problem because are available a big amount of data from the two satellites.

The first work which shows the potentiality of the new Band X (CSK from COSMO Sky-Med) was proposed (Bonano, et al., 2013).
This work represents the first application of the deformation time series method deriving from SAR data to the urban areas using the new X-band SAR sensor. In particular it was noticed the potentiality of the Cosmo-SkyMed constellation respect the previous RADARSAT satellites. It's important to notice that evaluated deformation time series deriving from SAR data it's often used with other techniques in order to make the analysis more consistent; in this area were available GPS measurements. In Figure 17 is shown the comparison between SAR data from CSK constellation and GPS measurements:

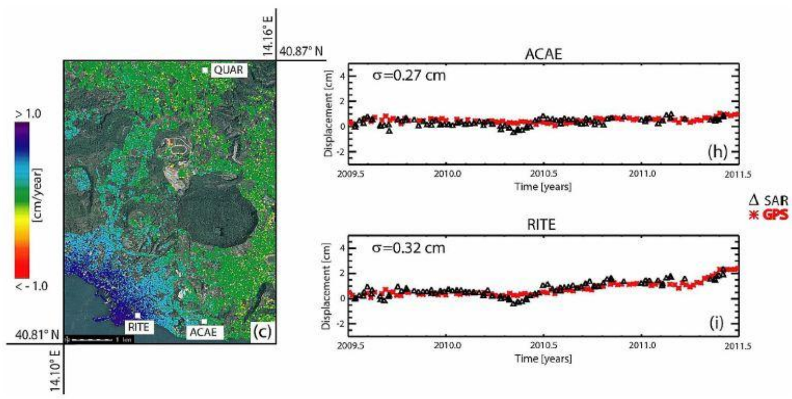

Figure 17: Comparison between SAR and GPS measurements in Campi Flegrei area, (Bonano, et al., 2013).

The GPS measurements are referred to two selected stations labeled as ACAE and RITE as shown in the figure. To make consistent the comparison of different data it's is necessary to project geodetic data into the sensor Line Of Sight; moreover it is important to notice that all the data displacements are referred to a Reference Point located in the QUAR GPS station, this point is the centre of the referring system and it is important to be stable and away from the displacements area.
The results show a good agreement between the two different data, in particular the computed standard deviation values are always smaller than 5 mm.

2.3 Case of studies

2.3.1 Masonry ordinary buildings

The application of satellite data for the diagnosis of existing masonry structures and its integration with in-situ standard monitoring systems is still an emerging field of research. About the few studies available in literature, an important work focused on the application of Advanced Differential Synthetic Aperture Radar Interferometry (A-DInSAR) was carried out in the city of Rome, which was affected by important subsidence phenomena and related damages to structures (Bozzano, et al., 2018). In particular the authors combined different type of data in order to make the analysis more consistent: the first pillar of the work was the reconstruction of the spatial evolution of the subsidence processes using ERS, ENVISAT and COSMO SkyMed satellites data from 1992 to 2010; the second step of the study was the evaluation of a geotechnical model which give and idea of the type of terrain below the structures. With this data it was possible to find the most compressible layer and its related parameters, this result is important because a compressible layer is subjected to a bigger amount of displacements. The third step consists to check the urbanization of the monitored area, this was important because it allows to recognize the amount of load in every subset area and the start deformation period; it is expected that a bigger load generates a bigger displacement. The most effective part of the work was the division of the data deriving from Persistent Scatterer interferometry in subsets considering characteristics of the buildings (foundation and age of construction). Only with these accurate considerations it is possible to evaluate the relationship between subsidence phenomena and the constitution subsoil. One of the areas investigated during this work is shown in Figure 18, with the comparison between buildings age and thickness of the compressible soil.

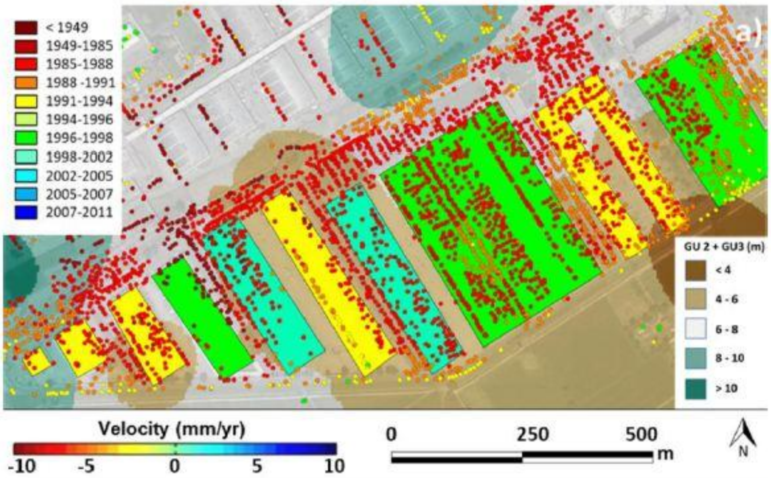

Figure 18: Velocity of persistent scatterers of COSMO-SkyMed over a thickness map of compressible soils, (Bozzano, et al., 2018).

In conclusion, the results deriving from this work show the potentiality of the SAR technique to evaluate the deformation time series due to subsidence phenomena. However, in some area displacements data seemed to contradict working hypothesis. This aspect means that geotechnical and foundation buildings data are not enough to evaluate with accuracy the displacements field in some scenarios. In general, it is necessary to consider also the footprint, the elevation/number of storeys and the weight of a building in order to make the analysis more accurate.

Another important work was carried out in the city of Las Vegas (NV) (Reale, et al., 2011) in order to demonstrate an application of SAR tomography to a data set of Terra SAR-X and COSMO-SkyMed constellation. The first important aspect worth of mentioning, is that with the use of medium resolution SAR data tomographic technique, it was the possibility to solve an interfering-phenomena called layover. This problem is typical of areas characterized by a high density of scatterers with steep topography in urban environment and consist in the superimposition of two scatterers located in different positions but with the same range. Furthermore, in the study it was possible to exploit the potential of the new (high resolution) sensor generation and the potential of SAR tomography for urban area analysis. In Figure 19 it is reported a three dimensional view of the monitored building (Mirage Hotel) using only SAR data deriving from Persistent Scatterer technique without a support of the optical image; this result was impressive because it was the first time when a building was rebuilt only with SAR data. Furthermore, it was possible to monitor the single building scale without the help of other techniques using satellite data.

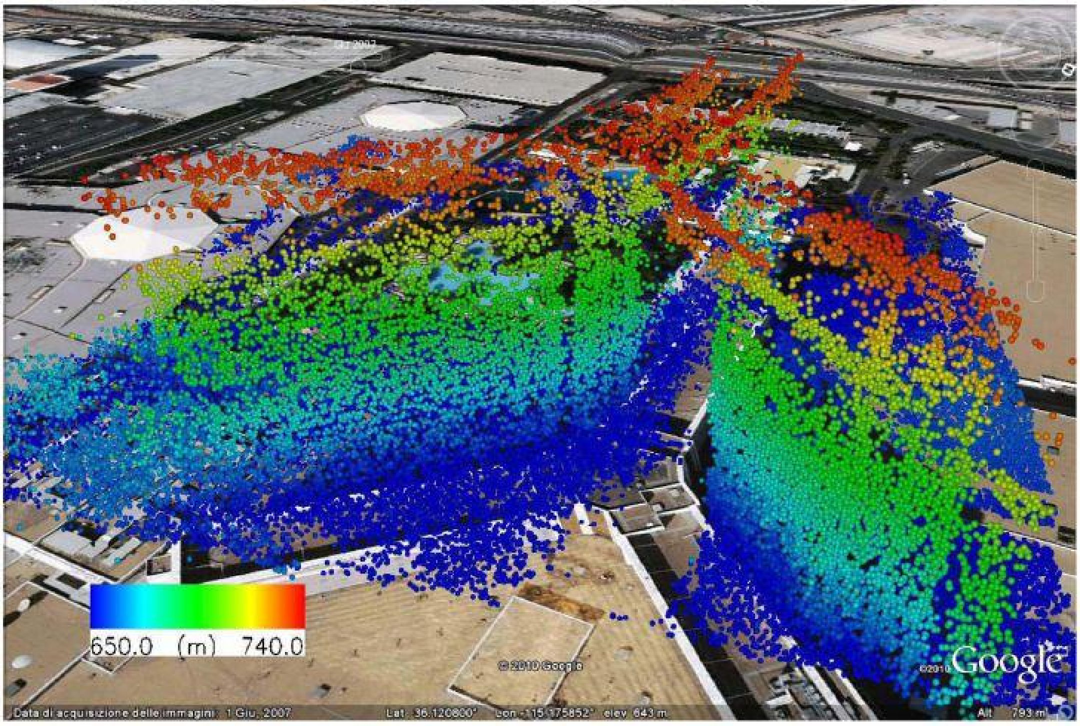

Figure 19: Three-dimensional view derived from scatterers with SAR tomography on Google Earth, (Reale, et al., 2011).

In this work it was proposed an innovative method to evaluate potential damage situations in buildings areas doing particular attention on the study of deformation time series, it is notice that an acceleration on the deformative trend and an anomaly of a single deformation data are a potential warning situation, considering the spatial and the temporal characteristics. The method applied data deriving from COSMO-SkyMed satellite and was referred to urban areas in China (Zhu, et al., 2018). First of all it was used a hierarchical clustering method in order to reduce the amount of detected points, paying attention only to representative points (convergence points). Later it was done a research based on deformation time series which show risk situations (these aspects characterized the spatial aspect of the analysis). Taking in to account the temporal part of the analysis it was applied a signal processing method to divide the deformation in to two subsets: periodic deformations and linear deformations.

Removing the periodic deformation which is related to temperature phenomena most of the time, it can be possible to isolate only the deformation part which can provide risk situations. In Figure 20 the key steps of the method are summarized.

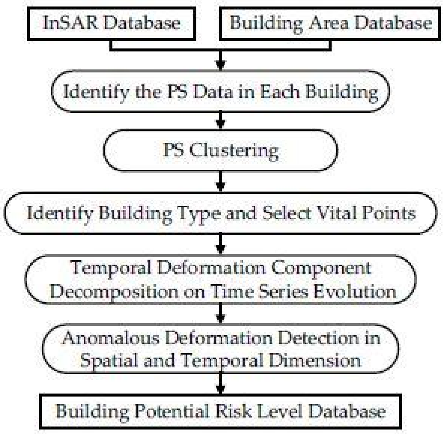

Figure 20: : steps of the risk evaluation of buildings, (Zhu, et al., 2018).

After the evaluation of building displacements with SAR data, in order to confirm the potentially risk situations were done buildings inspections; this procedure is often done to validate the method. The particularity of the method is that is able to analyze big amount of data automatically, a peculiarity of clustering methods. Furthermore, this shows the potentiality of the SAR technique in the monitoring field of urban areas and in the detection on potential risk situations. Finally, it shows the capability to use clustering method with SAR data in a successful way, hoping in future development. This approach is very useful especially when there are a significant amount of data and it is requested to focus to specific buildings. The choice of the classification algorithm is not immediate because of the numerous clustering methods available.

An application of building monitoring by Terrestrial Interferometric SAR (TInSAR) images was proposed in the city of Rome, (Mazzanti & Cipriani, 2009), which in that period sees the construction of the new Metro line. In this study were considered several buildings especially the ones which had pre-existing problems; between these buildings the attention was paid to the Carducci School. In particular another time were applied different techniques, first of all the monitoring campaign started with the use of tiltmeters and total stations and then it was applied the Terrestrial InSAR monitoring. In order to make consistent comparison between these different techniques, displacements measured by the total stations were projected along the Line of Sight. The results showed a good agreement to each other. Figure 21 reports the results of the study.

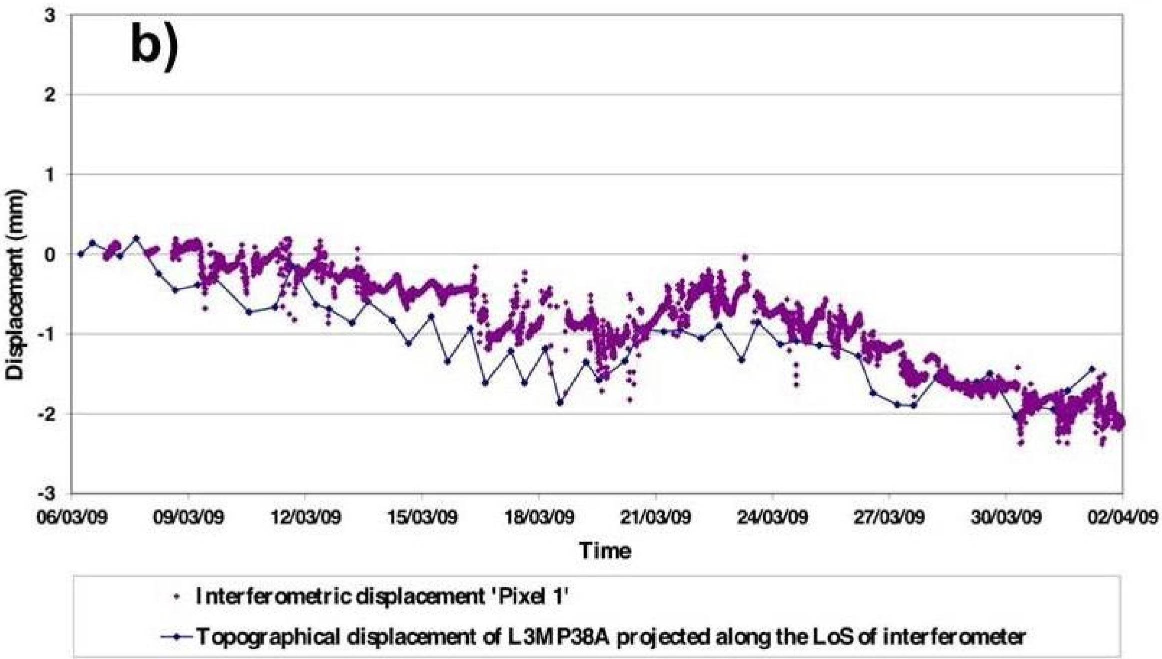

Figure 21: Time series of displacements derived from TS and TInSAR monitoring, (Mazzanti & Cipriani, 2009).

This technique is different from the classic InSAR ones, because it is carried out with a terrestrial instrument. Beside that the technique showed promising results in the field of the monitoring of urban areas; considering the high sampling rate this technique is useful in difficult situations where it is not possible to install a monitoring system. The hope is the development of this technique for future works in order to give another tool for the evaluation of damage in buildings not forgetting the permanent scatterer and SBAS technique. However, at the actual level of knowledge, the SAR technique is not enough to provide a complete analysis in terms of damage on structures. Thus, it is necessary to combine the SAR technology with other monitoring instruments to make the estimates of damage reliable.

Building damage deriving from post tunneling activity is an important topic which was evaluated along the Crossrail route in London (Macchiarulo, et al., 2019). The monitored area was characterized by a high percentage of load bearing masonry structures (68%). This work is an example of the application of SAR data used for buildings monitoring close to underground work systems. In order to evaluate the displacement time series of several buildings were used data derived from COSMO Sky-Med satellites and later it was detected the state of health of the buildings. In this study were used also information about the buildings (material, foundation typology and age of construction) in order to divide the totality of the monitored targets in multiple groups; buildings are considered as equivalent elastic beam by the model. It was also done a comparison between the displacement time series deriving from SAR data and the greenfield-based displacements. Figure 22 reports the results of the study.

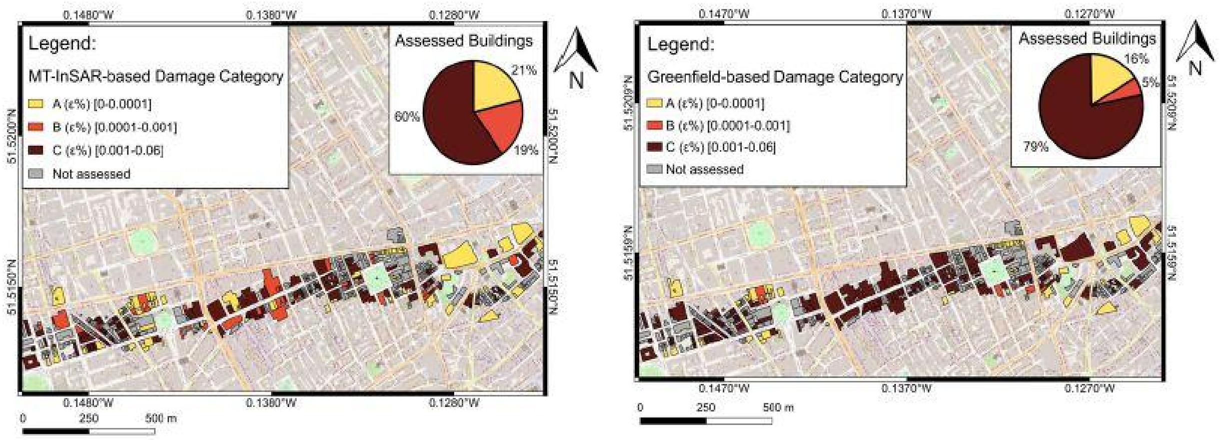

Figure 22: Damage map based on SAR and greenfield displacements, (Macchiarulo, et al., 2019).

The comparison between the two different type of displacement shows that the greenfield displacements were bigger than the SAR ones. Another time it was showed that the technique is a useful tool to the monitoring of buildings deformation; the hope is to build methodologies which consider different information like the foundation typology with the SAR technology. Make the analysis with all this data could improve the quality of the damage detection especially in masonry structures which are particularly sensitive to differential settlements.

An example of the effects generated from landslides to masonry buildings was shown in the study carried out in urban area in Calabria) (Peduto, et al., 2018). This study presents a new method which estimate the monetary loss deriving from buildings damage in several case scenarios. In order to get this aim were used different type of data like the previous examples: in particular were used geotechnical information with different remote sensing techniques, inspection of the buildings and vulnerability analysis. As mentioned before an important result was the estimation of the monetary loss deriving from the reparation of the buildings, this could be an important innovation to introduce also in future works. In Figure 23it is shown the level of damage for different masonry buildings, one of the steps mentioned before.

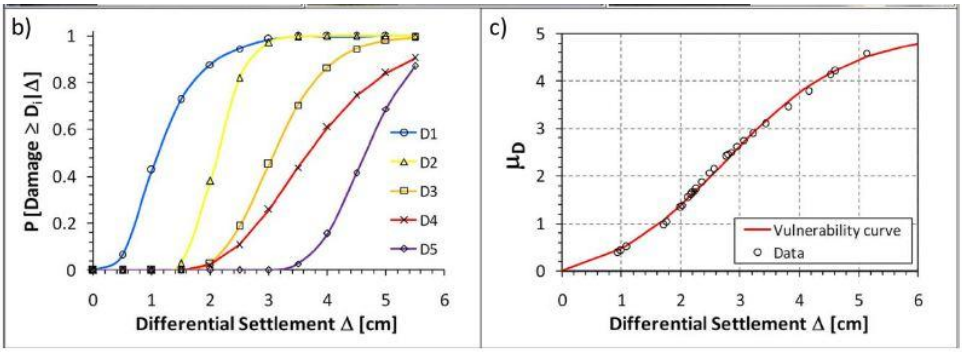

Figure 23: (b) fragility curves, (c) vulnerability curves for masonry buildings in Lungro, (Peduto, et al., 2018).

