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Comparison between topographic and photogrammetric techniques for deformation monitoring of the dome of the Massimo Theatre in Palermo

G. Dardanelli, P. Orlando, B. Villa, University of Palermo

Session TS 03F - Deformation Monitoring I

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Introduction

This paper outlines the first results of a interdisciplinary research work directed towards the deformations monitoring of the dome of the Massimo Theatre in Palermo, caused by thermal dilatations occurring in the space of a day, with the use of topographic and photogrammetric techniques.

Aim of the research work

- to compare topographic and photogrammetric techniques with reference to very small (submillimeter) deformation measurements.
- to verify the efficiency of the rollers on which the steel structure of the dome rests, after over one century from its making.

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The Massimo Theatre, built as from 1873 on design of G.B. Filippo Basile, famous Palermo architect, is the biggest opera house in Italy and one of the largest of Europe

Interior view of the dome with the sixteen steel ribbings

Detail of a roller a) fixed part b) mobile part

Connection between ribbings and masonry curb

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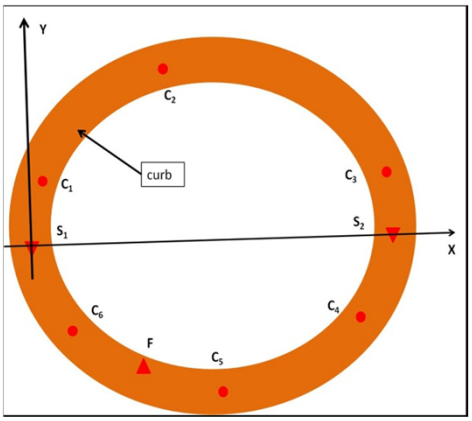
Topographic survey

Trimble S8 RTS



Scheme of the survey and reference system

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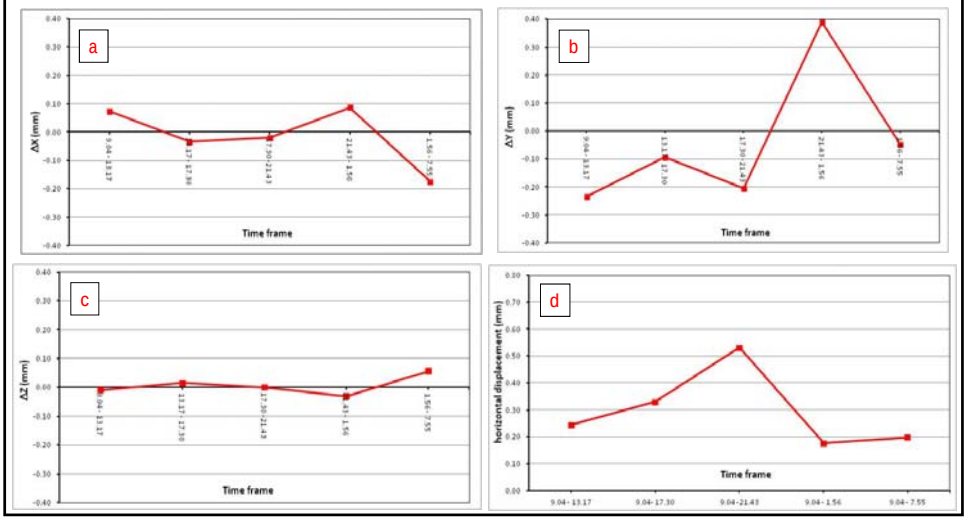
Displacements of the point C1/S1 a) ΔX b) ΔY c) ΔZ d) overall horizontal displacement



