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Mapping large surfaces of cultural heritage buildings by infrared thermography

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Mapping large surfaces of cultural heritage buildings by infrared thermography

G Cadelano[2], G Ferrarini[1], A Bortolin[2], P Bison[1]

[1] Consiglio Nazionale delle Ricerche, Istituto per le Tecnologie della Costruzione (CNR-ITC), Corso Stati Uniti 4, 35127, Padova, Italy
[2] Consiglio Nazionale delle Ricerche, Istituto di Scienze dell'Atmosfera e del Clima (CNR-ISAC), Corso Stati Uniti 4, 35127, Padova, Italy

paolo.bison@itc.cnr.it

Abstract. Thermographic mapping of cultural heritage buildings is nowadays a key technique to evaluate the status of a building, thanks to its non-destructive and non-invasive nature. Infrared thermography allows both to study the structure of the building itself, looking for hidden elements and defining the stratigraphy, and to assess the building status, checking for damages such as detachments or degradation due to ageing or humidity. The need for a fast thermographic scanning procedure, useful for investigating large surfaces, led to the creation and refinement of the IRpano device, that allows a rapid and complete thermal scanning of building surfaces and the visualization of results in a 360° panoramic environment. This work presents the conceptual framework of the IRpano device and the results of thermal scanning on cultural heritage buildings.

1. Introduction
Infrared thermography (IRT) is a powerful technique with multiple applications, ranging from industrial manufacturing to biomedical investigation [1]. In the cultural heritage field, IRT has a long track record of applications on artifacts and buildings [2,3]. Some crucial issue in surveys of cultural heritage can be solved only by IRT, thanks to its non-invasive and non-destructive nature that allows to inspect the object without contact and avoiding the risk of damages.

Another key issue for the cultural heritage building is that the availability of the site is usually very limited and the surfaces to be inspected are very large. Therefore, as the need for automation and fast building inspections is known since a long time, several authors have proposed different measurement techniques [4,5]. In this work, a portable automatic system based on infrared thermography is presented, aimed to reduce the inspection time and facilitate the measurement procedure.

2. The IRpano system
As described in the introduction, there are several practical challenges that could happen during a building survey. Some restrictions are unavoidable: the structure or orientation of the building under analysis or the climatic conditions cannot be modified and the operator can only take them into account and plan an appropriate survey.

However, there are different tasks, related to data acquisition and processing, that could be optimized resulting in a significant time saving and in a reduction of the human errors. To achieve this goal, a thermographic device (IRpano [3]) has been proposed aiming at:

- reducing the amount of time and effort needed to perform a building survey;
- allowing operators with a low qualification and expertise to perform the work in situ;
- making easier the interpretation and dissemination of the results.

The IRpano system is designed to automatically acquire and process thermal images in such a way to increase the reliability of the measurement. It also allows to perform time lapsed measurement, possibly lasting for for several days, enabling the analysis under dynamic thermal conditions [4], with the acquisition of thermal panorama sequences.

2.1. Hardware and software architecture

The IRpano device [4] is composed by a data acquisition system, a controlling unit and a data processing software, as shown in Figure 1. To perform a fast scanning, while containing the overall costs of the equipment, the chosen solution is the installation of a thermal camera and a visible camera on a pan-tilt unit. The pixel resolution of a camera can be of a middle or low level, as the final result is the integration of multiple images, increasing the overall resolution.
To perform a survey, the system is set on a tripod that is placed on the desired spot of the room. Then, the controlling unit starts the motion of the device, that moves the camera through several preset positions, sweeping the maximum area inside the pan-tilt constraints. The number of images, usually higher than 100, is sent to the data processing unit to create panoramic views of building.
While a vast number of stitching algorithm is available for the visible range, for the infrared range the standard algorithms based on segmentation and feature extraction can lead to poor results. To overcome this issue, an approach based on a preliminary calibration of the infrared camera and the knowledge of the pan-tilt angles and position is chosen [5]. The blending of the overlapping regions is handled with a weighted method, described as linear transition model [6]. When two images A and B are adjacent, analyzing at first the case of a row, the temperature value T of the i_{th} pixel having X coordinate is calculated with the following equation:

$$T_i = \frac{X_{max} - X_i}{X_{max} - X_{min}} * T_{Ai} + (1 - \frac{X_{max} - X_i}{X_{max} - X_{min}}) * T_{Bi} \qquad (1)$$

where X_{max} and X_{min} are respectively the highest and lowest X values in the overlapping region. The same applies, with vertical coordinates, when the vertical mosaicking is performed.
The final result is an equirectangular panorama [7], where the pixels height represents the tilt range while the width represents the pan range. In full equirectangular images, the width to height ratio is equal to 2.
The temperature scale of the image is automatically generated based on the image variance. The center of the scale is the mean value of the image while the maximum and the minimum are chosen as the mean value plus or minus one standard deviation.
The same mosaicking procedure is applied to the photographic images. Thanks to the application of the same procedure, the obtained panoramic image could be easily matched to the corresponding thermographic value.