It is important to notice that this analysis is peculiar of this study because used data deriving from a specific analysis of the area so it can not be applied in general. The importance of the empirical fragility curves is showed in this work because they can help the evaluation of the future damage states for masonry buildings also considering the activation of landslide phenomena; the fragility curves are derived from the SAR data and also from in-situ surveys. this concept can also be used in other type of buildings like reinforced concrete or steel structures underling the site dependence of this method.

An example of the combination of different band on board on satellite sensors has been applied in the Salerno province (Infante, et al., 2014); in particular the aim of this work was always the evaluation of buildings damage due to landslides, which is a common phenomena in Italy. The study allows the possibility to reconstruct empirical fragility curves which are site dependence and the causes of the deformation time series of the buildings. Another time is explained how these curves could be an useful tool to evaluate the future damage on buildings area. In particular it was possible to make a comparison between buildings damaged and repaired in order to get the efficacy of the work always with the use of SAR data time series.

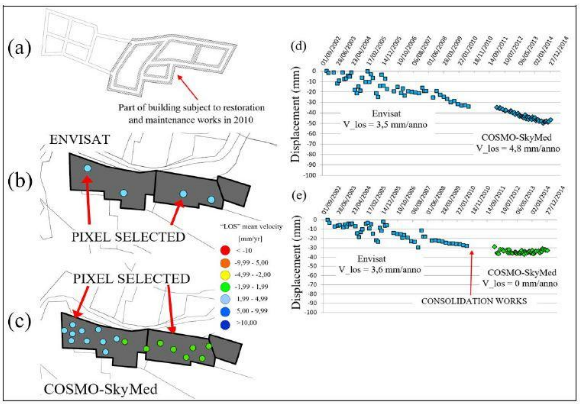

Figure 24: Behavior of buildings aggregate before and after the rehabilitation works occurred in 2010, (Infante, et al., 2014).

The results showed the potentiality of the application of SAR time series of displacements underling the change in the trend deformation; this means that the technique is also useful to evaluate the efficacy of a reparation work on a building and not only the detection of damage deriving from natural phenomena, see Figure 24 for clarity. It is worth mentioning that in order to estimate buildings damage in the best possible way, it is necessary to consider different time windows in the deformations time series, especially when there is a change of behavior in the deformation data.

In this study is presented a combining method always referred to the evaluation of building damage, which is the aim of the SAR technique. In particular, with the SBAS technique was considered a structural model which consider the building like an equivalent laminated beam (Arangio, et al., 2013). The inspiration of this work was the model proposed by (Finno et al.) which consider the building like an equivalent beam and evaluate the damage occurred in the structure looking the ratio between the deflection of the beam and its length; this value is then compared to a specific threshold in order to establish when the damage occurs Figure 25.
The results of this method are encouraging to consider it like an important instrument for a fast damage evaluation when there is no time to apply other techniques; furthermore it is possible to investigate the state of the building also back in time in order to see the evolution of the deformation phenomena.

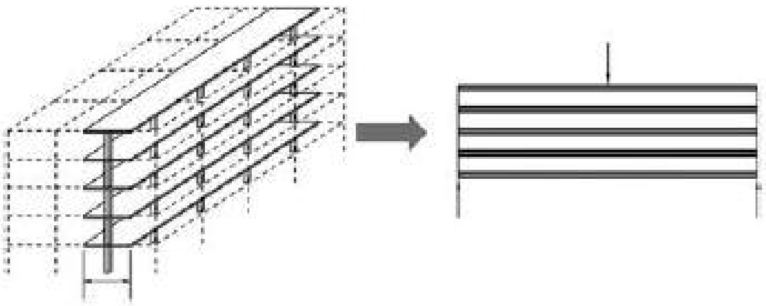

Figure 25: Equivalent beam scheme, (Arangio, et al., 2013).

Another application of DInSAR technique is showed in this work. In particular the causes of the deformation in the urban area of Sarno (Italy) were subsidence phenomena related to the changing of groundwater level (Cascini, et al., 2006). To get this aim were analyzed data deriving from ERS satellite in period of time from 1992 to 2002, another time the SAR data were validated with geodetic data as we seen in the previous work. In Figure 26 there are data derived from ground levelling and SAR technique.

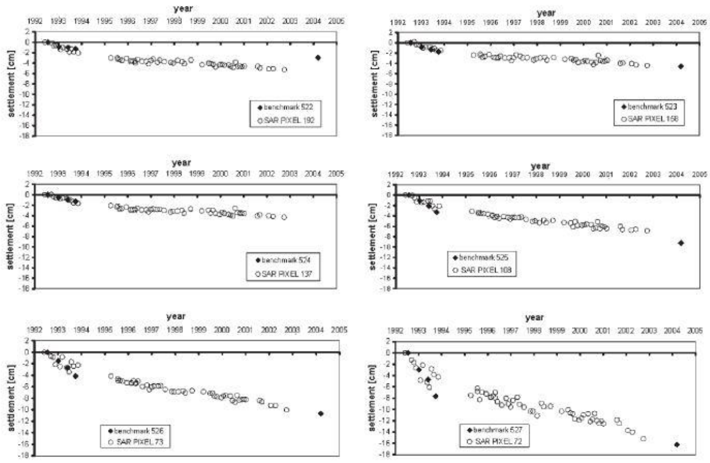

Figure 26: displacement comparison (from SAR and ground levelling data), (Cascini, et al., 2006).

The results showed that the displacement time series derived from SAR data are in agreement with the data derived from field measurements related to water conditions. The hope of this work is the combination of the use of SAR data with other information deriving from other techniques, in this case scenario were available data about the causes of groundwater level changing. This is another example that shows how SAR monitoring data has to be support by other monitoring techniques in order to confirm the amount of building displacements/damage.

To conclude, the previous studies show the capacity of different satellite techniques for the evaluation of time series displacements and predict damage of masonry buildings due to natural phenomena like subsidence and landslides. Despite these great potentialities of SAR systems, it is necessary that these techniques are used in conjunction with other monitoring techniques that support the results. In the previously mentioned studies, it was found that the monitoring techniques to support satellite technique are generally geodetic levellings with the use of total station and in situ survey, in order to evaluate and confirm the entity or the damage buildings. Particular attention should be given to assessing vulnerability curves to the scale of the individual building in order to make a prediction of damage in the medium to long term. This type of subject is therefore appropriate that it goes developed also in future works.

2.3.2 Masonry monumental buildings

Talking about monumental buildings it is notice how important is the evaluation of the state of damage before the execution of any type of restauration work, to get this aim the Synthetic aperture radar techniques can provide an useful for the damage detection and triggering factors. An important study that uses satellite data applied in the field of cultural heritage sites has been carried out in the city of Gubbio (Italy) (Cavalagli, et al., 2019) within the European HERACLES project, which was funded in the framework of Horizon 2020 with the purpose to find new monitoring solutions to preserve cultural heritage European sites. The survey was focused on The Consoli Palace, an important palace located in the centre of Italy, which was affected by a moderate crack pattern and the Town Walls. Particular attention was focused on the integration of different monitoring techniques, such as Persistent Scatterer Pair (PSP), Interferometric SAR (InSAR)**,** laser scanning and environmental and structural monitoring. Firstly, the velocity deformation maps from InSAR data find Persistent Scatterers (PSs) characterized by critical values and then, when the critical area was founded, an in-situ monitoring was done. In-situ monitoring was done using different instruments, in particular in the Consoli Palace were used crack meters (LVDT) and in the Town Walls were used inclinometers Figure 27. The analysis with both techniques were consistent to each other and shown that the opening-closing of the major crack of the Consoli Palace was related to environmental conditions, the position of the in-situ monitoring systems is shown in Moreover, InSAR data found the relation between a permanent opening of the same crack and an earthquake occurred in 2013. Furthermore, in the Town Walls InSAR and in situ inclinometric data results were consistent and shown that movements were related to seasonal fluctuations. This work shows how the integration of InSAR data and in situ monitoring data is very important to validate the remote sensing technique.

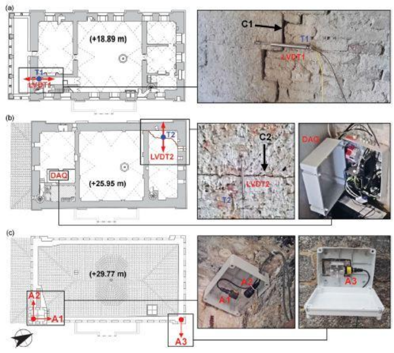

Figure 27: Static monitoring system: (a) LVDT1 in the south façade, (b) LVDT2 in the main crack of the north façade, (c) piezometric accelerometers on the roof of the palace, (Cavalagli, et al., 2019).

The integration of InSAR data with other monitoring techniques is becoming a very important topic also in the evaluation of displacements time series of monumental masonry buildings. An important work about this theme was carried out on the Cathedral of Orvieto, a small town in Terni province (Italy) (De Canio, et al., 2015). Data deriving from ENVISAT and COSMO-SkyMed satellites were compared and validated by:

- Visual crack inspections, crack meters and RFID sensors;

-3D reconstruction of the building with the use of laser scanning;

- Accelerometric field for a dynamic structural behavior of the cathedral;

- Sonic tomography, thermography and prospecting radar.

In particular it was possible to evaluate displacements on the nave near the facades and the transept after removing the thermal effects, the results obtained on the south nave near the façade are shown in Figure 28:

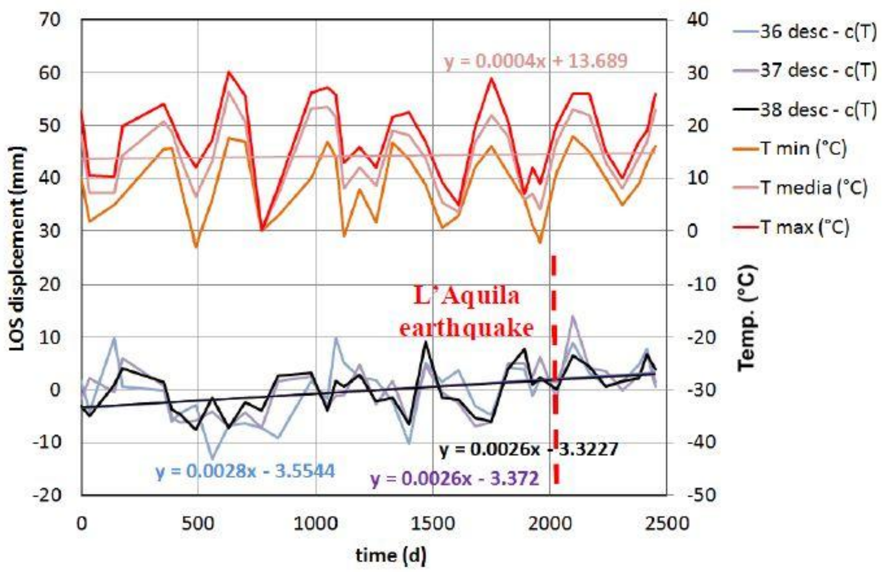

Figure 28: Displacements on Line Of Sight (LOS) direction in the south nave near the transept after removing thermal contribution, (De Canio, et al., 2015).

The effect of the thermal expansion correction was to refine the PSs description of macroelements displacements. However, the corrected trend lines substantially confirmed the same mean LOS velocities. In order to increase the performance of Persistent Scatterer InSAR analysis (PSInSAR) some devices with more stability and coherence were installed on the structure, these artificial PSs, made of metal plates, have dihedral or trihedral angle.

An important research was carried out in the framework of the "Smart management of cultural heritage sites in Italy and China: Earth observation and pilot projects". Another time it was showed the importance of the application of radar interferometry (PS technique) in the monitoring field of historical buildings in the city of Rome (Cigna, et al., 2014). During the study researchers acquired a big amount of data but the major attention was paid on the historic centre; in particular it was possible to show the capability of the permanent scatterer technique to identify a lor ho targets on the monumental buildings, this is important in order to access the survey in the best way possible using the displacement time series associate to each PS. The COSMO-SkyMed satellite provide the ability to monitor the center of Rome event at the building scale, which is an important tool for the researchers. An example of monitored area were represented by the Oppian and Palatine Hills and the most famous Colosseum Figure 29:

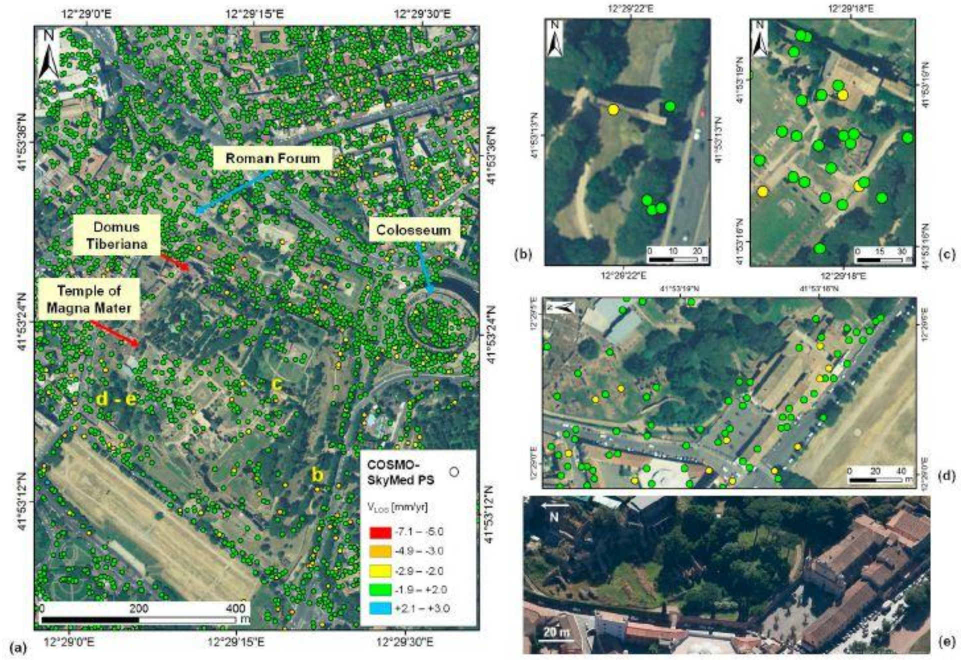

Figure 29: Velocity displacements of the COSMO-SkyMed PS over the archaeological site of Palatine Hill, Roman Forum and Colosseum, (Cigna, et al., 2014).

The results deriving from this study show successfully the capacity to detect damage by the Interferometric SAR technique; in particular it was possible to compare data deriving from two data sets, COSMO-SkyMed data from 2011 to 2013 and RADARSAT data available from Canadian Space Agency. Furthermore, it was possible to verify the good state of health of the majority of the historical buildings in the center of Rome and the no-existence of local damage.

Referring another time to the center of Rome an additional monitoring method was proposed. This time it was used a method which considered GBInSAR (the principle of this instruments is the same of the previous one but the sensor is installed near the monitored buildings instead of using a satellite) and Terrestrial Laser Scanning (TLS) in order to evaluate the displacement time series of the Domus Tiberiana (Tapete, et al., 2012). With this method it was possible to build a three dimensional model to make the analysis easier and more accurate; an example derived from this work is showed in Figure 30:

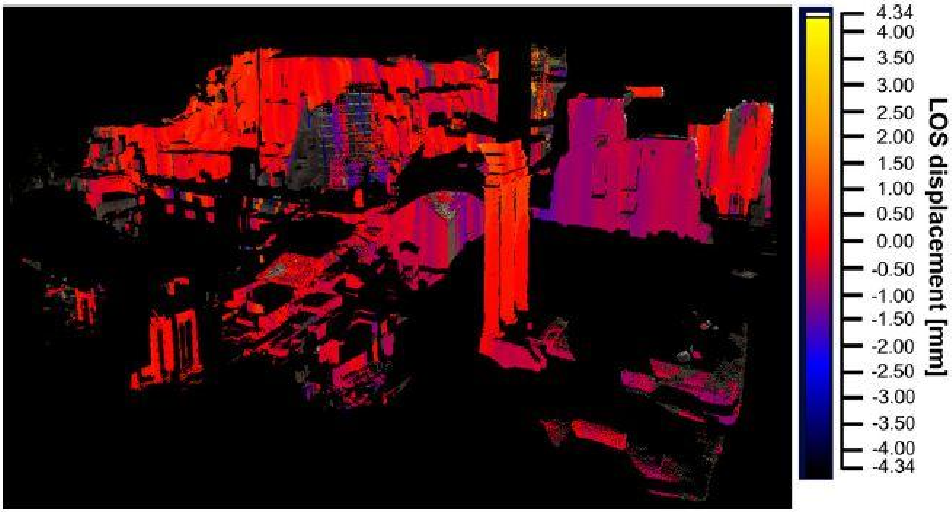

Figure 30: Reconstruction of a 3D model with GBInSAR and TLS, (Tapete, et al., 2012).

This approach which consider two techniques simultaneously was able to reconstruct the displacement time series and anomalies behavior of several monitored buildings in the city of Rome. The concept of Early Warning was applied when the displacement time series showed some anomalies during the time; in particular, with this time of data the anomalies are represented by acceleration of displacement during the time or the presence of displacement very different from the previous ones concentrated in a short period. The hope of these type of works is the application of the SAR technique with more frequency in order to protect cultural heritage sites but also different type of structures like bridges, subjected to deformation phenomena in general. It is clear that the application of more techniques simultaneously make the analysis more consistent and more accurate, so in future works it is important to take inspiration from this study.