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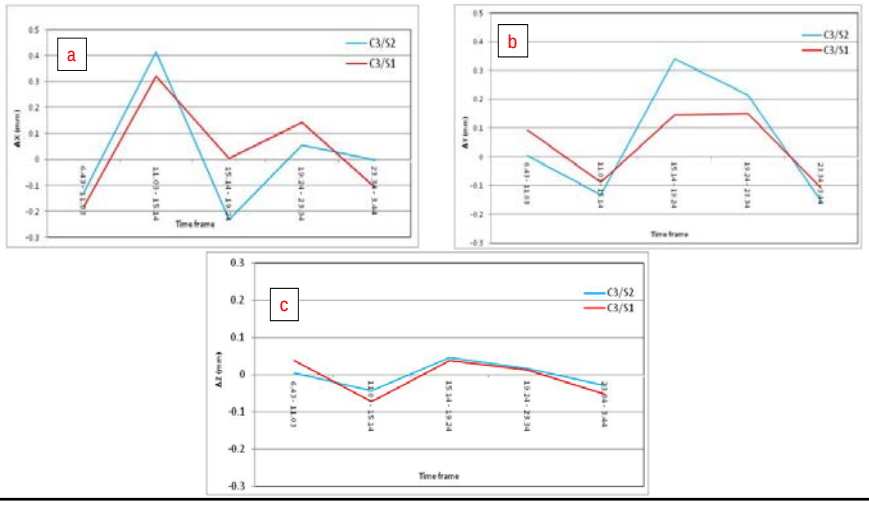
Displacements of the points C3/S1 (in red) and C3/S2 (in blue) a) ΔX b) ΔY c) ΔZ



Photogrammetric survey

Canon Eos-01 Mark II digital camera with slide

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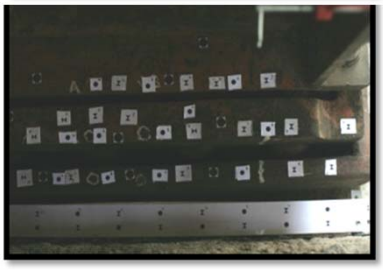
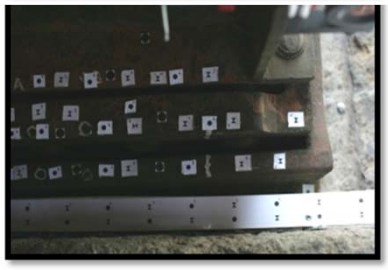
a

b





Stereopairs of photos of the roller C1 a) 2 p.m. b) 6 p.m.

Object distance

$$\sigma_X = \sqrt{m_b^2\sigma_\xi^2 + \left(\frac{\xi_1}{c} m_b \frac{Z}{B}\right)^2 \sigma_{P_\xi}^2}$$

$$\sigma_Y = \sqrt{m_b^2\sigma_\eta^2 + \left(\frac{\eta_1}{c} m_b \frac{Z}{B}\right)^2 \sigma_{P_\xi}^2}$$

$$\sigma_Z = m_b \frac{Z}{B} \sigma_{P_\xi}$$

- c is the camera focal length
- Z is the object distance
- B is the baseline
- $m_b = Z/c$ is the inverse of the average photo scale
- ξ_1, η_1 are the coordinates of the image point
- σ_ξ, σ_η are the st. dev. of the image points coordinates
- σ_{P_ξ} is the standard deviation of the parallax P_ξ

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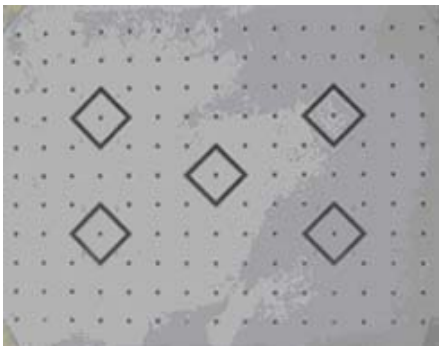
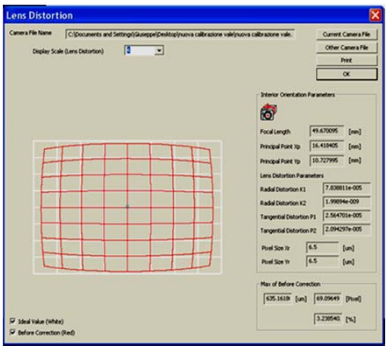
Photogrammetric data processing

- camera calibration to remove radial and tangential distortions;
- interior and exterior orientation of the stereopairs;
- calculation of the tie-points coordinates;
- analysis of the coordinates trend during the day.