The obtained panoramic images can be integrated in different visualization environments, such as the virtual visit of the Google Street View architecture or standalone web viewer panoramic software.

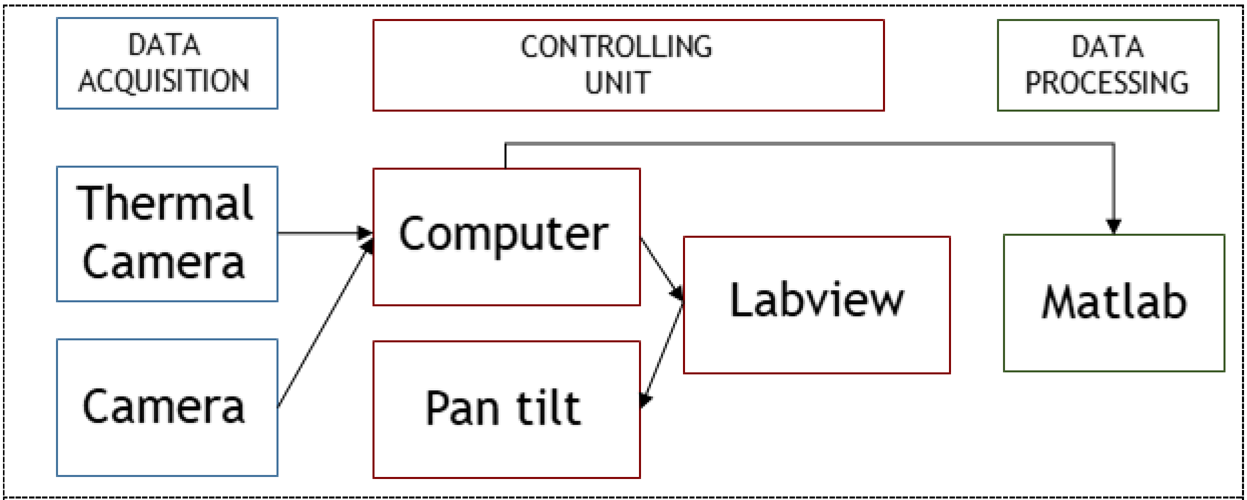

Figure 1. Scheme of the IRpano device

2.2. *Results*

The IRpano device has been applied in different conditions on various cultural heritage buildings, such as the Saint Gottardo Church in Asolo [8], the Padri Serviti Convent in Koper (Slovenia) [9], or the Santa Maria della Salute Basilica in Venice. The system has been employed in both passive and active (dynamic response to a heating-induced temperature variation) thermographic surveys. In both cases, the focus has been:

- the detection of hidden structures that are identified as thermal anomalies
- the localization of detachments of the surfaces, especially for frescos
- the evaluation of the moisture-induced damages on the walls
- the output of the conditioning system (radiant heating floor).

A typical output of the IRpano device is showed in the following Figure 2, obtained during the survey of the Saint Gottardo Church.

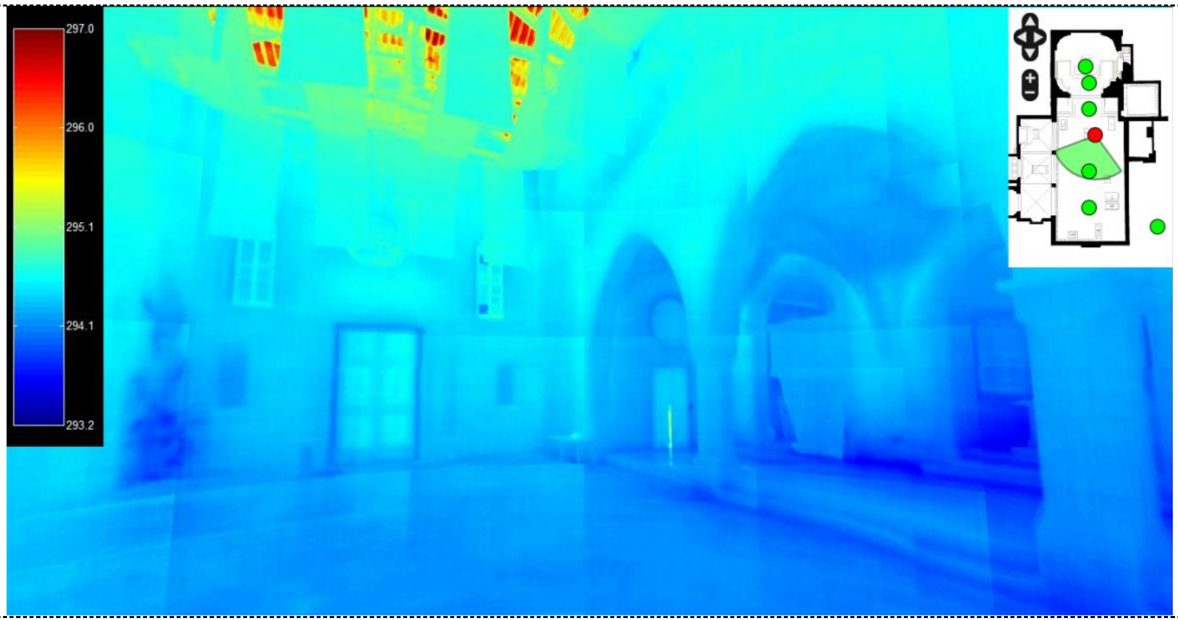

Figure 2. Output of the IRpano device at the Saint Gottardo church in Asolo [8].