Another important study was carried out in China, in particular was monitored the Summer Palace in Beijing in order to demonstrate the capabilities of the Interferometric Synthetic Aperture Radar technique (Tang, et al., 2016). In order to validate the displacements detected with SAR data, several solutions have been proposed: first, were used used images derived from Google Heart to discover potential displacements due to subsidence phenomena. Second, groundwater data were analyzed to find a possible connection with the deformation time series derived from SAR data in order to reconstruct a cause/effects stystem. Finally, in order to validate the technique it was necessary to do field investigations to evaluate the status on monuments. Furthermore, instabilities detected with SAR data were confirmed also by electrical sensors applied in several areas. Displacements and groundwater data of the detected area are shown in Figure 31:

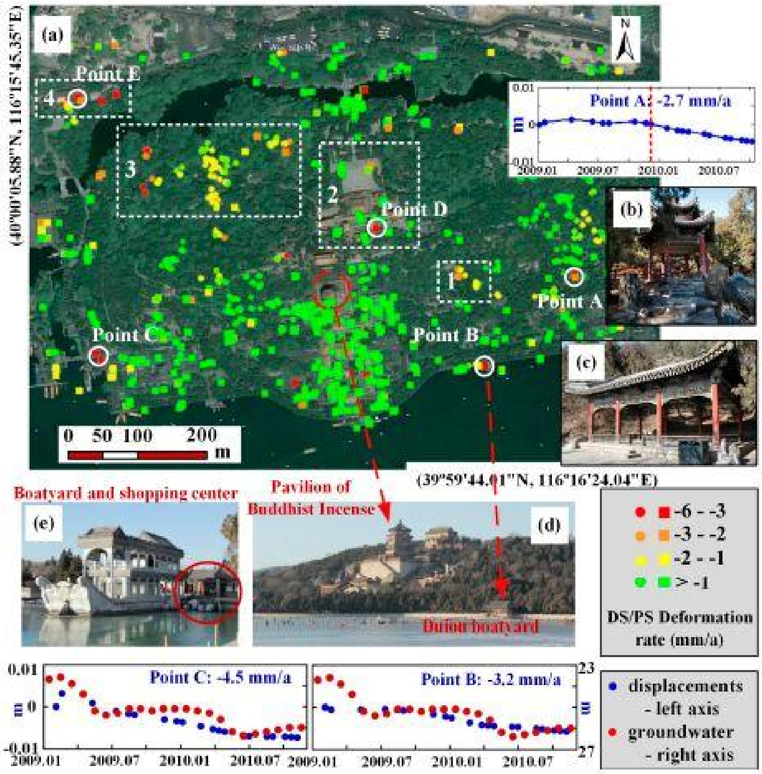

Figure 31: Map of deformations of the Longevity Hills and groundwater data used to validate motion evolutions of several points, (Tang, et al., 2016).

The results of the research showed the overall stability of the majority of the monitored monuments except few buildings affected by deformation phenomena. In particular it was possible to connect the subsidence phenomena to the displacements of the buildings, underling the influence of the variation of the groundwater levels.

A very important example is given by the work proposed by (Lasaponara, et al., 2016). In particular satellite radar data were used to identify and monitor archeological sites, where other techniques like optical data can't be used because the impossibility to use benchmarks. The work showed the potentiality of the COSMO Sky-Med satellite in concomitance with other techniques like Unmanned Aerial Vehicle (UAV) which provide useful images of the detected area and magnetic maps to discover archeologic remains in desert area located in Peru. In Figure 32 a SAR image of the investigated area is shown.

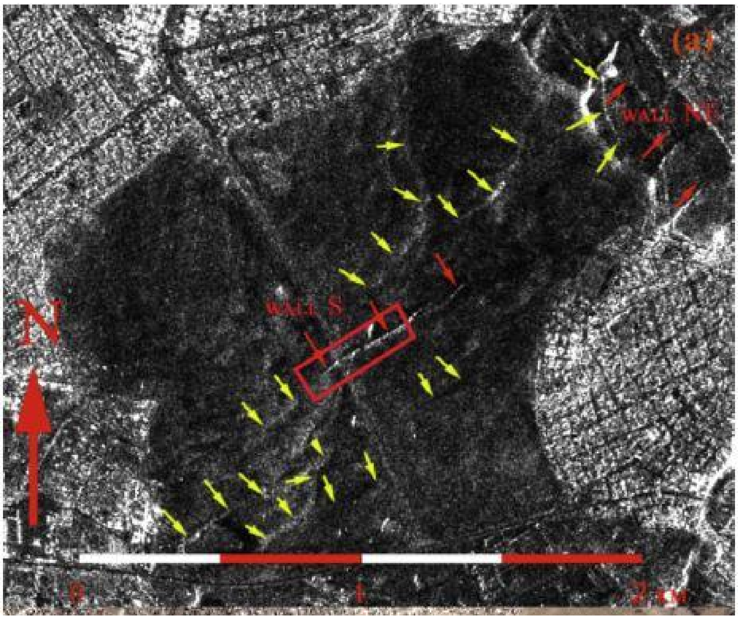

Figure 32: COSMO-SkyMed StripMap HIMAGE of the investigated area, yellow arrows underline potential anomalies from satellite data, (Lasaponara, et al., 2016).

This study can be considered a vehicle for the future works in the archeology field with the use of remote sensing data. Furthermore, in this work were used different instruments in order to validate the SAR technique like geophysical techniques, Ground Penetrating Radar (GPR) which are able to identify information about the dept of some archeological rests. The importance of use SAR data is evident in order to detect promptly any changes on the shape of the archeological rests.

Another work about archeological site monitoring was carried out in the town site of Qasrawet in the North Sinai Desert (Egypt) (Stewart, et al., 2018). The purpose of this work was the detection of structures in archeological sites with the cooperation of other techniques like optical data and the evaluation of possible displacements. The satellite used for this work was TerraSAR-X which is a satellite launched by the German Space Agency. Figure 33 shows an ancient temple of the investigated area.

Figure 33: : Central temple of the Qasrawet archeological monitored site, (Stewart, et al., 2018).

This study demonstrates the capability to detect deformation phenomena in archeological site by the remote sensing and complementary techniques; this aspect is always important because the other technique have the aim to validate the SAR methodology. In archeological site, where is not easy to detect information because of the difficulties to access to these areas, is important to have a instrument able to evaluate possible illicit excavations or others illegal activities.

An important research about monitoring archeological and cultural heritage the project named PROTHEGO. This research has the purpose to help the monitoring of cultural heritage sites all over the world using information deriving from the use of synthetic aperture radar, which are the deformation time series. In particular, the selected areas belonged to the UNESCO World Heritage List (WHL) and different sites of Europe (Cigna & Tapete, 2017).
An example of the selected areas from this project is the Choirokoitia site in Cyprus (Themistocleous K., 2019). It shows successfully how different technique can coexist in order to make the study more accurate and more consistent for the evaluation of displacement phenomena in archeological sites. In particular it was explained a low-cost method for the monitoring of the buildings with the use of Unmaimed Aerial Vehicle and Synthetic Aperture Radar. First of all, the method starts with the use of Synthetic aperture radar interferometry in order to identify potential hazards; then when the potential risk situation is identified it is necessary to carry out a in-situ survey in order to validate the data deriving from the previous technique (as we have seen in the previous work, field monitoring is often done to make sure the validity of the SAR data). At the same time the evaluation of

displacements can be done with other techniques like laser scanning, photogrammetry GNSS and drones. Finally, after the evaluation of the level of damage with an in-situ surveys another time SAR measurement are used to monitor the evolution of the deformation in the studied area.

Landlides are a very common risk natural phenomena related in most part of the world, the evolution of such natural phenomena is an important problem which has be solved in order to prevent more damage (Guzzetti F., 2009). Data recorded by Syntetic Aperture Radar (SAR) sensors and processed by Differential Interferometry (DInSAR) techniques are an important improvement for landslides observations (Bovenga, et al., 2012) and most of the time they are recommended because conventional monitoring techniques (GPS, ground based monitoring systems, etc) proves to be difficoult and resource intensive, this because this instrumentations are not the better technique when it is necessary to monitor for a long period of time; furthermore in many cases landslides sites are inaccessible or instrumentation installation costs are high.

An important work was carried out using SBAS DInSAR technique in the Ivancich neighbourhood site in the city of Assisi (Italy), characterized by an important deformation phenomenon like landslide. In particular another time it was showed the possibility to compare different techniques in a unique case of study: the union of DInSAR technique and geotechnical information was used in order to evaluate the changing of behavior in the landslide movements (Calò, et al., 2014).
A first important result was the comparison between data recorded by two inclinometers and SAR data, in particular inclinometer measurements were projected along the Line Of Sight (LOS) in order to make consistent the discussion of the data; the result was a superimposition of the two different series of displacements. Furthermore, it was seen that rainfalls were the cause for Ivancich landslide movements.
The most important aspect of this work was to introduce a new approach to survey landslide areas by the conjunction of Cosmo-SkyMed (CSK) DInSAR measurements with geotechnical information in order to create a two-dimensional model of the kinematical evolution of the landslide in the monitored area. All the information about the geometry of the problem was provided by previous studies and available topographic maps. An important assumption for the geotechnical model was the choice of Newtonian viscosities for the materials, then a kinematical analysis was done in order to reconstruct the phenomena evolution. These parameters were obtained from a simulation with Finite Element Model with an "inverse analysis". Finally, in order to give an idea of the results of this study is showed a two-dimensional cross section of the landslide area in Figure 34:

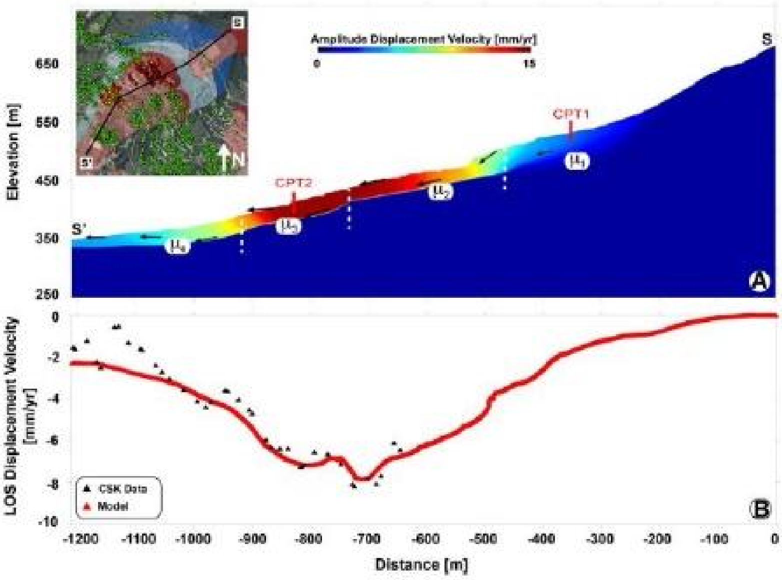

Figure 34: Displacements from SAR and FEM analysis, (Calò, et al., 2014).

Another important study (Manunta M., 2008) was carried out with the SBAS approach developed by (Lanari R., 2004) in order to demonstrate the capabilities of this technique both at large and locale scale in the city of Rome (Italy).

The deformation phenomena involved in this case of study was the subsidence and another time the Small Baseline approach was a useful tool to detect deformation phenomena at the large scale in the monitored area. As we have seen in the previous work, this technique is able to evaluate important information both in space both in time. Furthermore, the full resolution data also demonstrate the possibility to detect displacements also at the local scale (single building). The monitored areas were the Grotta Perfetta valley and the Tevere river area.

2.3.3 Concrete structures

A very important work was carried out in order to investigate the collapse of The Polcevera Viaduct occurred on August 14th 2018 in Genova (Milillo, et al., 2019). In this significative work a method for damage assessment and in particular the pre failure behavior was evaluated with the union of two different techniques: the Persistent Scatterer technique and the Markov Chain Monte Carlo (MCMC) method. in the first part of the work were identified the average deformation values of the most important elements of the bridge and in particular the local displacements of the elements which was increasing during the monitoring period, in this case started from 2015 to 2018. Once the data derived from the SAR studies were evaluated a Monte Carlo approach was done in order to reconstruct a three -dimensional behavior in terms of displacements of a specific deck. With this study was possible to show the increasing deformation value of the part of the bridge subjected to the collapse; this result underline the possibility to identify the occurrence of future failure with the analysis of deformation time series derived from SAR data. Several permanent scatterers next to the collapsed pier were subjected to relevant deformation values Figure 36.

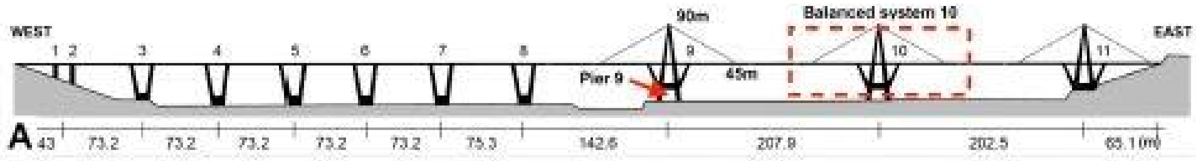

Figure 35: Scheme of Polcevera Bridge, (Milillo, et al., 2019).

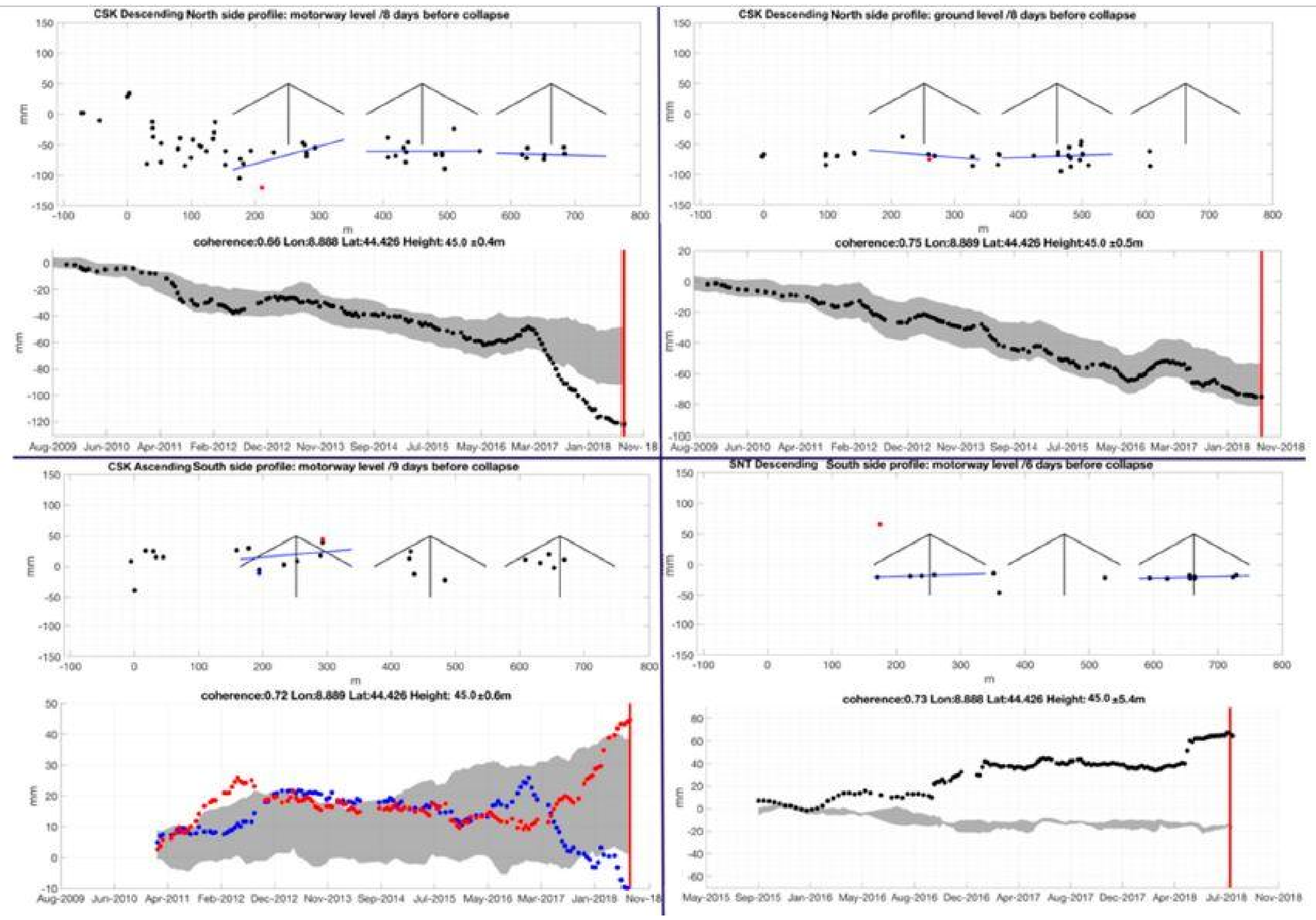

Figure 36: Time series deformation from CSK/ Sentinel satellites, (Milillo, et al., 2019).

This work underline the possibility to the synthetic aperture radar technique to evaluate displacements on the order of millimeters, such a small changes can be recognized also in thermal dilatations which is a phenomena regarding every building; the technique is also able to show accurate spatial resolution up to the meter scale. The study in terms of thermal response was carried out on the Musmeci bridge in the Potenza city (Italy) using the German satellite TerraSAR-X (synthetic aperture radar) and a MultiDimensional Imaging (MDI) approach (Fornaro, et al., 2013).
The most important result of the research was the possibility to evaluate the thermal coefficient using different techniques like remote sensing; the hope of this study is to be useful in the field of infrastructure monitoring and in particular in the thermal behavior of the structures Figure 37:

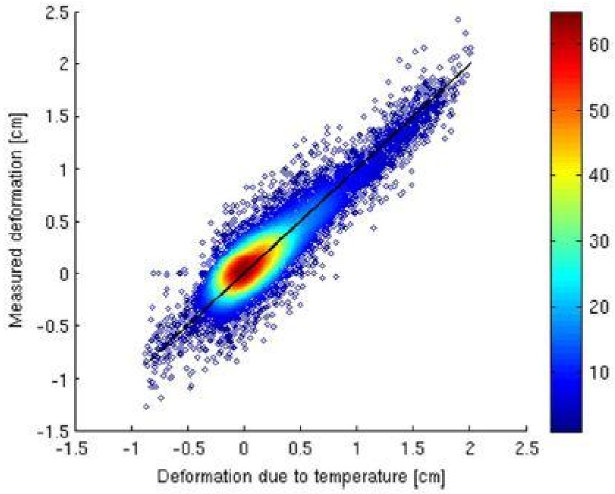

Figure 37: Thermal deformation measured by SAR data and simulated thermal dilatation, (Fornaro, et al., 2013).

In the recent years a lot of improvements were done in the technology and sensibility of radar sensors, in particular the smaller wavelength allows to detect very small deformation of the targets on the structures like the bridge showed in this work; these small deformation can be also thermal deformation which affects every structures during its life period. The differential SAR interferometry is becoming more useful to detect even these small deformations by studying in a proper way the signal evaluated. This work shows the capabilities of the multidimensional imaging technique with the help of synthetic aperture radar in order to recognize this type of deformation.

This study shows the potentiality of the SAR tomography technique to evaluate deformation effects due to creep and shrinkage phenomena, which are related to concrete structures like the two new buildings considered (Peifeng, et al., 2015). One of the results of the present study is the separation of the thermal component from the total deformation value, such contribute is time depending and not affected by structural problems; in particular it was showed that this contribute is strongly dependent from the height of the buildings. Secondly it was possible to monitor the displacement velocity time series studying the behavior of the buildings due to creep and shrinkage. The thermal expansion is a time dependent phenomenon related to seasonal changing.
It was shown also that the contribution due to creep and shrinkage is not easy to evaluate from the total deformation, in order to get this aim is important to make considerations about prediction models or knowledge of the monitored buildings. So the only synthetic aperture radar technique is not sufficient to make an easy separation of such a contribution but it's necessary more information; however, this study is an attempt to involve this monitoring method to other aspects which cares about structures in generale.