Interior orientation



Calibration grid



Parameters of the interior orientation

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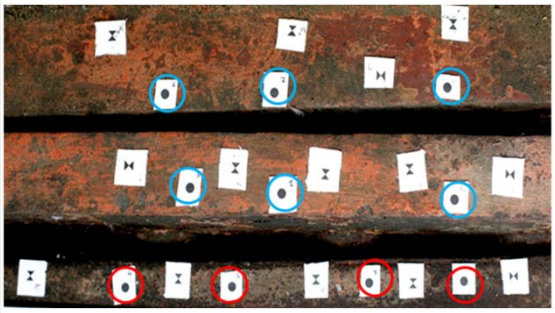
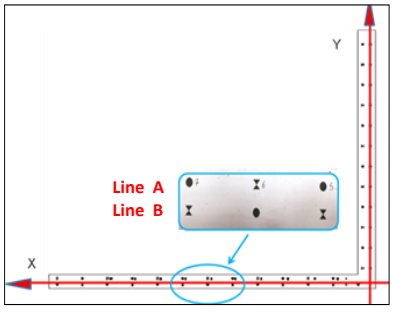
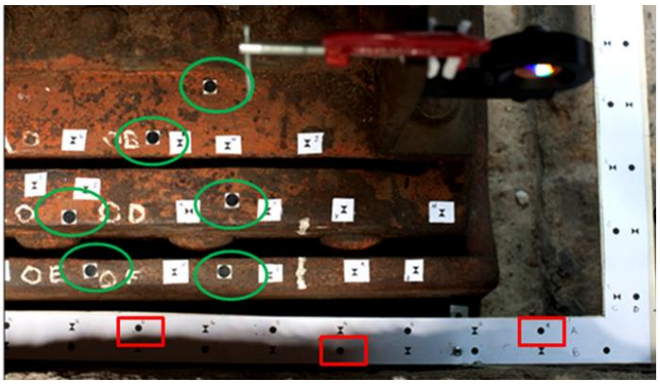
Relative and absolute orientation



Tie-points: fixed part (in red), mobile part (in blue)



Grid of the control points



Tie-points (in green) and check points (in red)

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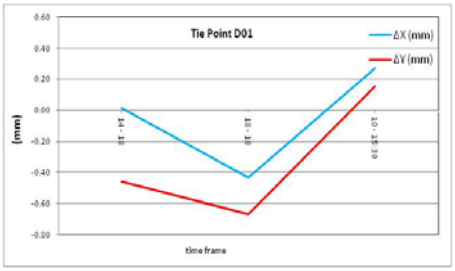
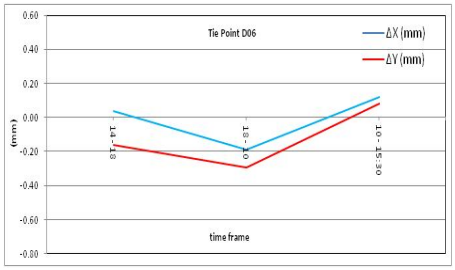
Parallax and absolute coordinates of tie-points

