Advantages and drawbacks in the use of non-contact radar techniques to perform dynamic measurements

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1 Introduction

The need for accurate static and dynamic measures is a long-standing problem affecting all fields of engineering. Most of the reliability of the performed experimental analysis depends on the quality and accuracy of the measures on which they rely. Dynamic tests are usually performed by means of a set of accelerometers or other sensors placed in specific points of the structure under analysis. Accelerometers are, in particular the most used sensors when dealing with vibration measurements. Sev-eral examples of applications are available in the literature and the advantages/disadvantages of these kind of sensors were widely studied in the past [1]. In general, the use of contact sensors has many advantages in terms of quality and reliability of the results. Not in all cases, however, the use of contact sensors is feasible or cost effective. In many practical applications, increasing the number of measured points leads to a significant increase on the number of useful information that can be given about a structure or its health. Many techniques of the structural health monitoring (SHM) field of research [2] are based on an accurate description of mode shapes or operational deflection shapes [3] which can be given providing the correct number of measurement points. In the case of contact sensors this means an increase in the number of sensors placed on the structure, with all the possible drawbacks in terms of costs and feasibility.

Against this background, the development of innovative non-contact systems for dynamic measurements seems very attractive. Non-contact techniques, however, are not

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as established as the contact ones. In the past years, several vision-based solutions were proposed [4]. The recent availability of high-performance vision-based systems, at affordable costs, has led to the development of several image-based vibration measurement techniques [5]. In this context, there is scope for providing the engineering community with further innovative non-contact systems, whose results are reliable. In this paper, the use of radar techniques to perform dynamic measurements is investigated. The use of radar systems for measurements of static type is a widely studied topic, particularly using the synthetic aperture radar (SAR) technique [6, 7]. Conversely, its use for dynamic measuring purposes is a fairly new topic. Recent works such as [8] and [9] demonstrate the interest in the field. Particularly in [9] an accurate vibration estimation method for synthetic aperture radar is presented. Using this method the authors, considering cases for which the vibrating scatterer is well separated from other scatterers in range, provide an accurate estimation of amplitudes and frequencies of a vibrating object.

In civil engineering, dynamic testing is often required to evaluate structural modal parameters and, subsequently, for SHM purposes. Although accelerometers are still the most widely used technique, radar-based measurements were widely used in the past years. The literature reports a variety of applications, such as bridges [10–16], stay cables [17, 18], wind turbine towers [19]. More specific applications also involve a bell tower [20] and a corrugated steel plate culvert [21]. In these works, the authors provided an extensive analysis of the advantages in the use of this technique for dynamic measurement purposes. In some of the abovementioned works [12, 13, 15, 21], a comparison between radar measurements and conventional sensors is also reported. In general, a good agreement was found between radar and conventional sensors. However, some of the authors also evidence that in the case of complex targets the detected radar response is the summation of all the phasors relative to the physical scatterers in the resolution cell [14]. The problem may become critical in the case of torsional motion [14, 15]. Therefore, a correct position of the measurement system with respect to the monitored structure is a key aspect, but anyhow errors may arise in case of targets placed at the same distance from the radar.

Some works, such as [22], propose methods to separate the target and background signals. This approach, however, assumes that only one target is moving at a single frequency and amplitude and background signals are due to static elements. This assumption is restrictive in many practical applications. This is the case, for example, of structures such as metallic bridges or in general buildings which have in their vicinity metallic reflective elements, both static and moving.

This work is about the use of the head of a static radar system (GBInSAR [23], developed by Ellegi using LiSA-Lab technology) for dynamic measurement purposes. With respect to state of the art, the work aims at experimentally evidencing problems that may arise when using non-contact radar techniques to dynamic measurement purposes. Particularly the works want to outline possible measurement errors in case of targets placed at the same distance from the radar.

To assess the radar performances, a dedicated test system was set up. In particular, some corner reflectors were used to simulate the presence of reflecting targets. One corner reflector was moved by a hydraulic actuator, while the others were static. We will first present the results of measurements made with the GBInSAR radar system in the presence of a single target, to verify the proper functioning of the system. Following are presented the results of measurements performed in the presence of additional static corner reflectors. The proposed tests aim at showing that improper use of this system can lead to measurement errors which cannot be corrected a posteriori. The experimental results were also compared with numerical simulations. Some results are reported in Sect. 5. This analysis adds an important knowledge about the sensor in question, offering the opportunity to better understand its potential and the types of applications where it could be used with satisfactory results.

2 Radar techniques

A Radar system is an active sensor that sends microwave pulses to the observed scene, consistently records backscattered signal and derives the information on the distance of several targets in the scene. Working with pulsed radar, usually this distance is calculated by means of computing the time lag between sent signal and received echoes. Among the various possible configurations of the sensor, in addition to classical pulsed radar, other variants that are sometimes preferable in relation to a particular application have been developed over the years.