It is known that SAR missions have improved a lot during last years, in particular sensors used for synthetic aperture radar are able to monitor the hearth surface with meter resolutions and evaluate displacement time series with millimeter accuracy. Furthermore, the revisiting time is reducing a lot: the ERS satellites have a revisiting time near to 30 days and the new generation of satellites can guarantee revisiting time of 12 or 14 days for each satellite. The work presented shows the potentiality of the COSMO SkyMed and the Terra SAR-X contellations, which are an Italian and German mission respectively (Milillo, et al., 2016) Figure 38. In particular it was used the permanent scatterers technique which can detect deformation time series deriving from coherent targets on the buildings monitored. The monitored structure was a dam wall and in particular were done temperature models in order to evaluate the deformation using data deriving from ground measurements and synthetic aperture radar. This study underlines the capability to monitor structures like a dam with the comparison of SAR data and ground measurements, also GPS data can be evaluated in order to give an additional support instruments for the validation of the technique. The dam deformation can be caused by seasonal thermic variation and the hydrostatic pressure which is subjected.

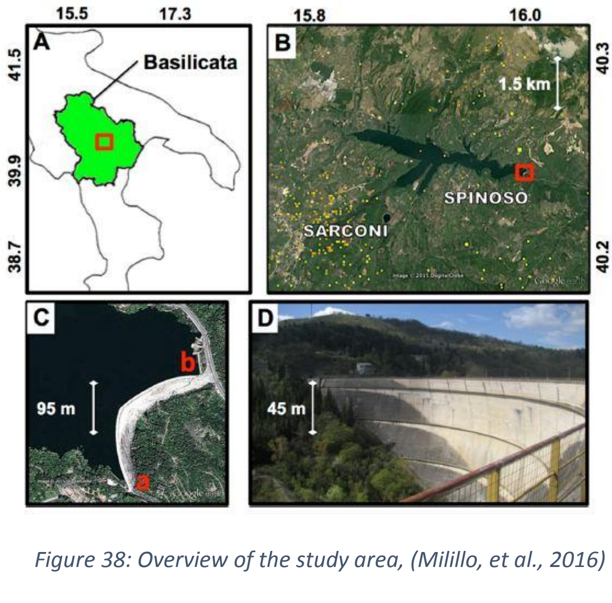

Figure 38: Overview of the study area, (Milillo, et al., 2016)

3. Classification algorithms in machine learnings

The Machine Learning technique is the union of different disciplines like computer science and statistics, the aim of the technique is to interpret and filter a big amount of data in order to make the analysis more efficient. The key aspect of the method is also the ability to program by itself a model with the use of experience and some parameters as input. As we can see in this paragraph the different typology machine learning methods can divide big data set in groups considering some features. (Mohssen, et al., 2017). In particular there are four types of learning Figure 39:

Supervised learning: this type of learning is focused on labeled data and is subject is to provide groups of data. Considering a big data set as input, the method consists in the evaluation different subset labeled data. These labels can be indicated by the researchers but also the machine can do this step.

Unsupervised learning: differently from the previous example we have unlabeled data. The key aspect of this typology is to find the relation between this data which it isn't known by the researchers. With this method the system can organize the entire data set using defined features in order to make more considerations step by step during the analysis.

Semi-supervised learning: this typology is the union of the supervised and unsupervised learning because it uses a combination of labeled and unlabeled data. The purpose is always to classify the entire data set and to predict future division deriving from these groups of data, which for the majority are unlabeled.

Reinforcement learning: this technique is an automatic learning method able to make choices in the analysis in order to get objective with the interaction between the all of data available.

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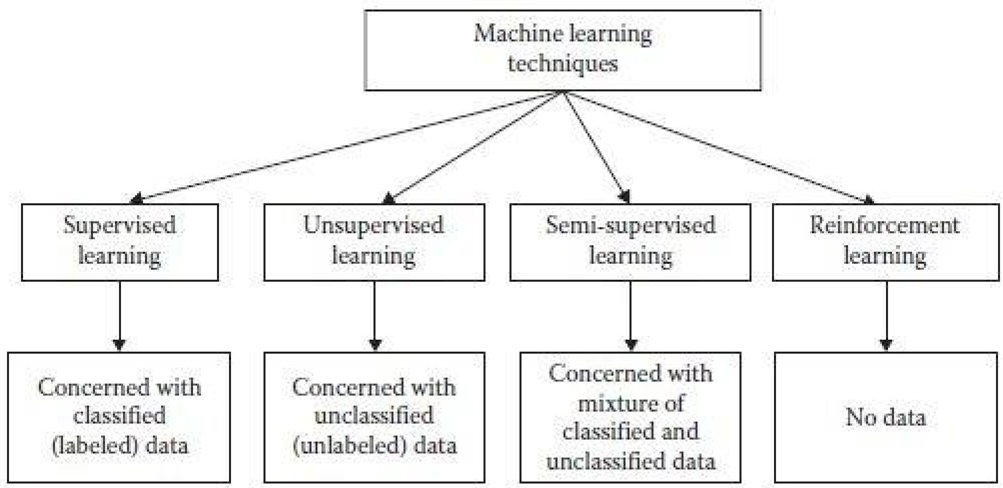


Figure 39: Machine learning techniques, (Mohssen, et al., 2017).

3.1 Clustering algorithms

Clustering analysis is a machine learning technique which is growing in importance because the variety of the application in the engineering studies where are used also remote sensing techniques (Anon., 2008). As mentioned before the method has the aim to divide the data set in groups and identify relation between the data in order to make more considerations during the analysis. Most of the time clustering algorithms are described by two tipology of data:

- **Data matrix** (object-by-variable): n objects with p attributes, like age, height, weight and so on:

$$\begin{bmatrix} x_{11} & \cdots & x_{1f} & \cdots & x_{1p} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ x_{i1} & \cdots & x_{if} & \cdots & x_{ip} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ x_{n1} & \cdots & x_{nf} & \cdots & x_{np} \end{bmatrix}$$

- **Matrix of differences** (object-by-object): this matrix take considers the differences between each pair of objects selected:

$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ d(2,1) & 0 & 0 & 0 & 0 \\ d(3,1) & d(3,2) & 0 & 0 & 0 \\ \dots & \dots & \dots & \dots & \dots \\ d(n,1) & d(n,2) & \dots & \dots & 0 \end{bmatrix}$$

Clustering methods are divided in these groups:

- **Partitioning methods**: these methods have a certain number of inputs and divide the entire data set into groups, which are named also clusters. Every single group deriving from the data set has to satisfy some rules: every cluster must have at least of element and each element have to belong to a group, this is necessary to consider every data in the analysis. The program creates a first division which is improved during the analysis changing the position of the data refining the division criteria.The most important rule is that objects within a group must be close to each others.

- **Hierarchical methods**: this method has the aim to create a hierarchical division as suggested in the name. Furthermore, these types of methods can be divided into agglomerative or divisive methods. In the first one at the beginning of the analysis every objects form a group; later with the refinement of the analysis objects are moved from a group to another group, until the division is the most accurate as possible. by contrast the divisive methos starts with every objects located into a bug group and then this group are divided in more subsets.

- **Density based methods**: the idea behind this type of method is to increase the dimension of a cluster until it reachs a threshold value. It’s necessary that every cluster has a minimum number of points; this method is useful to filter noise and for every shape of cluster.

- **Grid based methods:** this method divides the space of objects in a finite number of cells creating a grid structure. The main advantage of this approach is the calculation speed which is typically independent from the number of objects but only on the number of cells in each dimension.

- **Model based methods**: these methods assume a model for each cluster and find the best data position following the given model. It is possible to create automatically the number of clusters based on standard statistics, taking into account noise thus obtaining robust clustering methods. Here a list of algorithms and their computational properties Figure 40:

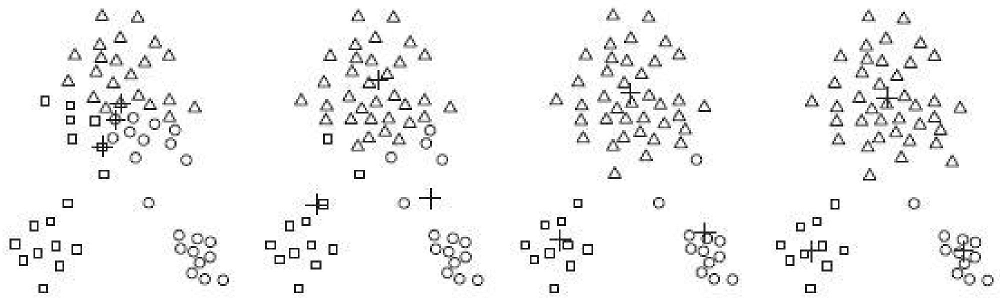
COMPUTATIONAL COMPLEXITY OF CLUSTERING ALGORITHMS

Cluster algorithm	Complexity	Capability of tackling high dimensional data
K-means	$O(NKd)$ (time) $O(N+K)$ (space)	No
Fuzzy c-means	Near $O(N)$	No
Hierarchical clustering*	$O(N^2)$ (time) $O(N^2)$ (space)	No
CLARA	$O(K(40+K)^2+K(N-K))^+$ (time)	No
CLARANS	Quadratic in total performance	No
BIRCH	$O(N)$ (time)	No
DBSCAN	$O(N \log N)$ (time)	No
CURE	$O(N^2_{sample} \log N_{sample})$ (time) $O(N_{sample})$ (space)	Yes
WaveCluster	$O(N)$ (time)	No
DENCLUE	$O(N \log N)$ (time)	Yes
FC	$O(N)$ (time)	Yes
CLIQUE	Linear with the number of objects, Quadratic with the number of dimensions	Yes
OptiGrid	Between $O(Nd)$ and $O(Nd \log N)$	Yes
ORCLUS	$O(K_0^3+K_0Nd+K_0^2d^3)$ (time) $O(K_0d^2)$ (space)	Yes

Figure 40: : Overview of complexity and capability clustering methods, (Xu & Wunsch, 2015).

3.1.1 Basic K-means algorithm

This method is a clustering technique which starts selecting K centroids, which are the center of each single group; this parameter is selected considering the final number of groups desired in the research (Anon., 2008). The analysis begins assigning points to the initial centroids and after that with the refinement of the analysis points move to one cluster to another cluster in order to refine the division. The study ends when it was found the best location for each single points of the entire data sets. Figure 41



(a) Iteration 1. (b) Iteration 2. (c) Iteration 3. (d) Iteration 4.

Figure 41: K-means algorithm steps, (Anon., 2008).

Basic K means algorithm steps:

1. Choose K initial centroids with no specific criteria.
2. Points which are close to a centroid belong to that group.
3. When the first assignment is done it is necessary to recalculate the best division for each points.
4. Repeat the previous steps until no more accuracy can be evaluated.
5. Consider a second level f the analysis.

Disadvantages:

1. This method can be applied when is well defined an average value (centroid) for each cluster. Sometimes this centroid value can't be found when are used data with categorical attributes.
2. Necessity to define as first step the number of K clusters.
3. K means method is not appropriate for convex shape clusters on clusters with different shapes.
4. The algorithm is influenced by outliers data because they can modify the centroid value of each cluster.
5. Difficulties to consider high dimensional data.

Advantages:

1. It is computationally fast.
2. It is a simple and understandable unsupervised learning algorithm.

3.1.2 Basic agglomerative hierarchical algorithm

Hierarchical clustering techniques are another tipology of clustering methods (Anon., 2008). There are two approaches for evaluating a hierarchical clustering:

- **Agglomerative:** the method starts with every single point belonging to an independent cluster and then with the refinement of the analysis these clusters are joined to each other.

- **Divisive:** it is the opposite of the agglomerative method, each points at the beginning belong to a unique group and then with the refinement of the analysis this large group is divided in different subsets.

A hierarchical method is represented with a dendrogram which shows the division in different level of clusters. It is possible to use a cluster diagram when the data have only two dimensions. In Figure 42 is given an example of these two types of diagram for a set of four two-dimensional points.

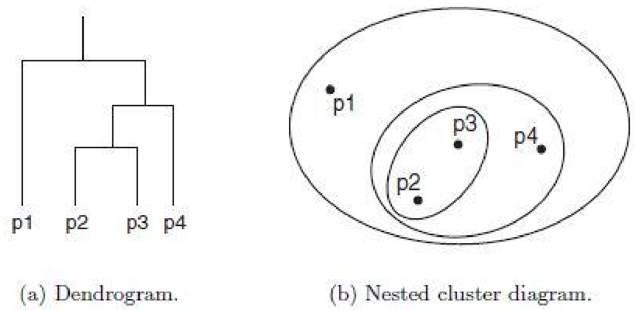


Figure 42: Graphical representation in hierarchical clustering algorithm, (Anon., 2008).

The most important aspect of this type of clustering algorithm is the evaluation of the proximity between different clusters, this proximity makes the difference in the choice of one group or another ones by a certain object. There are three techniques which define the proximity concept: the MIN technique defines the closeness taking in to account the minimum distance between points of two clusters; by contrast the MAX method considers the maximum distance between two objects belonged to different groups. Finally, the group average technique considers the average distance calculated considering all the points in the clusters. We have seen that the most important concept is the definition of the proximity parameter. These approaches are showed in Figure 43:

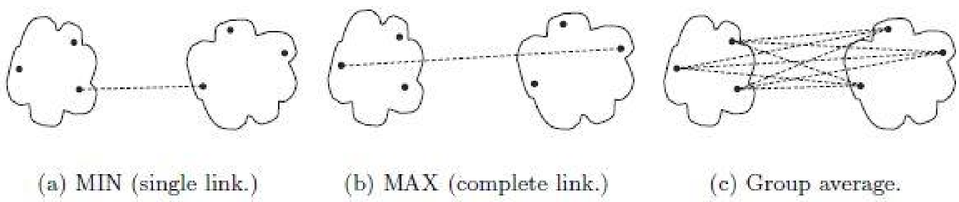


Figure 43: Typology of proximity in hierarchical clustering methods, (Anon., 2008).

Basic agglomerative hierarchical algorithm steps:
- Calculate the concept of proximity, which is the main aspect of the method.
- Repeat this step.
- The two closest clusters are joined.
- Change the matrix calculated at the first step in order to update the new organization of the data.
- Repeat these steps until we obtain one cluster.

Disadvantages:
1. If objects are grouped incorrectly at the initial stages, they cannot be relocated at later stages
2. Difficulties to select merge and split points.
3. The method is not scalable because selection of merge and split points need the evaluation of a big number of points or clusters.
4. The results vary based on the distance metrics used.
5. Difficulties to consider high dimensional data.

Advantages:
1. Easy of handling of any forms of proximity or distance.
2. Number of clusters is not fixed at the beginning. Hence, user has the flexibility of choosing the clusters dynamically.
3. Consequently applicability to attributes types.

3.1.3 DBSCAN algorithm

The DBSCAN algorithm is one of the most used in literature and it is based on the concept of density of objects; its purpose is to separate different regions considering low density groups and big density groups. In order to define the concept of density we focus on the center based approach: in particular the density is calculate starting from a specific point of a cluster and then are considered only the points which are contained inside a radius, which in Figure 44 is indicated with Eps:

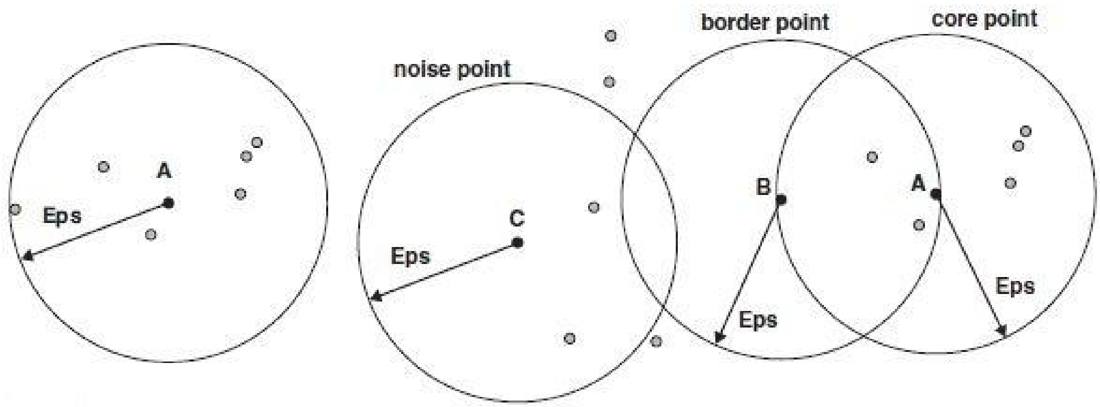


Figure 44: Core, border and noise points in DBSCAN method, (Anon., 2008).

In order to give an example of criteria the previous figure shows that the count of the points inside the radius Eps is 7. The choice of the radius Eps is the key aspect of the clustering method because it is easy to understand that a bigger radius allows to get a bigger density and vice versa. The center-based approach allows also to classify a specific point in different classes: core point, border point and background point. The meaning of these points is given in the following section and the graphic aspect is given in the previous figure:

- Core points: are points located inside a density-based cluster. More specifically the core point is a point which has a sufficient number of points close to him evaluated by a specific threshold value (MinPts), which is defined by the researcher. In order to give an example in Figure 44 the point A is a core point, the defined radius (Eps) if MinPts ≤ 7.

- Border points: this type of point is located near the Core point. The border points is near the core point but not satisfies the characteristics of this latter point. In the figure is defines with the letter B.

- Noise points: This category of point considers all the points which are not the previous two type of points.

DBSCAN algorithm steps:

- Classify all the points related to the analysis in the three categories mentioned before.
- Not consider for the analysis the noise points.
- Define a limit to distinguish all the core points.
- Define separate clusters for each core points.
- Repeat the same thing for the border points.

Disadvantages:

1. It is not possible to modify point assignment of a specific cluster.
2. Difficulties to select merge and split points.
3. The method is not scalable because selection of merge and split points need the evaluation of a big number of points or clusters.
4. Difficulties to consider high dimensional data.

Advantages:

1. Different type of clusters shape.
2. User doesn’t have to specify number of clusters at the beginning
3. It is robust towards outliers.

3.1.4 Support Vector Machine algorithm

The purpose of this method is always to find a classification for all the data points. In particular it is used a N dimensional space, which make the division in groups (Gandhi, 2018) Figure 45.
The particularity of the method is to find the maximum distance between the hyperplane in orde to separate the groups of points; this is important because a bigger distance corresponds to a better classification in groups and then a better confidence in the individuation of the data subsets.
These hyperplanes hare the constraints which divide the entire data set in groups, but it is necessary to underline that the N dimension could be reduced until the two dimension, which transform the hyperplane in to a line and so on so far.

Disadvantages:
1. this method is not the best choice if the data set has a big amount of data. This because the N dimension of the division could be 3 or less.
2. is not good when there are some overlapping in the data set, we have seen before that the criteria try to maximize the distance between two different groups.
3. It is not taken in to account a probabilistic explanation for the classification data.