Points	6 p.m.					
	Tie Points Y-parallaxis			Coordinates		
	Point	y-prx [pixel]	y-prx[mm]	X[m]	Y[m]	Z[m]
Control Points	3	-0.04	-0.0284	0.015	0.15	0
	4	0.04	0.0284	0	0.2	0
	5	-0.07	-0.0469	0.015	0.25	0
	6	0.08	0.0511	0	0.3	0
	7	-0.05	-0.0316	0.015	0.35	0
	8	0.22	0.01441	0	0.4	0
	9	-0.23	-0.01488	0.015	0.45	0
Tie Points	D05	-0.02	-0.011	0.0561	0.2522	0.0116
	D06	0.01	0.044	0.0549	0.3495	0.015
	D04	-0.08	-0.0492	0.0962	0.2253	0.0575
	D01	0.01	0.071	0.0945	0.3413	0.0613
	D07	0.08	0.0501	0.1417	0.3576	0.06
	D02	0.06	0.0415	0.1444	0.2622	0.0568

Displacements of tie-points a) D01 b)D06





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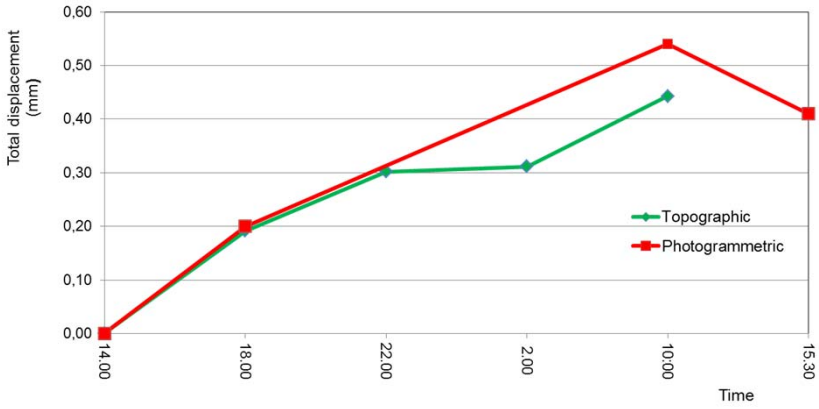
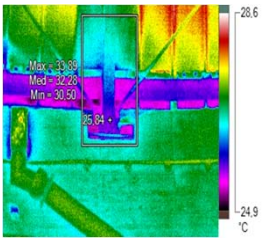
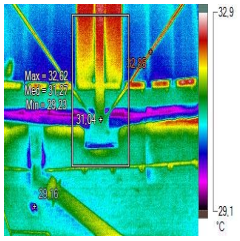
Absolute displacements of the roller C1 by topographic and photogrammetric techniques



Thermal data

Flucke TiR 32 thermal imaging camera





Thermal images of the roller C1 a) at 10 a.m. b) at 8 p.m.

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Conclusions (1)

The results obtained at the end of this first phase of the research work outline almost exclusively the horizontal component of the displacements; as it was expected, the vertical component is practically equal to zero.

Displacements determined by topographic techniques are of the same size of the ones determined by photogrammetric techniques and for both methods the mean value of the absolute displacements of the rollers results practically identical, equal to about 0.8 mm.

This result, quite in accordance with previsions of the theoretical model, demonstrates:

- both techniques, topographic and photogrammetric, are absolutely suitable to determine submillimeter displacements;
- until today the rollers accomplish its task very well.

Conclusions (2)

Topographic methods have two substantial advantages over the photogrammetric ones:

- complete automation of the measurements acquisition, apart from the initial cycle which requires necessarily manual intervention;
- rapidity of data processing; in fact robotic instrument is usually equipped with a software able to provide quickly coordinates, statistical parameters of the measurements and displacements.

For photogrammetric techniques instead:

- the cost of instrumentation, considerably lower than the one necessary for topographic survey;
- data processing (orientation and restitution of the coordinates) requires longer time and greater problem solving power.

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Many thanks for your attention!

I'd like to invite you all to come to Palermo and see the Massimo Theatre live!

For further information and technical details about this work please contact:

gino.dardanelli@unipa.it (topographic survey)
pietro.orlando@unipa.it (photogrammetric survey)