Regardless of the architecture used, a traditional radar system has an excellent ability to provide accurate information on the distance and velocity of isolated objects in all weather and lighting conditions.

In applications where the object of study is a complex scene and it is desirable to distinguish as much detail as possible, the system's ability to accurately locate the different objects in space and to discriminate between nearby objects becomes crucial. It is well known that the spatial resolution of a real antenna depends on its size in relation to the wavelength of the radiation used. In static radar, electromagnetic waves are emitted via an antenna that can

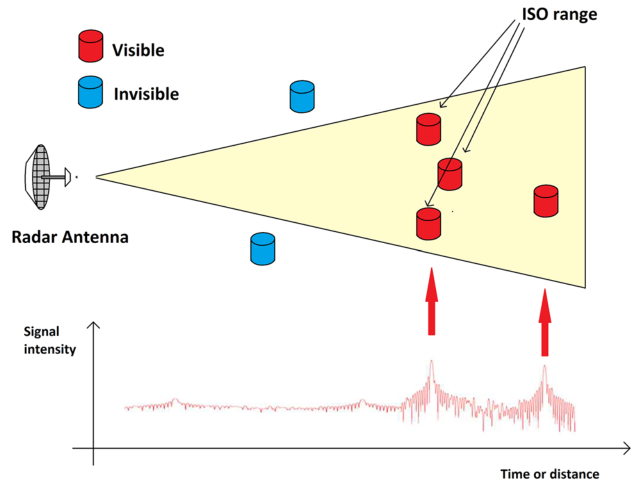


Fig. 1 Visible and invisible targets

be more or less directive, depending on its physical size and shape. Obviously, a radar system is able to perform measurements only on items that are within its emission lobe, as electromagnetic waves are conveyed within it. Anything that is outside of the emission lobe is not detected. Furthermore, in real-aperture radar, all objects which are located at the same distance and that are visible to the radar are identified as a single object.

Figure 1 shows an example of a possible scenario. In this case, in the track detected by the radar, it is impossible to distinguish the contribution of the three ISO range targets.

The latter consideration and the fact that the radar technique provides a measure of the displacement only along the line connecting the radar sensor to the illuminated target make the use of a static radar to vibration measurement purposes a very delicate issue.

3 Experimental set-up and major tests

Several tests were carried out to assess the capability of the radar, to perform dynamic measurements and to highlight possible drawbacks in the use of this technique on real structures. To assess the radar performances, a proper measurement set-up has been built to compare the non-contact measurement output to traditional and calibrated sensors.

Table 1 Metrological characteristics of the accelerometers

Sensor	Measurement range	Frequency range (±5 %)	Sensitivity
Piezoelectric accelerometer PCB 393A03	±5 g	0.5–2,000 Hz	1 V/g

To simulate the presence of sources of reflection of the electromagnetic waves generated by the radar, metallic trihedral corner reflectors were used.

One of the corner reflectors was driven by a hydraulic actuator. Figure 2 shows the actuator and the moving trihedron.

The displacement was measured by means of the radar and by means of a set of accelerometers. Four accelerometers were used. Two of them were placed on the basement of the actuator and the other two were placed on the shifting plate, along the shifting and the vertical direction, respectively. Using four sensors, a complete knowledge of the corner reflector absolute displacements could be achieved discarding any effect of possible movements of the actuator base. As harmonic signals have been used in the tests, it was quite easy and accurate to compute displacements starting from the measured accelerations by double integration in the frequency domain.

Table 1 shows the metrological characteristics of the used accelerometers.

Data were acquired with 24 bits ADCs with built in anti-aliasing filters (NI 9234). Final sampling frequency was set to 512 Hz.

The results were then compared in terms of absolute displacement. The actuator was used to impose a harmonic