Advantages:
1. this method is efficient when there's a god separation between the data subsets without superimpositions.
2. the method is efficient if it is possible to work with a high dimensional degree.
3. it works is the number which indicate the dimensions is bigger than the number of sampling.

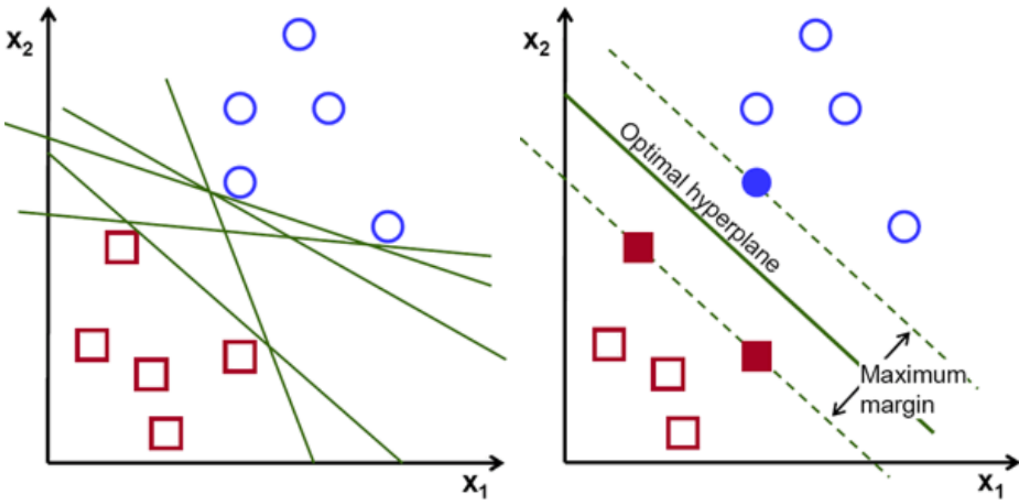


Figure 45: SVM hyperplane representation, (Ippolito, s.d.).

3.1.5 Decision tree algorithm

This type of machine algorithm represents a tree scheme like suggest in its name and is made by several nodes which indicates the labels and the branches represent some decisions to take by the algorithm, if the answer is yes ort not the result is different (Sivasankari, et al., 2014).
The particularity of the algorithm is that is easy to implement, and it is relatively fast because it doesn't take to much knowledge to build it.

Disadvantages:
1. This type of algorithm has the necessity to consider only discrete values for the objects considered.
2. it performs well if the decision making is easy to complete, if there are some particular criteria the algorithm is less suitable.

Advantages:
1. This algorithm is easy to build so it can be used also by no expert users.
2. It is easy to understand because the tree can be seen as a series of rules.
3. The decision making can consider different type of attributes.
4. It is a good algorithm for a big amount of data.

4. Classification of Line Of Sight (LOS) data for buildings detection

The classification of Line Of Sight (LOS) data for buildings identification is still a topic to be explored, in the literature there are not examples about that. However, taking into account the deformative time series deriving from SAR data and having information on how certain types of structures (reinforced concrete, steel, masonry) vibrate, it is possible to make further considerations and list potentials to be developed in the future.
An example to take inspiration is the work developed in New Mexico (USA) on the I-40 bridge over the Rio Grande River (Sohn, et al., 2002). In this study vibrational tests were carried out to study the behavior of modal parameters of the bridge, considering a progressive level of damage in the cross section: it was chosen to study four different levels of damage gradually cutting one of the bridge Girder through the electric saw cutting machine Figure 46. Then from these levels of damage it was possible to study the behavior of the bridge and in particularly the variation of the fundamental frequency Figure 47.

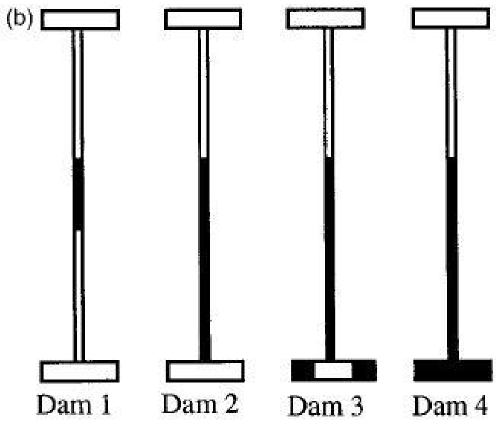


Figure 46: four sections damaged considered in the bridge(black area represents reduced cross section), (Sohn, et al., 2002).

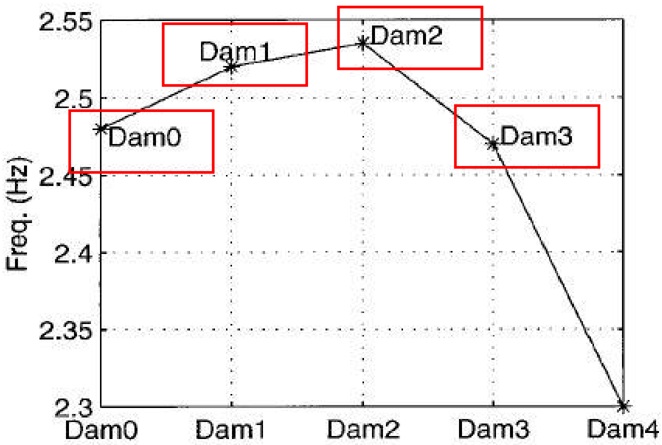


Figure 47: Frequency/level of damage graph of the bridge, (Sohn, et al., 2002).

These results can be used as a vehicle also for a study in the field of satellite monitoring. With the advent of increasingly powerful technologies, satellite sensors are able to identify and monitor a vast amount of points on the ground; However, associating these points to a specific structure remains an important aspect to be developed. Taking advantage of the knowledge on the ways of vibrating of the different structural types and having information about the time series of deformation, it can be defined a similar graph Figure 47 going to replace the classes of damage with structural classes (masonry, reinforced concrete, steel). Then it is possible to do some considerations about the relation between the fundamental frequency of the structure and the deformation time series (LOS) associated to a specific structure, in fact each structural typology reacts differently to the same event that induces deformation.

4.1 Conditional Random Fields

Extracting information from the big amount of SAR data is a challenge which has to be solved in the future, especially when ground information is not available and can be used images and data only at the global scale. In order to overcome this problem, there are several algorithms which extract from the SAR image features to recognize buildings footprint. The Conditional Random Field (CRF) approach ca be a useful tool for predicting sequences of data and detect buildings in the investigated area. The site of study for the application of this method is the city of Dorsten (Germany) (Wegner, et al., 2011) and explain the possibility to recognize buildings using the interferometric SAR technique and one orthophoto of the same area. The features extracted from the previous data are introduced to a vector with is able to recognize two categories: building and no building.

The SAR data deriving from the interferometric technique are able to extract stable features which represents buildings; in particular are analyzed the two fundamental characteristics of every SAR image, the phase and the amplitude. It is possible to extract buildings looking some reflecting phenomena peculiar of the SAR images, in fact buildings are characterized by layover area, corner lines as shown in Figure 48. The most useful between these aspects is the building corner line. Furthermore, the phase contribution considered in the SAR image makes easier the evaluation of the corner lines in the entire image.

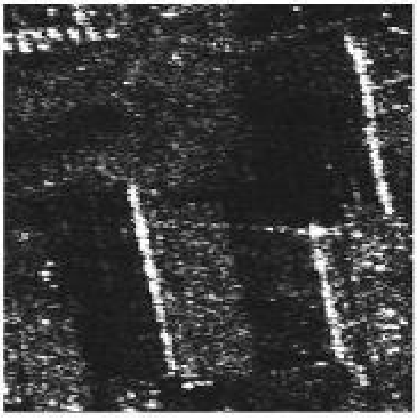


Figure 48: Corner lines of InSAR magnitude site region, (Wegner, et al., 2011).

First of all, it is necessary to set some threshold values in order to extract the corner lines. Then it is possible to select the corner lines with the use of the segmentation of bright lines in the SAR images characterized by the amplitude values. These characteristics belong to each single pixel and the algorithm determines the probability of belonging to a line considering different orientations; furthermore, most of the time the magnitude threshold values are set to 10db and the probability to 0.5 and then bright pixels are chosen and extracted from the entire image. With this procedure it is possible to build straight lines associated to a cluster (lines which are shorter than 2 meters are neglected). It is important to notice to repeat that building corner lines are extracted also considering the interferometric phase values. This because the phase value is associated to the radar target distance and this value can be associated to the local height of the terrain.
At this point the feature extracted by the SAR images (corner lines) are associated to the optical data The extracted corner lines are projected from slant into ground geometry using the InSAR heights at the line locations in order to enable joint feature classification with the optical features. Considering several aspects like the objects height and the position from the optical sensor, it is possible to show that buildings in the optical data are not perfectly aligned with the corner lines extracted in the SAR images Figure 49:

Figure 49: Optical data and extracted corner lines from InSAR data, (Wegner, et al., 2011).

Because the analysis in at the pixel level the corner lines are not sufficient by themselves to extract buildings. An important method to solve this problem and add information is the Normalized cut method which allows to segment the optical image in order to find gradients between building roofs and other objects in the optical image Figure 50:

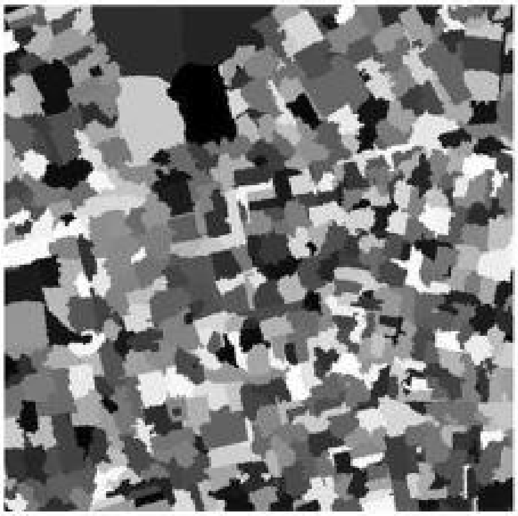


Figure 50: Segmentation of the optical image, (Wegner, et al., 2011).

Considering this segmentation with the previous corner lines it is possible to make an association and extract only segments which are behind a corner line; the other segments are neglected because a building is characterized by the corner line.
The next step consists in the construction of the distance map, which set all the pixels extracted to the value of one and the other pixels are associated to a different value considering their distance to the segment boundaries Figure 51. At this phase it is important to set threshold values in order to solve small missed superimposition, so segments which are in the range of two meters from a corner lines are considered matched.

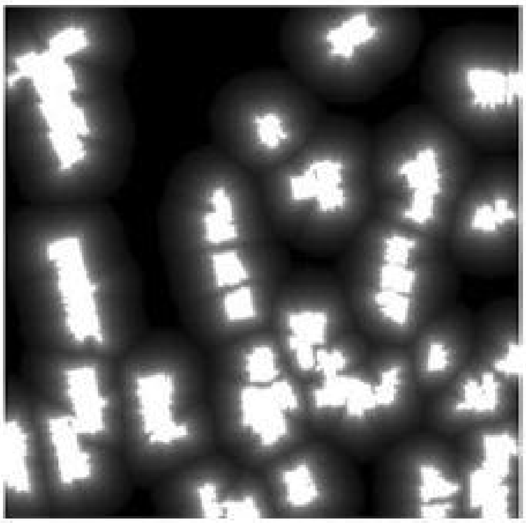


Figure 51: Distance map of InSAR corner lines, (Wegner, et al., 2011).

When features both in optical both in InSAR data are extracted, they are put in a vector as mentioned before. The advantage of this method is the calculation of a probability associated to the final labeling instead of making decisions only. The conditional random field approach is able to make very accurate results with the help of the maximum entropy approach.
An example of the approach used based on the exponential function and the conditioned probability is given in the following equation:

$$P(y|x) = \frac{1}{Z(x)} e^{\left(\sum A_i(x,y_i) + \sum\sum I_{ij}(x,y_i,y_j)\right)} \tag{3}$$

where:
- x rapresents all data.
- y contains all labels (buiding, no-building).
- Z(x) is the particion function
- $A_i(x,y_i)$ is the association potential which measures how likely a site i is labeled with y_i given the data x.
- $I_{ij}(x, y_i, y_j)$ is the interacion potential which describes how the sites i and j interact.

The results of the CRF method are showed in terms of True Positive Rate (TPR) and False Positive Rate (FPR) are encouraging for building detection:

Table 4: Comparison of building detection results different combination of data, (Wegner, et al., 2011).

CRF (optical features)		CRF (optical + corner features)	
TPR		FPR	
μ	σ	μ	σ
0.85	0.04	0.24	0.06

In particular Figure 52 demonstrate the relation between the real buildings distribution truth and building detection with the CRF method:

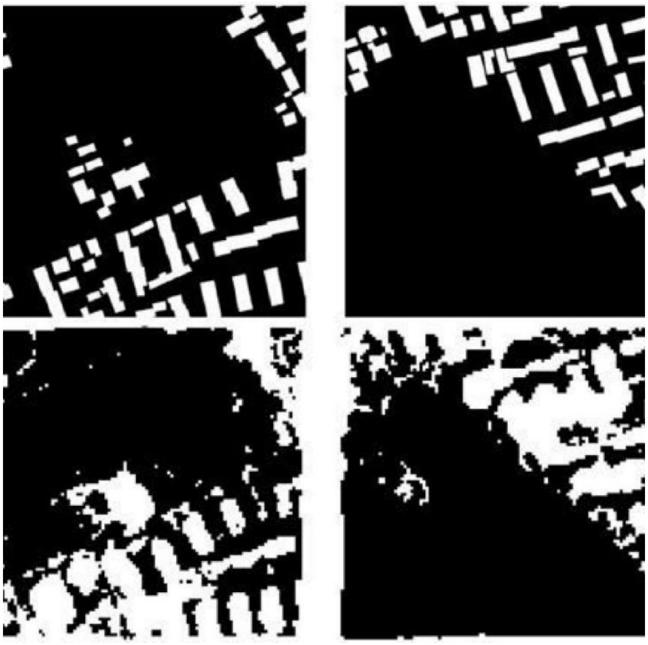


Figure 52: Top figures, real buildings distribution; bottom figures, show CRF results based on optical and corner line features, (Wegner, et al., 2011).

4.2 Support Vector Machine

The second method for building detection was proposed in the city of Foshan (China) and it is based on Support Vector Machine (SVM) algorithm (Peng, et al., 2011). This method follows several steps which can be described as follow: the first step consists in the application of the Stationary Wavelet Transform (SWT) on the SAR image; then it is necessary to calculate the alpha stable distribution in order to model the wavelet coefficients. Finally, it is possible to classify the SAR image using the parameters evaluated in the previous steps.

The wavelets method is become important because it can divide the image in to multi scale sub bands; in particular, in the presented work it was used a three-scale method. The alpha stable distribution has the role to model the wavelet coefficients, this method is used because the distribution is efficient to describe heavy tailed signals. Because of the lack of close formulas for the evaluation of the probability density function, the distribution as defined as:

$$\varphi(\omega) = \begin{cases} exp\left(j\mu\omega - |\gamma\omega|^{\alpha}\left[1 - j\, sign(\omega)\, \beta\, tan\left(\frac{\pi\alpha}{2}\right)\right]\right), & \alpha \neq 1 \\ exp\left(j\mu\omega - |\gamma\omega|\left[1 + j\, sign(\omega)\, \beta \frac{2}{\pi} \ln(|\omega|)\right]\right), & \alpha = 1 \end{cases} \tag{5}$$

where:
- $j = \sqrt{-1}$.
- α, β, γ, μ are the parameters typical of this distribution.

These parameters are calculated at each scale (3 in this work) and for each pixel. Then, starting from these distribution values the feature vectors is calculated, which is referred for each pixel in the following way:

$$F(x, y) = \{\alpha_1, \beta_1, \gamma_1, \mu_1, \alpha_i, \beta_i, \gamma_i, \mu_{i,} \alpha_L, \beta_L, \gamma_L, \mu_L\} \quad i = 1,2, \dots, L \tag{6}$$

In this equation the index i considers the number of scales taken on to account in this work. Most of the time it is not necessary to calculate every single parameter of the distribution, 4L parameters are expensive to calculate; it is enough to consider a combination of both of these parameters depending on the level of precision which we want to reach. Taking in to account all these steps the image classification can be done:

- Calculate the number of scales for the Stationarity Wavelet Transformation.
- Then it is possible to evaluate the parameters of the alpha stable distribution at the pixel level.
- At this point it necessary to build the feature vector starting from the previous steps.
- Finally, the classification of the image can be done.

In order to give an idea of the percentage of features labeled correctly, the confusion matrix is calculated (diagonal elements) and it is possible to see a high degree of correct labeling, exempt for the river areas:

Table 5: Confusion matrix of the Support Vector Machine algorithm, (Peng, et al., 2011).

	Farmland	Marsh	River	Building
Farmland	0.6313	0.0728	0.0001	0.2957
Marsh	0.0071	0.9587	0.0010	0.0332
River	0.0043	0.4013	0.5400	0.0544
Building	0.0514	0.0571	0.0001	0.8914

It was also possible to compare the SAR image with a graphical land classification with the Support Vector Machine algorithm Figure 53:

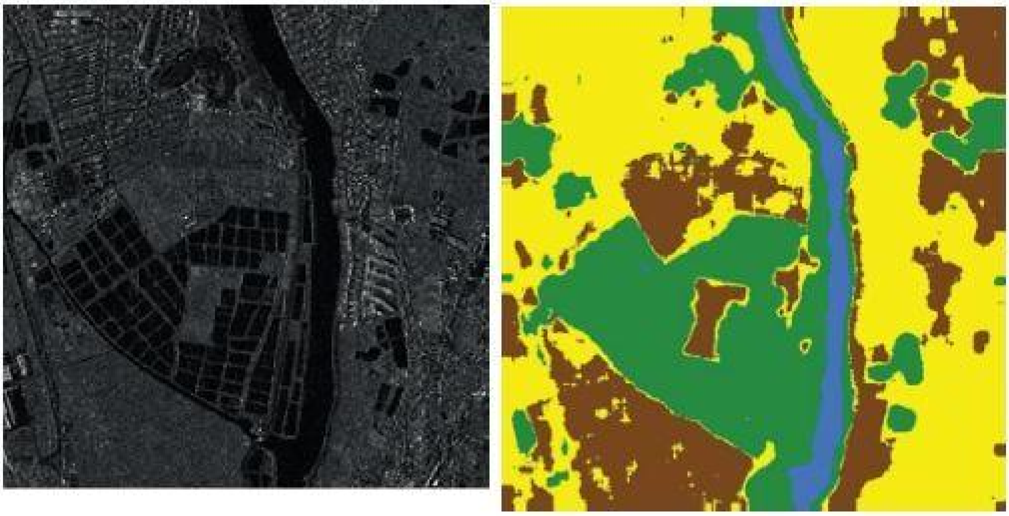


Figure 53: : (left) SAR image of Foshan (China), (Right) Results of SVM method with alpha stable distribution: buildings (yellow), river (blue), marsh (green), farmland (brown), (Peng, et al., 2011).