Another survey, the Servitski Convent in Koper (Slovenia), is shown in the next Figure 3.

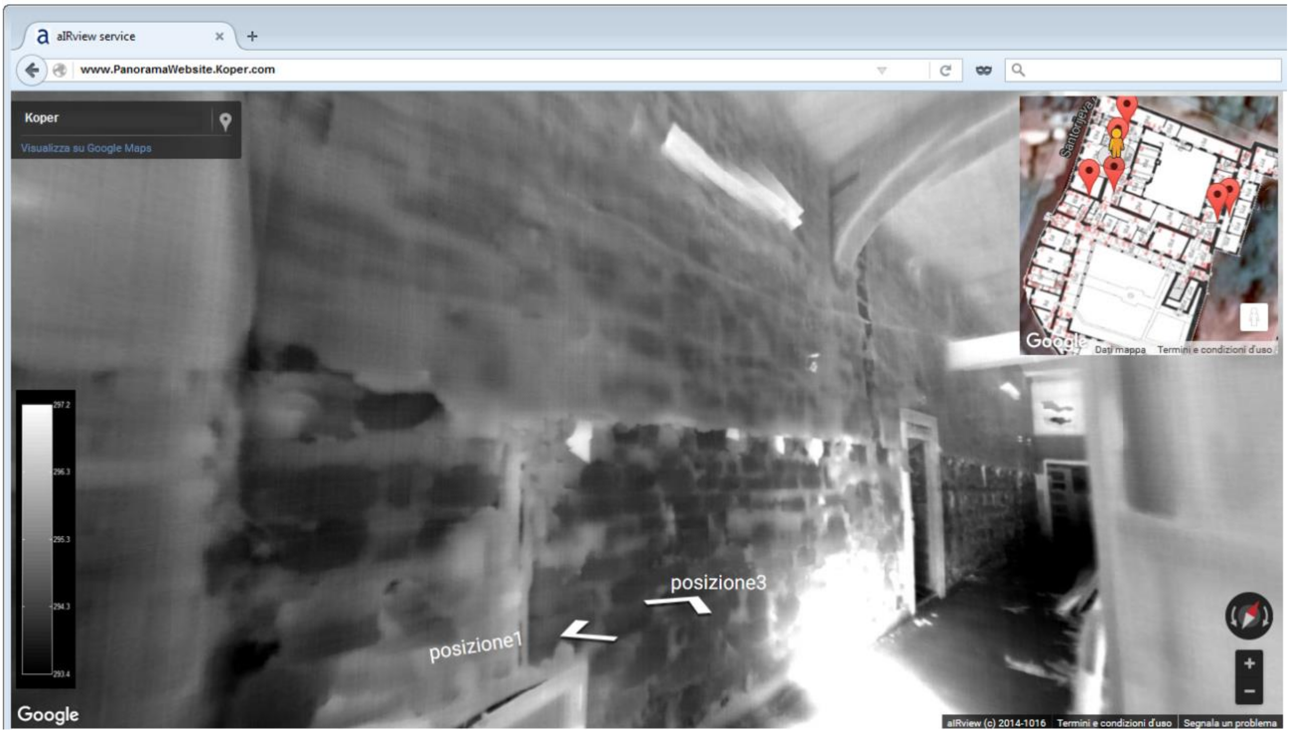

Figure 3. Thermal scan of the Servitski monastery in Koper. The different wall layout is highlighted by the thermal stimulus. The results are shown on a virtual visit of the building, where adjacent rooms could be easily compared [9].

Like in the previous case, the building was scanned in multiple locations. The objective was to check the possibly different texture of the walls. Hence, the rooms were heated before the survey. The results are integrated in a virtual visit of the monastery, facilitating the navigation and the comparison of different stone distribution.

3. Conclusions

The infrared survey of buildings is a time-consuming activity, possibly affected by operator mistakes. The IRpano device, that is here presented, is a scanning device that performs a fast scan of a room and presents as an output the panoramic images of both the visible and infrared spectrum. The automatic feature that furnishes the correspondence between photographs and infrared panoramas makes it easy the identification and localization of the thermal anomalies.
The results can be displayed in real time over a web server, with a significant cost reduction in building survey. Indeed, the device can be installed in the place by untrained personnel but the data analysis can be done, both at the same time of the survey or later, by trained experts at a remote location.
The high resolution of the infrared image and the possibility to automatically program the device for repeated scans over time opens the path for the study of the building behaviour in transient conditions, that could give precious indications on the energy performance.
Future work on IRpano will regard the increase of sensor and devices compatible with the backbone hardware and software structure.

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