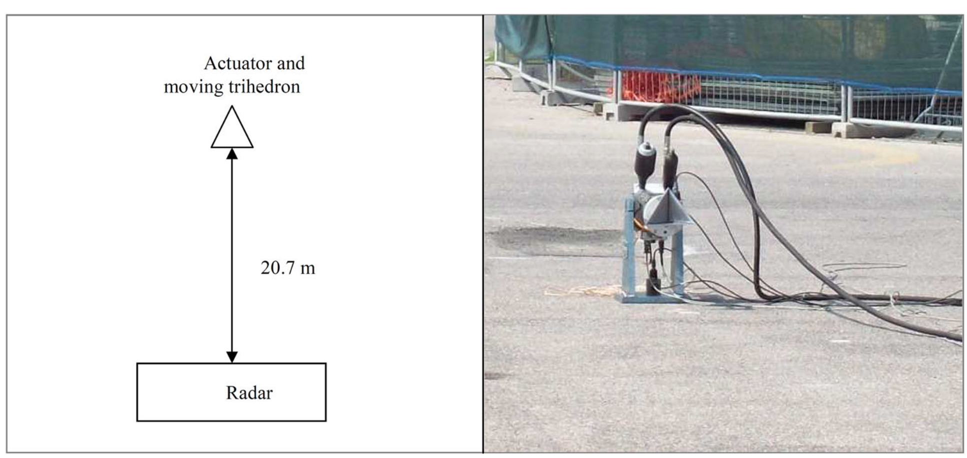


Fig. 2 Moving corner reflector and actuator, plain configuration

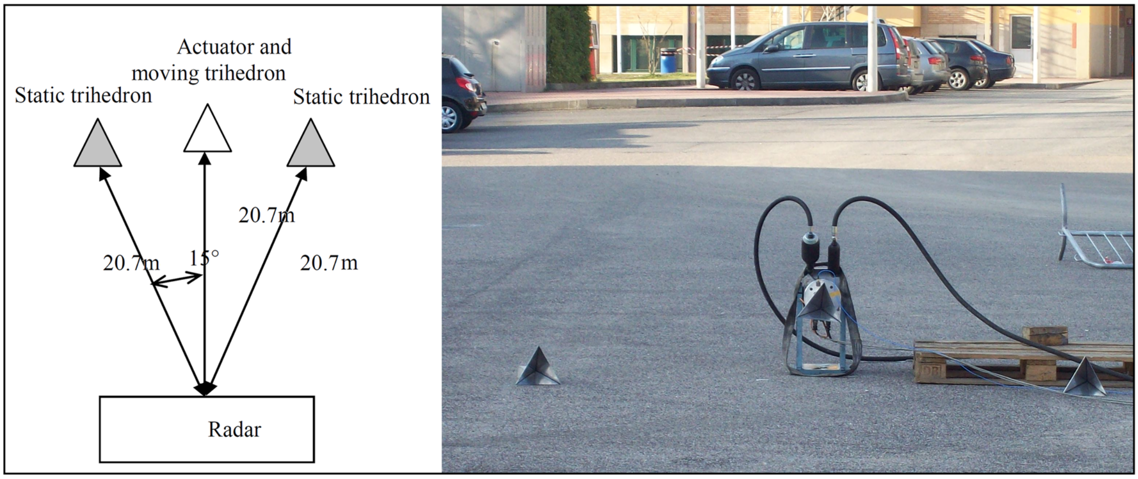


Fig. 3 Three corner reflectors in the scene, configuration 1

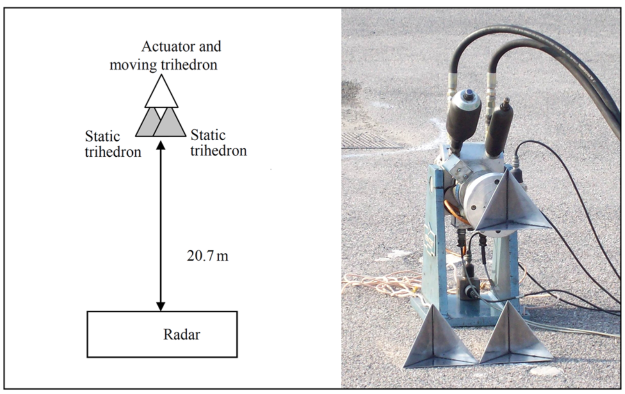


Fig. 4 Three corner reflectors in the scene, configuration 2

movement to one corner reflector. Amplitudes of ±1, ±2, ±4, ±7, ±10 mm and frequencies of 1, 3, 5, 10, 20 and 40 Hz were imposed.
Two kinds of tests were performed:

(a) using only the moving corner reflector, and no other corner reflectors in the scenario (see Fig. 2) to test the effectiveness or the radar in the absence of external disturbances.
(b) including additional corner reflectors to simulate the presence of other reflecting bodies in the scene. Two more corner reflectors were used to simulate bodies with radar cross-sections comparable to the one of the object under investigation. Figures 3 and 4 show the two configurations used for the tests.

In configuration 1, the secondary corner reflectors are ISO range and rotated ±15° to the main corner reflector, while in configuration 2 the corner reflectors are positioned under the main corner reflector.

The results of the tests are reported in the next section.

4 Experimental results

As described in the previous section, two different kinds of tests were performed. The first tests were carried out with only the moving trihedron in the scene and no other reflecting bodies, while during the second tests two more trihedron have been added.

4.1 Single corner reflector

For the first tests (single corner reflector), the results of the measurements performed with the accelerometers and with the radar are generally in agreement. Figure 5 shows, as example, the time histories of one test, with a harmonic of about 3 Hz, and ±2 mm. As it can be seen, there is good accordance between the two measurement methods.