4.3 Permanent Scatterer height method

The proposed method aims to associate permanent scatterer (PS) to a specific target type and then evaluate the related deformation. The PS data have been recorded in the region of Diemen (Netherlands) (Dheenathayalan, et al., 2011) Figure 54.

In this work the data related to each permanent scatterers in terms of height is used to estimate a differential height map of the studied region. In order to verify the capability of the method the work is carried out in a region where it is already known the buildings distribution.

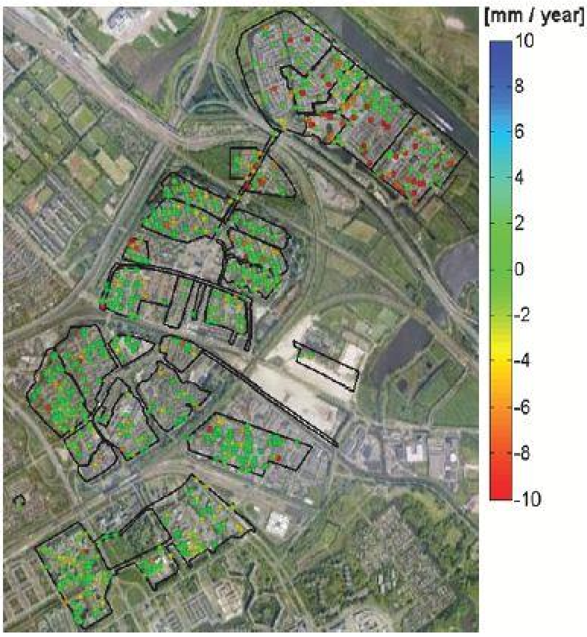


Figure 54: PS deformation of the Diemen region, (Dheenathayalan, et al., 2011).

Considering the height associated to each permanent scatterer a classification can be done with the following criteria: elevated targets with a height bigger than 3 meters, which show a type of reflection classified as type 1 and ground level targets with height lower than 3 meters classified as type 3.
Then it was possible to make consideration about the level of velocity displacements associated to each permanent scatterer, in particular with v1 and v3 are indicated the deformation velocity rates of the type 1 and 3; a threshold value of 2mm/year is fixed and combining the typology of the target with the deformation values it is possible to distinguish the nature of the permanent scatterer. The research shows the following results:

Table 6: Deformation type using height information, (Dheenathayalan, et al., 2011).

P_{v1}	P_{v3}	**Deformation type**
0	0	Everything being stable
0	1	Ground not stable
1	0	Building not stable
1	1	Both building and ground not stable

In the entire work another method was carried out to classify permanent scatterers and it was done using height, amplitude and polarization; in this case only the classification method based on PS height has been exposed. However, when compared with the other more refined study, results show that height-based interpretation exhibits 89% of agreement Figure 55.
It is was possible to understand that the height information was the crucial aspect of the problem in order to classify correctly the ground objects.

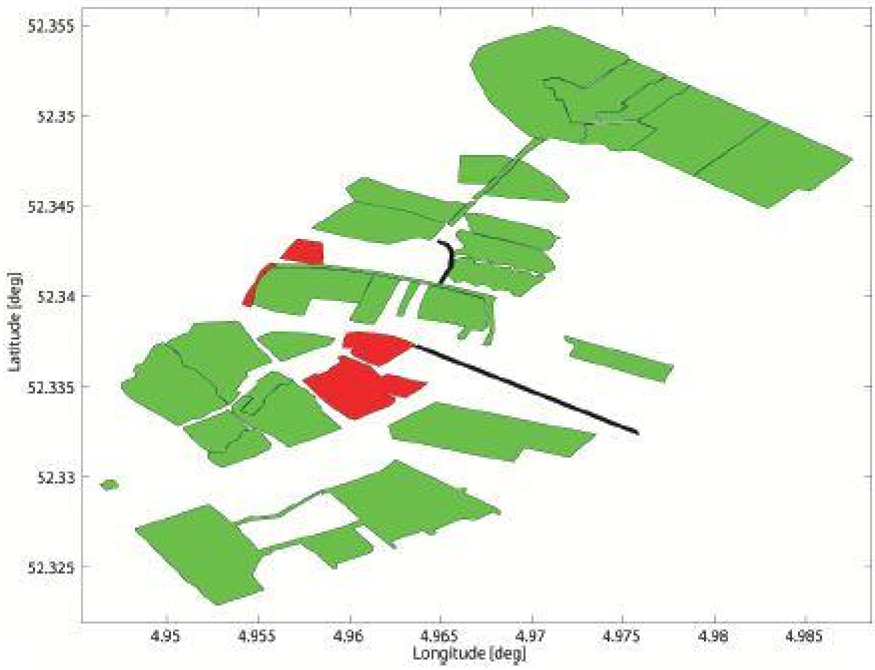


Figure 55: Deformation data for feature extraction: height method / height, amplitude, polarization method. Legend: agree (green), disagree (red), (Dheenathayalan, et al., 2011)

5. Early warning

The definition of Early Warning (EW) is "the provision of timely and effective information, through identified institutions, that allows individuals exposed to hazard to take action to avoid or reduce their risk and prepare for effective response.", and is the integration of different aspects which are very important according to the United Nations:

- **Risk Knowledge**: the purpose of this step is the definition of early warning systems in order to mitigate or event prevent damage events.
- **Monitoring and Predicting**: the capacity to predict and monitor potential damage situations by the systems is a very useful tool for different field of monitoring such environment and communities.
- **Disseminating Information**: an effective communication system is crucial to exploit the information earned from the previous analysis. The messages have to be synthetic and rapid to understand from the researchers or the population.
- **Response**: not less important is the cooperation of different authorities in order to make action plans to mitigate the risk associated at one event. Make people sensible to a particular problem is important to improve the response in difficult situations.

The Early warning system is an important instrument which ha the aim to prevent damage situations or to reduce potential disasters deriving from natural phenomena, affected in most part of the world; the analysis of deformation data and then the prompt activation of alarm messages allow to protect the communities. It is important that most countries become more sensible to the activation of early warning systems because it can provide only benefits if used in concomitance with risk assessment studies and action plans (Grasso, 2012).
It's important to notice that a prediction is not useful if it is not translated into an early warning and alert the population or eventually an in-situ inspection of the monitored area. As we have seen in the previous line the early warning system is an articulated structure which consider a lot of aspects: in particular it take in to account the risk assessment which is one of the most important part; it has to guarantee an active monitoring in order to evaluate the position of the potential risk situation and the intensity of the natural phenomena like an earthquake. Finally, it is important to disseminate messages to people subjected to the risk or make inspections of buildings if the level of damage detected is bigger than defined threshold values. All of these aspects are crucial in a early warning systems and the missing of one of them could potentially fall the entire research. Unfortunately most of the time early warning systems are not complete of efficient because are not present some of the previous citated part; so it is important the entire process: monitoring and predicting associated to a fast response plan can be considered an effective early warning system which can guarantee the mitigation of damage situations Figure 56.
The early warning system can be considered at different levels, in fact it can be used by local users or by bigger communities. As mentioned before the key aspect of the system is to prevent damaging situations for the people and for the buildings/structures which are an important resource for the community.
Considering the quality of the entire process it always be present a compromise between the accuracy of the prediction of the damage situation and the rapid response of the warning situation; this means that a major quantity of data can evaluate a phenomena with more precision but it takes more time to be evaluated. So it is important to do a trade between the two aspects and find a balance.

At the same time, it is important to notice that a level of uncertain is associated to a every risk situation; because of that not every prediction is always correct, and it is possible to make wrong decision in some case scenarios. Considering all possible situations can be present missed alarms, which means the missed alert when a real damaging situation is happening; by contrast, false alarms sees the detection of the risk situation when it is not necessary.

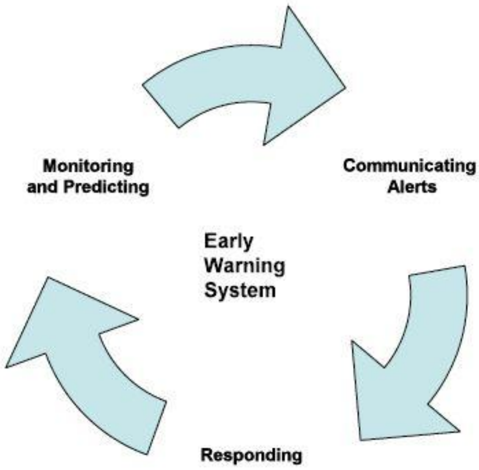


Figure 56: Early Warning systems operational aspects, (Grasso, 2012)

5.1 Seismic Early Warning Systems

Seismic Early Warning systems (EWS) in configuration both regional and on-site may be useful in mitigating the impact of medium and strong earthquakes. The ability of such systems to provide the location and magnitude of the earthquake in real time, can be used to activate countermeasures before the arrival of more energetic waves to the site of interest. Even when target-source distances (consequently alarm times) do not allow evacuation of risk structures and infrastructure, information provided by a system of EWS can be used to automatically activate measures that reduce in an almost instantaneous way the vulnerability and/or the exposure of structures of interest and therefore the expected loss.

An example of this type of Early Warning system is PRESTo (PRobabilistic and Evolutionary early warning SysTem), which was developed in the Irpinia Seismic Network (Italy) (Elia, et al., 2010). This monitoring system allows to obtain an evolutionary and probabilistic estimate of the parameters of an earthquake while the seismic phenomenon is still in act, and to disseminate warning messages in the presence of potentially destructive events. It uses probabilistic and evolutionary techniques developed for the calculation in real time of the parameters of the earthquake: using an algorithm of localization (RTLoc) it produces a density of probability relative to the position of the event; similarly, the one for the calculation of the magnitude (RTMag) uses a Bayesian approach to determine a probability density function of the magnitude from the measured displacement peaks. In addition, both the location and magnitude estimation are continuously updated and made more reliable during the phase of acquisition of new data by each seismic station.

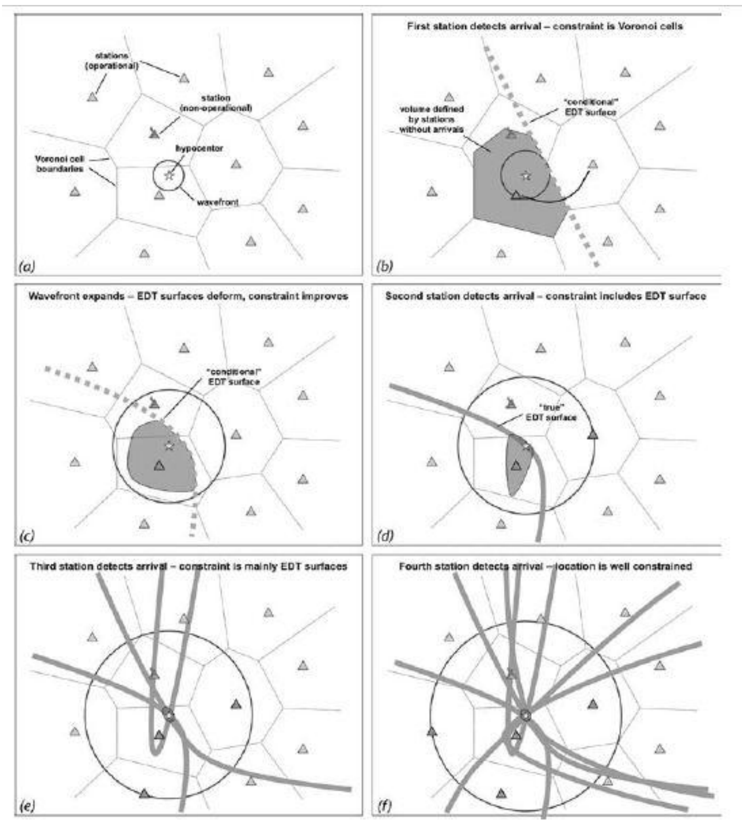


Figure 57: Steps for the evaluation of the earthquake hypocenter, (Satriano, et al., 2010)

PRESTo is able to disseminate information about the earthquake during the propagation of seismic waves. This can be done either through dedicated lines and in an encoded format, or via the internet in the form of easily interpretable messages. The alarm, traveling through data communication lines in the form of electromagnetic waves, infinitely faster than the seismic waves themselves, can reach sensitive structures seconds/ tens of seconds before destructive waves, as a function of distance from the hypocentre. This amount of time is sufficient for those who receive the alarm to activate a series of automatic safety procedures effective in order to contain the damage caused. The assessment of the cost/benefit ratio relating to the activation of the procedures mentioned, and therefore the choice to undertake them or not, is obviously left to the structures targeted by the alarm. The task of the seismic warning system is rather to provide all the useful information, including uncertainties, in a timely and robust manner.

Structures like bridges should be monitored periodically in order to evaluate the bridge health at any given time. An important work was carried to show how neural networks can be an useful tool for detection damage and the subsequent creation of the early warning system (Suryanita & Adnan, 2013). This early warning systems was applied to the model of the bridge on three sections of the spans bridge Figure 58. The results deriving from this work are encouraging for future studies in terms of bridge monitoring.

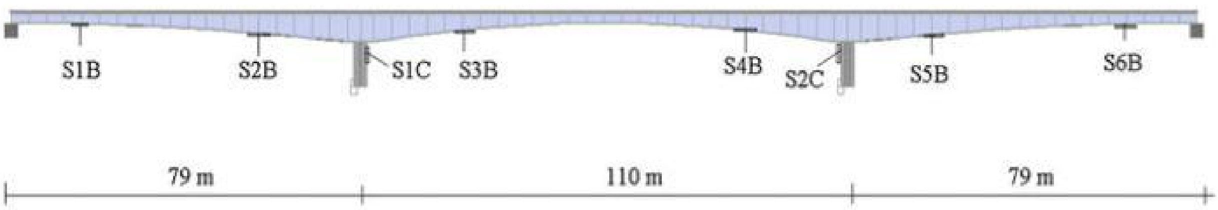


Figure 58: Sensors location on the three spans of box girder bridge model, (Suryanita & Adnan, 2013).

In this work it was used a Neural Network Back Propagation (BPNN) in order to build an early warning system able to evaluate different levels of damage when earthquakes phenomena occurs; this typology of algorithms is represented by neurons, which contains input values and output values; the middle part of the network contains neurons which are able to recognize the relation between all the data in order to give the output values which are the damage levels. Figure 58 shows the bridge model which was reconstructed with a finite element model analysis; then it was applied a time history analysis with several earthquakes in input in order to evaluate the bridge condition at a given time, The output obtained from the time history analysis it was used as input in the neural network in order to evaluate the level of damage in the bridge Figure 59.

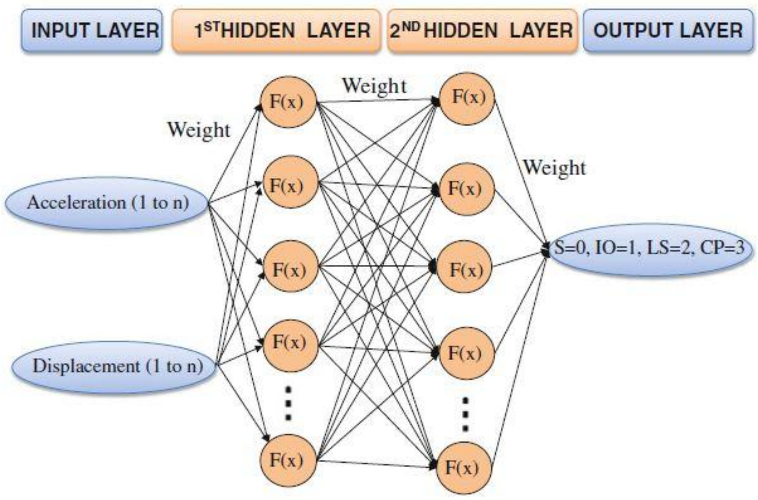


Figure 59: neural networks structure for the early-warning system, (Suryanita & Adnan, 2013).

In order to give an example of the data structure of this system is showed the table with two sensors associated to the New Zealand earthquake Figure 60. It is possible to see the values of displacements and acceleration associated to the two sensors and the level of damage evaluated with the neural network.

Data	Input					Output
	Time	S1C		S2C		
		ACC1	DISPL1	ACC2	DISPL2	
1	0	0	2.11E−02	0.00E+00	−9.77E−02	S=0
2	0.05	1.23E−04	2.13E−02	−4.95E−04	−9.71E−02	S=0
⋮	⋮	⋮	⋮	⋮	⋮	⋮
160	7.95	−1.29514	−1.72	−2.29747	−10.31	IO=1
161	8	−4.73E−01	−3.39E+00	−1.75E−01	−1.70E+01	IO=1
162	8.05	1.77E+00	−4.75E+00	3.01E+00	−2.35E+01	IO=1
163	8.1	3.81E−01	−2.98E+00	−3.32E+01	−2.65E+01	IO=1
164	8.15	−8.37E−01	−2.12E+00	2.67E+01	−4.57E+01	IO=1
165	8.2	4.46E−01	−2.78E+00	−1.99E+01	−3.22E+01	LS=2
166	8.25	−2.82E−01	−2.66E+00	1.43E+01	−4.05E+01	LS=2
167	8.3	−1.70E−01	−2.67E+00	−9.72E+00	−3.31E+01	CP=3
168	8.35	7.63E−01	−3.34E+00	6.85E+00	−3.68E+01	CP=3
169	8.4	−4.05E+00	−2.62E+00	−2.80E+00	−3.14E+01	CP=3
170	8.45	−6.48E+05	2.55E+01	−8.78E+01	−2.73E+01	CP=3

Figure 60: The example of input data S1C and S2C sensors due to New Zealand earthquake, (Suryanita & Adnan, 2013).

In order to distinguish the different levels of damage are considered three categories: immediate occupancy (IO), life safey (LS) and collapse prevention (CP). The first one indicates that the bridge is secure even after the effects of the earthquake; the second one describes a situation where several structural elements are damaged but the risk of injury is low. Finally, the third category is near to a partial or total collapse. Once the level of damage is calculated as output of the neural network it is possible to build the early warning system.

This early warning method can be described in three steps: the first step consists in the neural network which evaluate the bridge level of damage; the second step is the use of the monitoring software and then it is necessary to develop the alert system, which send messages in case of alarm.
In order to give an example of this type of system works is reported Figure 61. The different levels of alert are distinguished with three colors, then is an alert alarm is sent at the same time of a message of warning. After the evaluation of the level of damage indicated in the previous lines the system notifies eventually that the bridge is not secure, and it has to be closed.