Table 2 summarizes the results of all the tests performed in the presence of only the moving trihedron. The values reported in Table 2 are:

- The target values of the actuator
- Frequencies and amplitudes measured with the radar
- Frequencies and amplitudes measured with the accelerometer
- The amplitudes normalized ratio $= \frac{\text{RadarAmplitude} - \text{AccelerometerAmplitude}}{\text{RadarAmplitude}}$
- The frequencies normalized ratio $= \frac{\text{RadarFrequency} - \text{AccelerometerFrequency}}{\text{RadarFrequency}}$

As it can be noticed looking at the results, there is generally good accordance between the two measurement methods, exception made for the tests at 1 Hz. In this case, however, it is the response of the accelerometer to be

Fig. 5 One trihedron, 3 Hz, ±2 mm

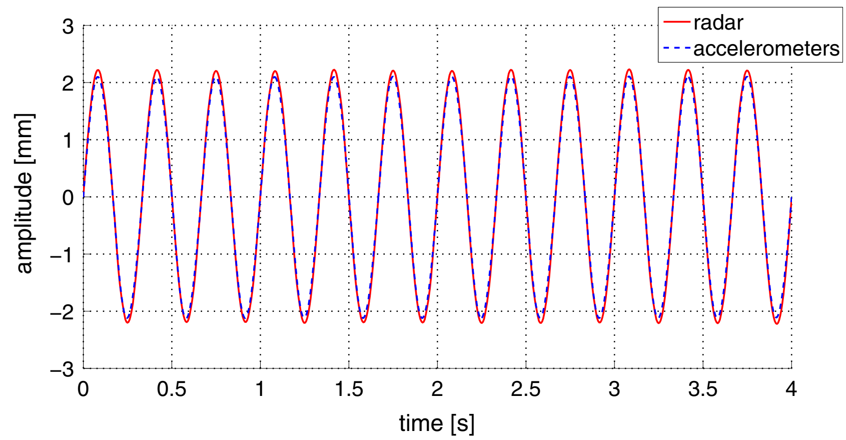


Table 2 Results of the first tests (1 corner reflector)

Target		Radar		Accelerometer		Amplitudes normalized ratio	Frequencies normalized ratio
Frequency (Hz)	Amplitude (mm)	Frequency (Hz)	Amplitude (mm)	Frequency (Hz)	Amplitude (mm)		
1	1	1.02	1.14	1.00	0.93	0.22	0.02
1	2	1.02	2.16	1.00	1.83	0.18	0.02
1	4	1.02	4.12	1.00	3.61	0.14	0.02
1	7	1.02	7.00	1.00	6.26	0.12	0.02
1	10	1.02	10.01	1.00	8.90	0.13	0.02
3	1	3.00	1.15	3.00	1.03	0.11	0.00
3	2	3.00	2.16	3.00	2.06	0.05	0.00
3	4	3.00	4.10	3.00	4.08	0.00	0.00
3	7	3.00	6.94	3.00	7.12	−0.03	0.00
5	1	5.00	1.11	5.00	1.05	0.06	0.00
5	2	5.00	2.14	5.00	2.09	0.02	0.00
5	4	5.00	4.08	5.00	4.17	−0.02	0.00
10	1	9.98	0.91	10.00	0.85	0.07	0.00
10	2	10.00	1.74	10.00	1.64	0.06	0.00
20	1	19.99	0.93	20.00	0.90	0.03	0.00
20	2	19.99	1.81	20.00	1.82	−0.01	0.00
40	1	39.99	0.41	39.99	0.46	−0.11	0.00
3	2	3.00	2.21	3.00	2.06	0.07	0.00
5	2	5.00	2.20	5.00	2.08	0.05	0.00
10	2	10.00	1.74	10.00	1.64	0.06	0.00
20	2	19.99	1.88	20.00	1.82	0.03	0.00

deficient because of the properties of the acquisition module [24]. In all cases, the radar provided displacement measurements with sub-millimeter accuracy.

4.2 Multiple corner reflectors

After the first tests, other tests were carried out adding two trihedron in various configurations (Figs. 3, 4). In the following, the results of some of these tests are reported.

1. Configuration 1: Figure 6 shows the time history corresponding to one test in configuration 1 (Fig. 3). In this test, the same frequency and amplitude of the test reported in Fig. 5 (i.e., 3 Hz, ±2 mm) were imposed. The presence of the secondary trihedron modifies the radar measurement. In this configuration, the radar sees the trihedron moving with lower amplitude than the one imposed. The frequency, however, remains the same.

Fig. 6 Three trihedron, 3 Hz, ±2 mm, configuration 1

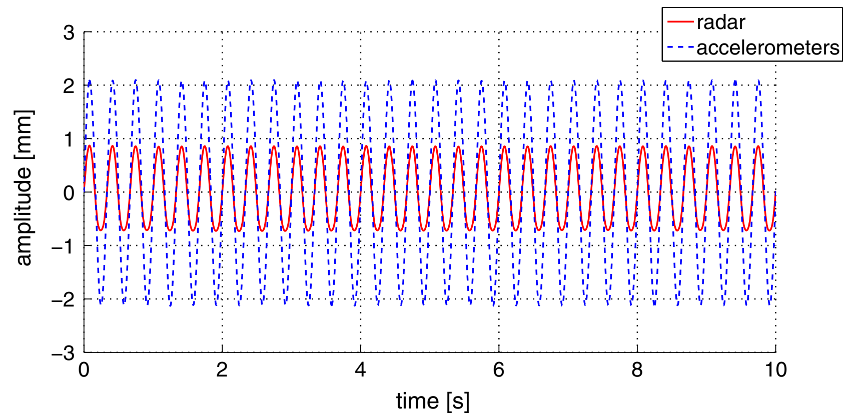
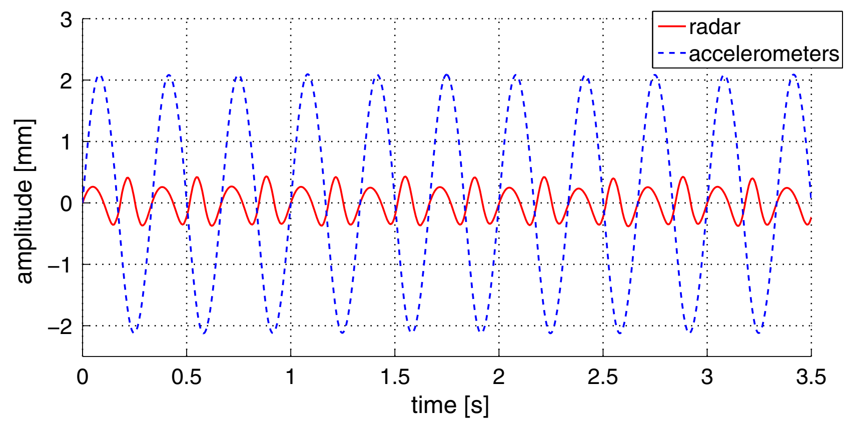


Fig. 7 Three trihedron, 3 Hz, ± 2 mm, configuration 2



2. Configuration 2: Figure 7 shows the time history, in terms of displacement, corresponding to the configuration 2 (Fig. 4). Also, in this test a harmonic oscillation at 3 Hz and ±2 mm was imposed. In this second case not only the amplitude but also the frequency is distorted. As it can be better noticed looking at the spectrum in Fig. 8, due to the presence of multi-reflections, the radar measures a signal that is a combination of different harmonics at frequencies that are multiples of the fundamental one (imposed by the actuator) and with different amplitudes. In general, it was found that the first or second multiple of the imposed frequency becomes predominant. Particularly in the second case (with an imposed frequency of about 3 Hz) the main frequency of the recorded signal is 6 Hz, with minor contributions at 9 and 3 Hz.
3. Figure 9 reports the result of a test performed in a configuration similar to configuration 1. In such case, one secondary trihedron was moved of 5 mm along the line connecting the radar and the trihedron itself. The same test parameters imposed during the previous tests were used. As it can be noticed from Fig. 9, the results of the two tests are significantly different, both in terms of amplitude and frequency of the measured signal. Small changes in the scenario, therefore, can cause considerable changes in the signal recorded by the radar.

In all the considered cases, therefore, the response is strongly affected by the presence of the secondary elements. All the performed tests showed a similar behavior, but the magnitude and kind of the distortion were strongly affected by the position of the secondary trihedron.

In all the performed tests, it was known that the target was moving with harmonic motion and the disturbance was generated by stationary elements. Therefore, in such cases, the contribution of these elements could be separated from the contribution of the moving element post-processing the data. However, this is not the general case. Normally more than one moving element could be iso-range in the scenario and only in very few cases the movement of the target is harmonic. These simple examples are thus intended to show that the use of such a technique for dynamic measurements, without knowing a priori the nature of the phenomenon, can lead to errors in the measurement.