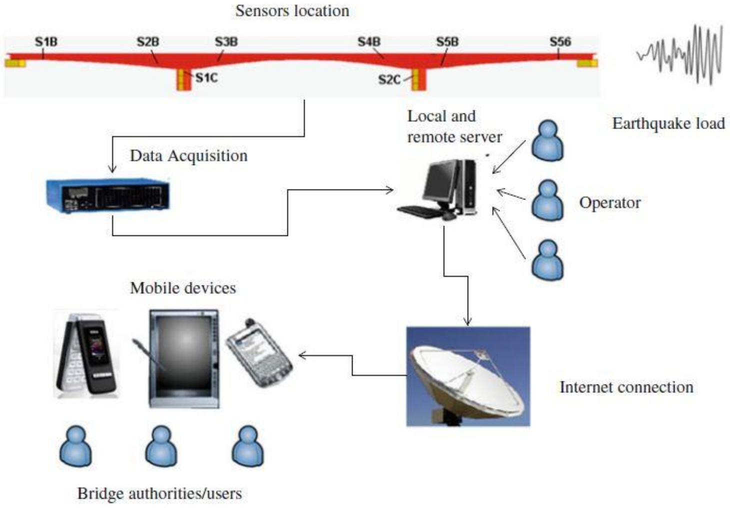


Figure 61: The bridge monitoring system, colours indicate level of damage in the structure, (Suryanita & Adnan, 2013).

This is an example of how neural network can be used to implement an early warning system to help researchers to monitor with efficiency structures like bridges, predicting different level of damage in the fast way possible. In order to have all this information it is necessary to have the software which sends messages to the public and most important predict the level of damage when the earthquake is in act or even later.
This approach can be used also with satellite data which provide displacement time series of different target on the monitored structure changing the sampling time which in case of satellite data is in the order of 14 days with the current sensors available.

A new approach for early warning systems given by the integration of the fragility curves was proposed in the work carried out by (Megalooikonomou, et al., 2018).
The fragility curve is an important concept which underline the potential loss in buildings monitoring; in particular, this curve represents the state level of damage of a particular building on function of the structural response; this concept is related to a specific case scenario and it has to be calculated in relation to each structure monitored. This relation between these two parameters is often expressed in terms of probability, the probability to exceed a level of damage. Usually in literature it is common to find to parameters associated to the level of damage in buildings: the maximum interstory drift ratio (IDR) and the peak fool acceleration (PFA). Because of the majority of the structural part are influenced by lateral deformation, these two parameters are good for evaluate the level of damage in buildings.

The Eurocode 8 gives some information about the threshold deformation values associated in case of earthquakes. In particular taking in to account the serviceability limit state for a seismic design intensity the paragraph (4.4.3.2) indicates the limit values of the peak story drift as a function of the no structural typology elements

- For buildings having non-structural components fixed in a way so as not to interfere with structural deformations: $d_r \nu \leq 0.010h$
- For buildings having ductile non-structural components: $d_r \nu \leq 0.075h$
- For buildings having non-structural components, realized with brittle materials, attached to the structure: $d_r \nu \leq 0.005h$

Where:
- d_r: is the interstorey drift.
- h: is the storey height.
- ν: is a reduction factor which takes into account the lover return period of the seismic action associated with the damage limitation requirement. The recommended value of ν are 0.4 for importance classes 3-4 and 0.5 for classes 1-2.

As we have said before fragility curves gives a probabilistic approach to the evaluation of the damage in buildings monitoring; considering the previous threshold, values it is possible to give alert messages when the deformation values reach critical damages. The purpose of this system is to identify the damage in non-structural elements during earthquakes phenomena.

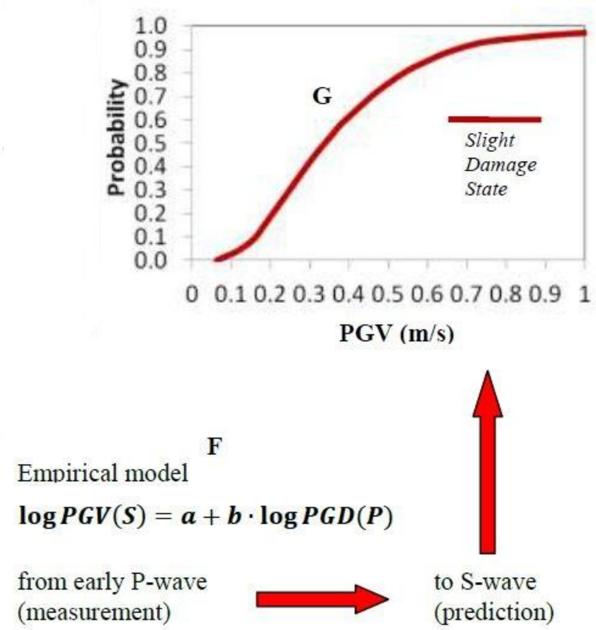


Figure 62: Prediction of the PGV for S-waves and example of derived fragility curve, (Megalooikonomou, et al., 2018).

A different example in the early warning field is given by the work carried out by (Todorovska & Trifunac, 2008). In particular it was possible to build an early warning system considering the variation of building stiffness with the evaluation of the travel time of seismic waves through the structure monitored. The advantages of this method are that is very efficient when is applied in response to earthquakes damages, is not affected by the interaction between the soil and the structure and it is able to evaluate local damage state.
The principle of the method is founded of the D'Alambert's equation which considers the relation between the level of damage of a structure and the change value of the shear wave velocity, which modify its value when the structure is damaged or undamaged. The changes in the wave velocity depends only in the variation physical properties between sensors present in the structure; for this reason the minimum number of sensors installed in the structure is two (at the base of the building and on the roof) but more sensors can guarantee a major level of accuracy in the analysis.
The method can be seen as an intermediate method between the non-destructive testing (NDT) methods and global vibrational methods (GVM). The first one evaluates the damage in the structure at the global level and the second one is good when it is necessary to detect a local damage in an element.
With these typology it is possible to evaluate global changes and local changes in the monitored building, in the first case with the total change in the wave travel along the total height of the buildings; by contrast, the local damage can be evaluated looking the change in the wave travel time between two sensors, which are located where there's necessity. This methodology could be used to assess the damage statement of a structure after a damaging event and evaluate a fast early warning if the damage reach a define threshold.

In the previous example we have seen the utility of the fragility curve. In this work we can see that this concept can derive also by the capacity curve, which is a diagram indicating a relation between forces and displacements along the structure; this can be related to the response of the structure in relation with the fundamental mode of vibration (Pujades, et al., 2010).
These capacity curves derived from a non- linear analysis and considering acceleration and displacements can be called also capacity spectra, from that it is possible to evaluate the fragility curves. In this case the curve allows to evaluate the probability associated to a certain level of damage to reach a spectral displacement.
This method is useful because can evaluate the Performance Point, which indicate the spectral building displacement associated to a specific earthquake event. In this work it is used the equivalent linear displacement method in order to derive that point and then the fragility curves are used to evaluate in a probabilistic way the level of damage, which can be divided in 4 levels: slight, moderate, severe, extensive to collapse.
For each level of damage, the fragility curve indicates the probability to reach that level of damage and when no damage occurs the fragility curve is equal to 1.

It is common to define the fragility curve with a lognormal distribution, which has the following equation:

$$P(DS \geq DS_k|\, S_d) = \phi\left[\frac{1}{\beta_k} ln\left(\frac{S_d}{S_{dk}}\right)\right] \qquad k = 1 \dots 4 \tag{7}$$

where:
- Φ: is the cumulative standard lognormal distribution function
- S_d: is the spectral displacement
- S_{dk}: is the mean value of the distribution function.
- β_k: is standard deviation of the distribution function.

All these parameters can be evaluated from the capacity spectrum, while the S_{dk} values, also called damage thresholds, are calculated with these equations:

$$S_{d1} = 0.7D_y \;\; ; \;\; S_{d2} = D_y \;\; ; \;\; S_{d3} = D_y + 0.25(D_u - D_y) \;\; ; \;\; S_{d4} = D_u \tag{8}$$

To evaluate the standard deviation, we consider a binomial distribution for the analysis. For each building analyzed the spectral displacement can be used in the fragility curve to obtain the related probability of exceed the damage thresholds like we have explained before, while the mean damage state Dm is described by the following equation:

$$D_m = \sum_{k=0}^{4} kP_k \tag{9}$$

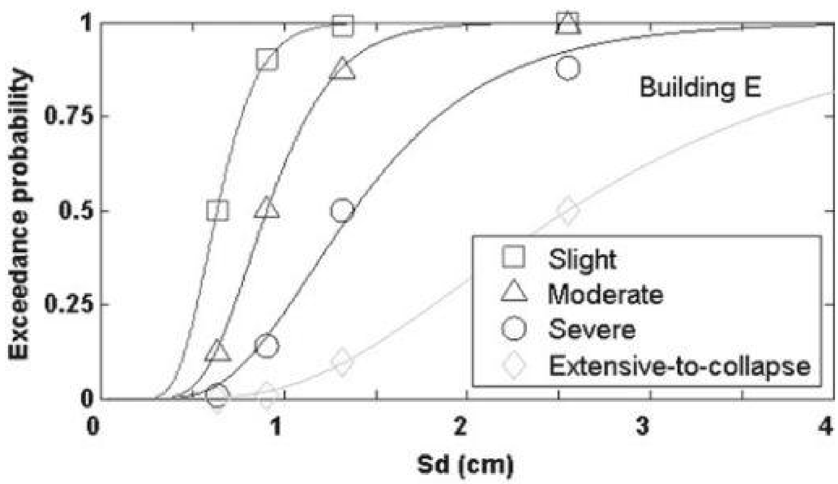


Figure 63: Fragility curves of the selected building in Barcelona, (Pujades, et al., 2010).

The production of natural gas is inducing earthquakes in the Groningen field in Netherland, for this reason recently a study was carried out about a probabilistic damage assessment of the buildings, defining three levels of damage: slight non-structural, slight structural and moderate structural damage (Crowley, et al., 2019). This time the fragility curves are evaluated using numerical methods, knowing the characteristics of the material used and from shake table tests at the buildings full scale. It was possible to evaluate the drift ratio levels associated at the occurrence od the damage in unreinforced masonry buildings; these damage state levels can be described as follows:

- Minor structural damage: it is possible to see this level of damage when the craking in the primary resisting elements occur; this level of damage can be repaired with no difficulties
- Significant structural damage: this type of damage was observed in all the piers of the building.

As mentioned before, were done shake table tests and after that were done in situ surveys in order to obtain the maximum drift damage level at which a certain level of damage was not present. These important values were used then as limit state displacements for each damage states (DL_i) Table 7:

Table 7: SDOF drift limits for each damage state, extracted from shake-table tests, (Crowley, et al., 2019).

Shake table test	**ϑ_{DL2} [%]**	**ϑ_{DL3} [%]**
2 storey terraced house, cavity walls, concrete floor	0.09	0.26
1 storey terraced house, cavity walls, concrete floor	0.13	0.30
1 storey detached house, solid walls, timber floor	0.01	0.25

Because of the buildings in this area were already subjected to some earthquake events the threshold values, considered at the first time as conservative values, were considered good parameter to the current analysis and for future investigation. For example, in the literature sometimes are given bigger limit values but considering buildings which no have had deformation phenomena before.
talking about reinforced concrete buildings the drift levels associated to damage where calculated from cyclic tests on cast in place and precast reinforced concrete specimens. The results obtained in terms of displacements have been used for the correspondent fragility curves:

Table 8: drift limits for each damage state derived from Reinforced Concrete cyclic tests, (Crowley, et al., 2019).

Shake table test	**ϑ_{DL2} [%]**	**ϑ_{DL3} [%]**
cast-in-place low-rise	0.8	1.25
pre-cast low-rise	0.14	0.50

- Damage state 2: full-depth hairline cracks at base of walls, and also cracks appearing at wall-slab joints.
- Damage state 3: Hairline cracks lengthen and extend, though with limited opening. Strength degradation begins.

Whereas the damage states observed in the precast reinforced concrete specimen are instead described as:
- Damage state 2: cracks start to grow in the proximity of the wall connectors.
- Damage state 3: permanent flexural deformation in the connectors leading to residual displacements. Strength degradation initiates in this part of the building.

5.2 Rainfall Early Warning Systems

Changing typology of early warning system and speaking about thresholds rainfall values, in the city of Messina (Italy) were evaluated several storms which triggered natural phenomena like debris flows, which may cause big amount of damage to buildings.
Because of the rapidity of the event and the low time available to take preventive actions to mitigate the risk levels the Civil Protection in that area had thought a series of initiatives in order to optimize the response during these rainy events: they installed sensors able to measure rain levels and temperature, meteorological radar and studied a rainfall alert model based on threshold rainfalls. More important they studied a plan for the civil protection (Basile & Panebianco , 2013).
Establish these threshold values is not an easy problem and also associate the relative alert levels; this fact is related to the local validity of the problem, all the information available about rainfalls and geological aspects are related to a specific area and are not attributable to other areas.
In this study they registered data for cumulative rainfalls from 1 to a maximum of 15 days between the different years Figure 64:

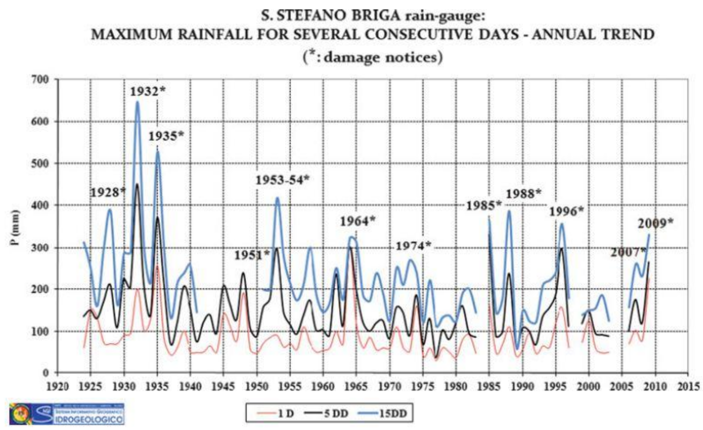


Figure 64: Annual trend of S.Stefano Briga (Messina) rain gauge, (Basile & Panebianco , 2013).

From these data examination it was possible to make some considerations Table 9 the value "d" indicates the rainy days before the generic event:

Table 9: Alert situations associated to rainfalls.

Very critical situations	Critical situations
P(1d) > 100 mm	P(1d) > 70 mm
P(5d) > 150 mm	P(5d) > 100 mm
P(15d) > 200 mm	P(15d) > 150 mm

In addiction it was possible to calculate thresholds based on two indicators: the pre-conditional factors, which are related to cumulative rainfall and the triggering factors with rainfall intensity. The results show three thresholds value associated to three alert values Figure 65:

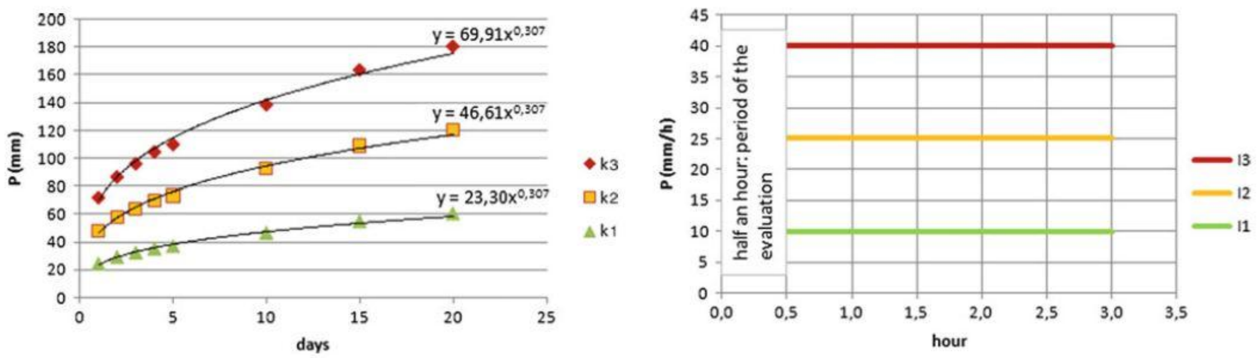


Figure 65: : Threshold equations due to cumulative rainfall (left), thresholds related to rain intensity (right), (Basile & Panebianco , 2013)

The values of cumulative rainfalls and intensity have to be combined in order to evaluate all the case scenario possible.

The landslides phenomena are influenced not only by the quantity of rainfalls which subjects a certain area of study but also by the nature of the terrain, considering physical and mechanical aspects of the soil. The experience has suggested to define thresholds based on rainfalls because most of the time rainfalls are one of the triggering factors of the landslides. The purpose of this study is to evaluate values of rainfalls which can guarantee the prevention of the occurrence of landslides and the relative damage to buildings (Salciarini, et al., 2013).
Currently there are two approaches used in literature to define rainfalls thresholds: empirical and physically based methods. the first method is based on the experience and depends from data registered in the past which indicates the activation of a disaster phenomenon; the second one is a more accurate model which considers more aspects, like the site properties in terms of mechanical and physical soil properties. This aspects is crucial because the alert situation is certainly site dependent and the definition of rainfalls thresholds by themselves is not sufficient.

In order to give an example of a physically based approach is shown the Critical RainFall (CRF) model. In particular a first attempt to certify the potentiality of a method of this type was done in the Umbria region (Italy), where were done previous studies regarding landslides phenomena. The model considers a series of hypothesis at the base:

- The loose soil cover thickness is small compared to the slope length.
- The failure surface is localized in the part between the loose cover and the underlying bedrock.
- The bedrock is considered impermeable.
- Before the critical rainfalls event the slope is considered saturated.
- The values of rainfalls which triggers the activation of landslide is uniform in space and time.

Using this method, it is possible to find the potential slope unstable in the monitored area. The map shows the relation between the rainfalls duration and the reach of the limit conditions; the results showed a good agreement between the model and the real activation of landslides. Furthermore, it was possible to recognize that the threshold rainfalls values were not the most significant parameters (they described a range from 1 mm/h to 20mm/h), but the physical properties of the soil were the most important aspect of the problem Figure 66. It is important to notice that a empirical threshold value of rainfall describe only a critical value without any information about the soil behavior. Repeating the analysis for the different zones the Critical RainFall method permits to produce thresholds which consider also the properties of the soil.