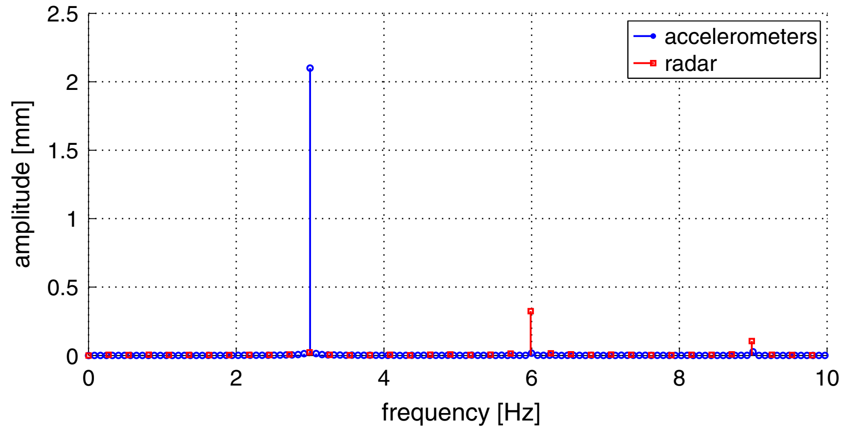


Fig. 8 Three trihedron, 3 Hz, ±2 mm, configuration 2, spectrum

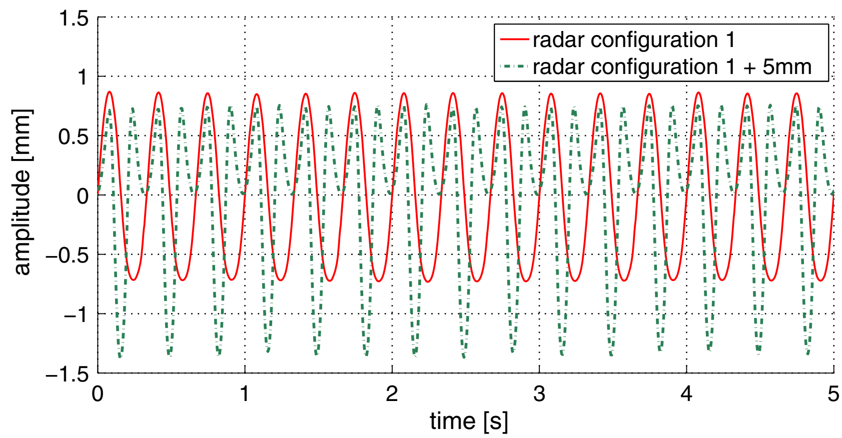


Fig. 9 Three trihedron, 3 Hz, ±2 mm, configuration 1 and configuration 1 + 5 mm

5 Numerical simulations

To better understand the obtained results, scenarios with corner reflectors were simulated and operating conditions similar to those experimental were investigated numerically. In this section, the principle underlying the generation of the simulated data and the results of the analysis will be presented.

As regards the simulations, a simple procedure was used to generate a data set entirely equivalent to those measured experimentally. For the sake of simplicity only the target responses to electromagnetic waves, as if they were isolated and without any interaction with the surrounding scenery, have been considered.

Each target contributes to the backscattered signal with a quantity proportional to

$$Ae^{\frac{j4\pi f_i R_k}{c}}$$

being f_i the ith frequency of the chirp, R_k the distance of the kth target and c the speed of light. Like in the experimental case, a frequency band of 17.0–17.4 GHz divided into 201 points and acquisition frequency of about 200 Hz have been imposed.

Table 3 shows schematically the principle underlying the simulations.

The simulations of the scenario, in the form of the matrix reported in Table 3, were then analyzed with LisaLAB technology in the exact same way used for the experimental data.

The numerical tests were carried out simulating the presence of two corner reflectors on the ground at the sides of a corner reflector set in motion (harmonic movement 3 Hz, ±4.8 mm). The scenario being measured and compared to the simulations is the one reported in Fig. 3.

Several simulations were carried out changing the position of one or two corner reflectors of just a few millimeters with respect to the nominal configuration. Figure 10 shows the results of four different simulations. The results of the experimental test are shown in Fig. 11. In this particular configuration not only the amplitudes but also the frequencies are recorded incorrectly. Since the distance of the corner reflectors could not be measured with the accuracy of

Table 3 Radar simulations

	$f_0 = 17$ GHz	$f_1 = 17.002$ GHz	…	$f_n = 17.4$ GHz
Sweep 1 ($t_0 = 0$)	$\sum_{k=1}^{N_{CR}} Ae^{\frac{j4\pi f_0 R_k(t_0)}{c}}$	$\sum_{k=1}^{N_{CR}} Ae^{\frac{j4\pi f_1 R_k(t_0)}{c}}$	…	$\sum_{k=1}^{N_{CR}} Ae^{\frac{j4\pi f_n R_k(t_0)}{c}}$
Sweep 2 ($t_1 = 1/200$)	$\sum_{k=1}^{N_{CR}} Ae^{\frac{j4\pi f_0 R_k(t_1)}{c}}$	$\sum_{k=1}^{N_{CR}} Ae^{\frac{j4\pi f_1 R_k(t_1)}{c}}$	…	$\sum_{k=1}^{N_{CR}} Ae^{\frac{j4\pi f_n R_k(t_1)}{c}}$
…	…	…	…	…
Sweep m ($t_m = (m–1)/200$)	$\sum_{k=1}^{N_{CR}} Ae^{\frac{j4\pi f_0 R_k(t_m)}{c}}$	$\sum_{k=1}^{N_{CR}} Ae^{\frac{j4\pi f_1 R_k(t_m)}{c}}$	…	$\sum_{k=1}^{N_{CR}} Ae^{\frac{j4\pi f_n R_k(t_m)}{c}}$
…	…	…	…	…

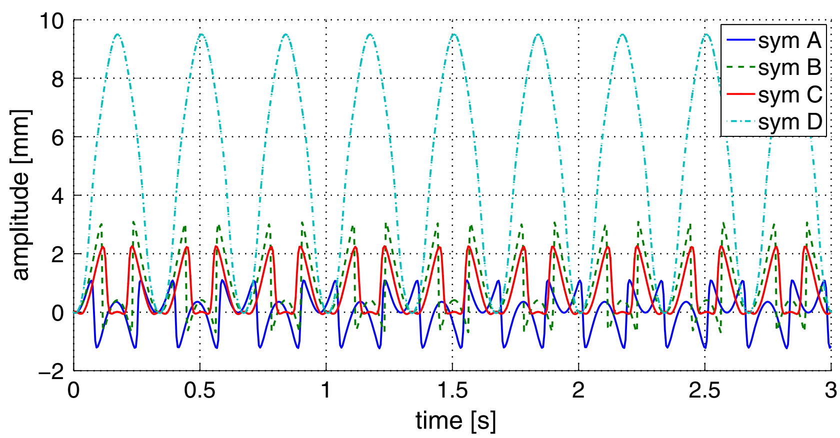


Fig. 10 Simulations: 3 Hz, ±4.8 mm

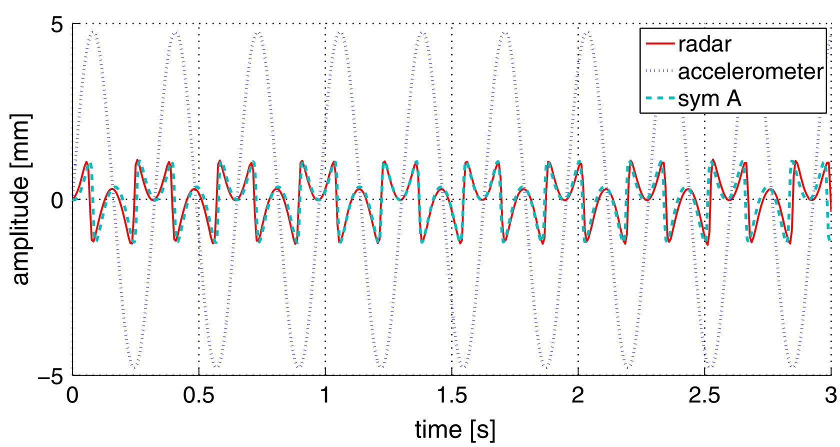


Fig. 11 Simulations: 3 Hz, ±4.8 mm, configuration 1

the mm, it was possible to make only a qualitative comparison, changing the position of the secondary corner reflectors to obtain the desired result. The result of simulation A is the one that better resembles the experimental one. Within the experimental uncertainty, experimental results and numerical simulation are still compatible.

The most interesting thing to note, however, is how small changes in the configuration can produce significant changes in the results.

The problematic aspect is that the same result could be obtained with numerous targets with radar cross-section much lower than the object in motion, distributed at equal distances. Similarly, in case of a stationary object surrounded by other moving objects, the movement could be erroneously attributed to the static target.

Hence, the use of this technique for dynamic measurements remains a delicate issue that needs further investigation.

6 Conclusions

This paper analyzes the performances of the radar GBInSAR, developed by Ellegi using LiSALab technology, for dynamic measurement purposes. While the use of radar for static measurements is in fact a widely studied topic, its use for dynamic measuring purposes is a fairly new subject that needs further investigation. Several tests were performed to assess the performances of the radar system. The instrument was first tested in 'ideal' conditions, with only one moving element with high reflectivity and without disturbing elements. The radar output was compared with accelerometric measures. In this case, good results in terms of measured signal were obtained. To simulate possible real conditions, elements with radar cross-section comparable with the one of the element under analysis were added. Different configurations were considered. In the case of complex scenarios, the measurements made by the radar system were, in most of the cases, adversely affected by the presence of multi-reflections. Furthermore, small changes in the context could cause considerable changes in the signal recorded by the radar. Numerical simulations have been made to check the results obtained experimentally. The simulations confirmed the experimental results at a first level of approximation. The radar, being a non-contact measurement system, presents many advantages in several applications but it might be necessary to have a good knowledge of the investigated scenario to understand what is being measured, and to verify the absence of factors that may cause a distortion in the signal. Its use for dynamic measurements purposes is still a delicate task that needs further investigation.