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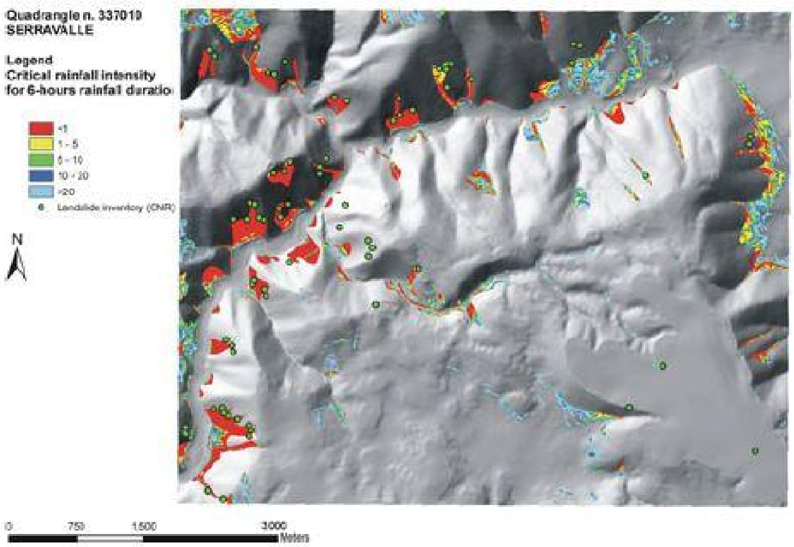

Figure 66: critical rainfall thresholds in the monitored area, (Salciarini, et al., 2013)

5.3 Early Warning System from SAR data

In this paragraph we talk about early warning systems connected to Synthetic aperture radar systems. We mentioned several times the importance of an effective system which can guarantee the prevention of damage induced by natural phenomena like landslides and this aspect can be even more significative when we talk about cultural heritage sites. The ground-based radar interferometry can be a useful tool to create early warning systems and an example is showed in the city of Rome (Italy) (Tapete, et al., 2013).
In particular it was possible to monitor several archeological area (Colosseum) and even single monuments (Domus Tiberiana) Figure 67:

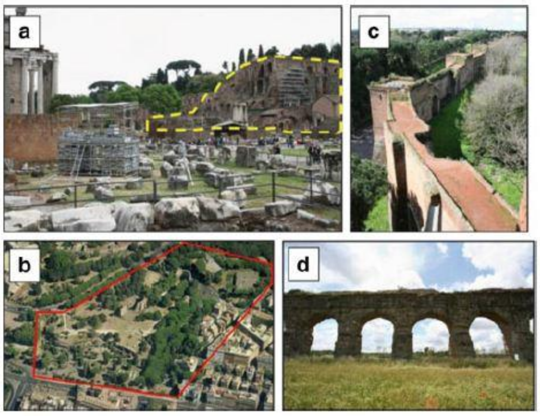

Figure 67: Archeological sites monitored with radar interferometry, (Tapete, et al., 2013).

All the procedures adopted for the early warning systems were decided with the collaboration of the local conservators, which monitor the sites every day and can provide suggestions to improve the early warning system Figure 67.
The system starts with the background phase which considers all the historical data deriving from the literature are used like start point to organize the radar monitoring campaign, which was defined by the permanent scatterer InSAR technique for the archeological scale and by the ground based InSAR technique at the single monument scale.
The second step consists in the investigation phase, where it was possible to combine a continuous monitoring activity between in field survey in order to validate the technique and the SAR data. With this data available prompt communication of possible anomalies allow the conservators to activate immediate evaluation of risk situations. At this point when a potential risk situation is evaluated it is possible to activate the third step of the early warning system, which consists in the interpretation phase. At this point of the analysis all the SAR data are integrated by local hazard factors. The local conservations with a better knowledge of the monuments situation can help in the definition of the alert levels.

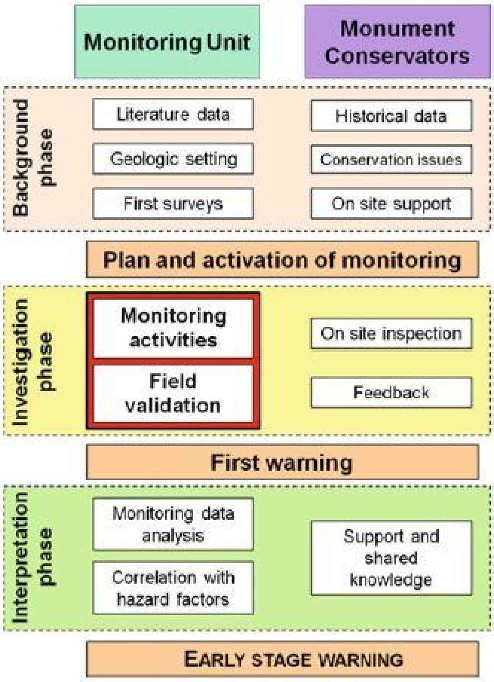

Figure 68: Flow chart of the 'early stage warning', (Tapete, et al., 2013).

The first step of the analysis starts with the evaluation of the LOS deformation rates, later when all the data are acquired it is necessary to find anomalous situations like the acceleration or deceleration in deformation of a particular permanent scatterer which can correspond to a change in the structural behavior; this type of anomalies is not the only one, also discontinuities from the previous deformative trend have to be considered like potential risk situations.
In order to give an example of the data it is shown the data set of the Oppian Hill area which was classified apparently as stable; the displacement values along the Line Of Sight underline sensible deviation from the previous trend and the velocities of displacements reached the value of 5.1 mm/year in the last period of monitoring in august 2009. The alert level was considered high because of the importance of the buildings monitored

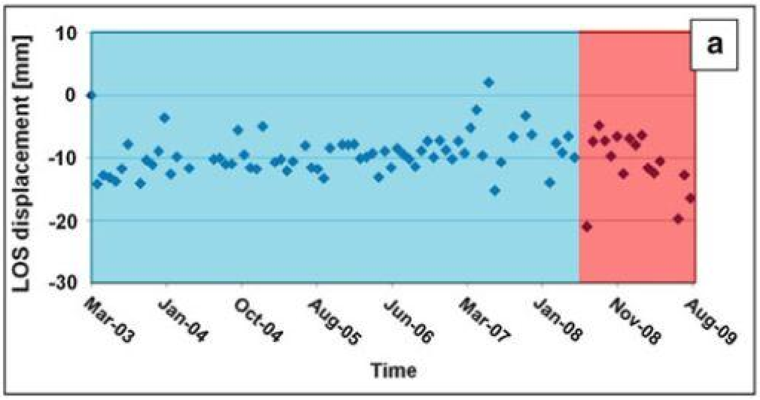

Figure 69: Time series of deformation identified in the NW corner of the Nero's Golden House, Oppian Hill, (Tapete, et al., 2013).

This work showed the capabilities of the Synthetic aperture radar technique for the early warning system. In particular with the use of the Permanent Scatterer technique at the site scale and the ground-based interferometry technique at the scale of a single building it was possible to recognize promptly warning situations and monitor with more accuracy. This is an encouraging work for the future studies in terms of archeological site monitoring but also for buildings or structures in general.

The common techniques used to monitor surface deformations, such as total stations, GPS networks and strain gauges, are not the best solution for a real-time monitoring.
In fact, for these systems it is necessary to have access to unstable areas for the instrumentation engraving and do not provide a sufficiently high sampling frequency. Conversely, satellite interferometric techniques can surpass conventional monitoring methodologies due to areal coverage characteristics, time continuity in data acquisition, the possibility of obtaining accurate deformation measurements without having physical access to the area to be monitored and consequently being able to control places characterized by poor accessibility. The use of interferometric techniques can therefore be fundamental for the detection of deformative phenomena associated with buildings in urban areas and the study of their evolution over time.
The potential of satellite monitoring to identify potentially critical areas and alert thresholds may be:

- Ability to detect deformative series both on a large scale and on a local scale.
- Possibility of monitoring without the installation of instrumentation in areas subject to deformation risk.
- Possible measurements in all atmospheric conditions.
- Through the time series of deformation it is possible to reconstruct deformative trends that show in an intuitive way the presence of possible criticalities.
- Identification of critical areas and their alert thresholds.

An approach for satellite monitoring and surveillance was proposed in (Cigna, 2010) and is divided into:
- Satellite and alert system design.
- Development of reporting models for anomalous time series.

The satellite monitoring and alert system is divided into two successive levels:
- First Level: surveillance of the whole national territory, aimed at identifying significant accelerations of deformative phenomena.
- Second level: detail monitoring, which is activated on first level reporting, aimed at narrower areas and at assessing the criticality level of the individual deformative phenomenon.

The creation and calibration of a satellite monitoring system, both first and second level, is composed of two fundamental moments:
- Preliminary phase: analysis of all available data for the area of interest, first processing of satellite radar data, definition of satellite alert zones and calibration of the signal model and alert thresholds. In this phase falls the choice of alert thresholds, which is the main purpose of the early warning system.
- Operational phase: consists of real-time monitoring of the phenomena of interest and includes subsequent updates of the interferometric analysis on the area of interest; the detection of possible precursor movements of deformative events and the determination of criticality levels.

In the framework of the SAR.net project and with the collaboration of TRE, a research was carried out to develop a tool for rapid and automatic analysis of deformation time series, Capable of detecting alterations or abnormalities in the behaviour of radar targets, correlated with the activation, acceleration or presence of deformative phenomena.
The alert thresholds triggering a risk situation are determined by calibrating the chosen reporting model. The determination of the reporting model consists in the search for criteria for identifying risk situations related to the development of surface deformations and in the creation, testing and improvement of an algorithm capable of selecting radar targets that change behavior from an initial multi-interferometric analysis to the next update.
The general operation of the instrument sought is as follows:

- The characteristics of the deformative trend of the test point are highlighted before updating and it is assumed that this will remain unchanged during subsequent acquisitions.
- Once the analysis has been updated, the expected trend is compared with that obtained from the updated analysis. The target trend is abnormal if, in the update interval it differs significantly from the forecast.

In relation to the purpose of the research, namely the design of a national-scale satellite surveillance system, the algorithm sought can be applied directly to the output deformation time series.
The historical series of deformation, are obtained by the elaboration of temporal groups of SAR images, assuming a priori a model of well precise deformation for the discrimination of the interferometry phase components related to the deformations. This model is generally linear and, all phase contributions that behave nonlinear over time, are attributed to phase contributions other than deformation, such as atmospheric components. However, if deviations from the deformation model are contained relative to the deformation model, alterations and/or accelerations can be identified and discriminated against during the monitoring period.

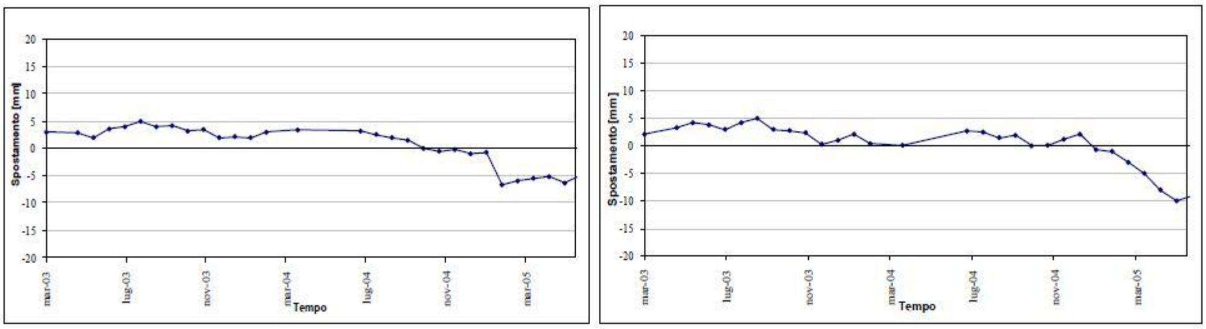

Figure 70: Examples of anomalies trend deformation: High deformation (left), acceleration of deformation (right), (Cigna, 2010).

In the city of Ancona after an important landslide phenomenon reactivated in 1982 which produced a lot of damage it was necessary to create an Early Warning system connected to an emergency plan. In this monitoring systems were applied several different instruments belonging to a surface monitoring system and a subsurface monitoring system. the first one was composed by robotic stations which were able to detect angle and distances of the surface monitored area, reflectors were installed both in some buildings and in the consolidation structures inside the landslide; this surface systems were also provided by different geodetic GPS stations and tiltmeters sensors.
The geotechnical monitoring systems was equipped with modular dynamic systems columns installed at 100 meters of depth. This continuous monitoring system is able to monito the surface and the subsurface of the landslide area Figure 71:

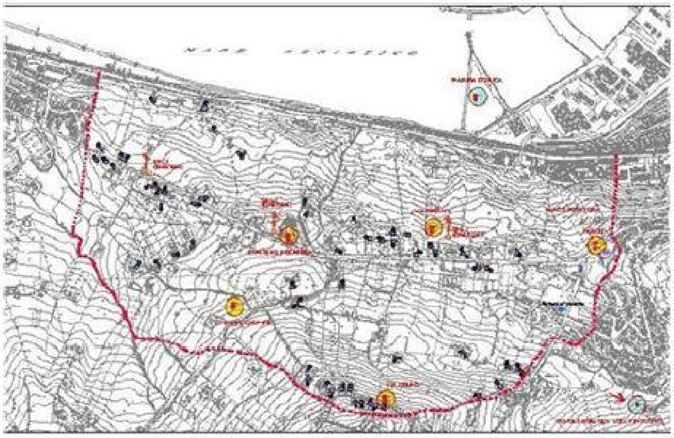

Figure 71: : Map of the instrumented sites, (Cardellini & Osimani, 2013).

The responsibilities to monitor the entire area is given to a staff of technicians, who control the area during the all day in the control center placed in the town hall. The cycle of acquisition of the data is configured on 30 minutes, this means that every 30 minutes are available new data of the monitored area; but if it is necessary it is possible to monitor in real time acquiring more data. These data are compared with threshold values which are decided by the technicians avoiding risk situations with the most efficacy as possible; an example of the structure of the early warning system is given in Figure 72.
When the system evaluates a displacement valued bigger than the given thresholds it is necessary to send message to the monitoring center in order to make decision to mitigate the risk situation. The level of alert is divided in four levels considering the importance of the event; this systems has a series of software which have different roles in the entire monitoring; the software GeoMaster downloads all the data stacked in the control unit, while the DMS Early Warning software visualize the data relative of the surface.

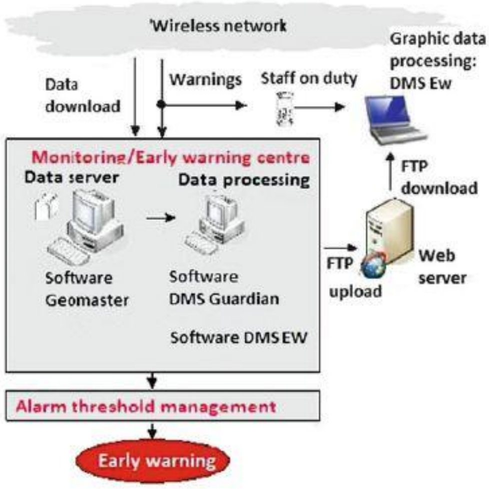

Figure 72: Dynamic monitoring system Early warning, (Cardellini & Osimani, 2013).

These instruments are not sufficient to guarantee a complete early warning system, it is also necessary to build an evacuation protocol to make effective the precedent steps.
This type of Early Warning system can also be used with deformation time series deriving from satellite monitoring replacing all the instruments, in fact this monitoring system has the advantage to detect the structural health without an operator having to install particular instruments on site.

In the Volterra site (Italy) it was provided the capability of the remote sensing technique to structures monitoring in order to prevent relevant damage. The technique used in this study was the ground-based radar interferometry in cooperation with the terrestrial laser scanner technique (Pratesi, et al., 2015).
In this case of study it was possible to recognize a risk of collapse with two days in advance of a big city wall section in 2014. The technique was able to detect displacements of buildings and monuments almost in real time this allowing to prevent the loss of life and to make effective conservation actions. As mentioned before the variation in the velocity of displacement is an index of a risk situation, in this case scenario the registered data started from values near to 0.1 mm/hours to 1.7 mm/hours; the authorities were immediately alerted and the area was closed before the collapse Figure 73.

Figure 73: Displacements toward the sensor measured along the LOS, (Pratesi, et al., 2015).

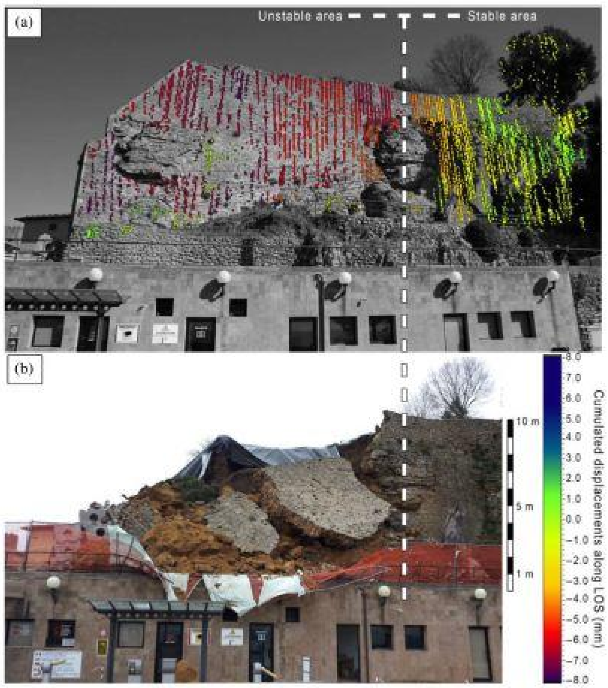

Figure 74: Prevision of walls collapse with LOS displacements, (Pratesi, et al., 2015).

As final result of this study it was possible to verify the effectiveness of the ground based InSAR interferometry, which has the same key aspects of the SAR technique using satellite data but is more indicated for the monitoring of individual buildings or limited areas. The areas characterized by anomalies values where classified in alert areas, which include unstable buildings; pre alert areas which were characterized by movements but not considered critical. In order to avoid some missed alarms, the pre alert area were studied with accuracy with also in situ inspections; in particular when were noticed anomalies displacements the pre alert areas were changed in alert areas.
The results deriving from this technique are encouraging for future works, also for monitoring bigger areas the SAR technique provide a useful tool for the improvement of the early warning systems.

6. Conclusions

Considering the numerous fields of application of differential SAR interferometry for the monitoring of urban areas analyzed, it can be concluded that this is a very useful tool to reduce the risks arising from deformative phenomena. The possibility to monitor large urban areas subjected to natural phenomena (earthquakes, landslides, subsidence, etc.) without the need to install equipment, the availability of historical archives of multi-year deformation and a high spatial density of measures are advantages that can give to this technique an increasing importance in the protection of urban works

Finally, from the examples reported it has been possible to see how the monitoring through satellite data allows to identify abnormal situations that may compromise the functionality of the monitored structures. In fact, following the time series deformation it is possible to identify with promptness any variations in the speed of deformation or changes in the deformative trend; this monitoring method aims to identify threshold values or warning deformation trends that allows operators in charge to carry out a visual inspection in situ or possibly evacuate the area at risk.

Another important result of the thesis is to outline the state of the art in the field of satellite monitoring and this is certainly attributable to the new satellites available, in particular it refers to the mission COSMO-Skymed of the Italian space agency and the Ministry of Defence. There are currently 4 first-generation COSMO-Skymed satellites and a second-generation satellite whose launch was carried out on December 18, 2019; the latter will soon be flanked by a second satellite with the arrival in orbit scheduled for the year 2021. The peculiarity of this project is to have available in the near future a constellation of 6 satellites having the same orbit, this means having data with greatly reduced revisiting times up to a final result of 12 hours. These satellites allow to measure the deformation of ground targets with millimeter precision and have the possibility to provide images with variable resolution, the best available resolution is metric and can be obtained in Spotlight mode.

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