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References

1. Cigada A, Moschioni G, Vanali M, Caprioli A (2010) The measurement network of the San Siro Meazza Stadium in Milan: origin and implementation of a new data acquisition strategy for structural health monitoring. Exp Tech 34:70–81
2. Fan W, Qiao P (2011) Vibration-based damage identification methods: a review and comparative study. Struct Health Monit 10(1):83–111
3. Ewins DJ (2000) Modal testing: theory and practice. Research Studies Press Ltd., Hertfordshire
4. Wahbeh M, Caffrey JP, Masri SF (2003) A vision-based approach for the direct measurement of displacements in vibrating systems. Smart Mater Struct 12:785–794
5. Doignon C, Knittel D, Maurice X (2008) A vision-based technique for edge displacement and vibration estimations of a moving flexible web. Instrum Meas IEEE Trans 57(8):1605–1613
6. Curlander JC (1995) Interferometric synthetic aperture radar for terrain mapping, Acoustics, speech, and signal processing, 1995. ICASSP-95 1995 International Conference, vol 5, 9–12 May 1995, pp 2801–2804
7. Pieraccini M, Tarchi D, Rudolf H, Leva D, Luzi G, Bartoli G, Atzeni C (2000) Structural static testing by interferometric synthetic radar. NDT E Int 33(8):565–570
8. Wang J, Wang X, Chen L, Huangfu J, Li C, Ran L (2013) Noncontact distance and amplitude-independent vibration measurement based on an extended DACM algorithm. Instrum Meas IEEE Trans 99:1
9. Qi W, Pepin M, Beach RJ, Dunkel R, Atwood T, Santhanam B, Gerstle W, Doerry AW, Hayat MM (2012) SAR-based vibration estimation using the discrete fractional Fourier transform. Geosci Remote Sens IEEE Trans 50(10):4145–4156
10. Pieraccini M, Fratini M, Parrini F, Atzeni C (2006) Dynamic monitoring of bridges using a high speed coherent radar. IEEE Trans Geosci Remote Sens 44(11):3284–3288
11. Pieraccini M, Parrini F, Fratini M, Atzeni C, Spinelli P, Micheloni M (2007) Static and dynamic testing of bridges through microwave interferometry. NDT E Int 40(3):208–214
12. Gentile C, Bernardini G (2008) Output-only modal identification of a reinforced concrete bridge from radar-based measurements. NDT E Int 41(7):544–553
13. Pieraccini M, Fratini M, Parrini F, Atzeni C, Bartoli G (2008) Interferometric radar vs. accelerometer for dynamic monitoring of large structures: an experimental comparison. NDT E Int 41(4):258–264
14. Dei D, Pieraccini M, Fratini M, Atzeni C, Bartoli G (2009) Detection of vertical bending and torsional movements of a bridge using a coherent radar. NDT E Int 42(8):741–747
15. Bartoli G, Facchini L, Pieraccini M, Fratini M, Atzeni C (2008) Experimental utilization of interferometric radar techniques for structural monitoring. Struct Control Health 15(3):283–298
16. Gentile C, Bernardini G (2010) An interferometric radar for non-contact measurement of deflections on civil engineering structures: laboratory and full-scale tests. Struct Infrastruct Eng 6(5):521–534
17. Gentile C (2011) Structural health monitoring of stay cables using the microwave interferometry. IOMAC'11, 4th International Operational Modal Analysis Conference, 9–11 May 2011
18. Gentile C (2010) Deflection measurement on vibrating stay cables by non-contact microwave interferometer. NDT E Int 43(3):231–240
19. Pieraccini M, Parrini F, Fratini M, Atzeni C, Spinelli P (2008) In-service testing of wind turbine towers using a microwave sensor. Renewable Energy 33(1):13–21
20. Pieraccini M, Parrini F, Dei D, Fratini M, Atzeni C (2007) Dynamic characterization of bell-tower by interferometric sensor. NDT E Int 40(5):390–396
21. Beben D (2011) Application of the interferometric radar for dynamic tests of corrugated steel plate (CSP) culvert. NDT E Int 44(5):405–412
22. Muth LA, Wang CM, Conn T (2005) Robust separation of background and target signals in radar cross section measurements. Instrum Meas IEEE Trans 54(6):2462–2468
23. http://www.lisalab.com/engl/?seze=6. Accessed 11 May 2014
24. NI 9234 Measurement System, Manual and Documentation (http://sine.ni.com/ds/app/doc/p/id/ds-316/lang/). Accessed 11 May 2014