AUTOMATION OF THERMOGRAPHIC 3D MODELLING THROUGH IMAGE FUSION AND IMAGE MATCHING TECHNIQUES

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ABSTRACT: Infrared thermography has proved to be an adequate technique for building inspection, as it can be used to determine energy efficiency through the measurement of heat losses, air leaks and infiltrations, and also to detect humidity areas. These parameters have great influence in energy consumption of buildings and in their users' well-being, which is demonstrated by the appearance of regulations as the Directive 2002/91/CE about Energy Efficiency.

Geometry and spatial relationships are very important in building inspection because they make location of thermal defects possible. Moreover, quantification of heat losses is not possible without measuring the area affected. As plans are not always available or updated, especially in the case of old buildings, the metric survey is essential when developing an energetic study. Metric documentation in old buildings is hindered due to their complex and irregular geometry; therefore, geomatic techniques are an appropriate solution to achieve an accurate geometric data acquisition of buildings and 3D models.

A procedure to fuse infrared and visible images in order to combine geometric information from photographies with thermal data from thermographies in the same image automatically is described in this paper. Fused images are then used for the automatic generation of a thermographic 3D model of the building through image matching. The proposed methodology is suitable for building inspection, where working space and time are usually limited so a reduction on the number and size of instruments is appreciated. Furthermore, automation of the process diminishes the error in results by avoiding operator's influence.

Keywords: *Infrared Thermography, Pan-sharpening, Image Matching, Geometry, Building*

1. INTRODUCTION.

Infrared thermography is the technique of measuring infrared radiation emitted by bodies, proportionally dependent on their superficial temperature [1]. Thanks to this, infrared thermography is a technique applicable to many different fields, such as medicine, fire detection, mechanical and electrical maintenance, and building inspection, among others.

Referring to building inspection, infrared thermography has proved to be an adequate technique in measuring surface temperatures in a continuous way, avoiding the need for measuring hundreds of points with a contact thermometer [2]. But apart from temperature measurement, infrared thermography has been widely used in building inspection for the detection of defects, especially dampness and air leaks, as can be seen in [3] and [4].

Taking into account the adequacy of the thermographic technique to building inspection, it would be interesting to complement thermal information with geometry, especially given that energy losses require the knowledge of both the temperature acquired and the area affected. In order to combine thermographic and metric information, one solution is the fusion of thermographies with laser scanner point clouds, as can be seen in [5] and [6]. However, these methodologies are not practical for small spaces or in those cases where time is limited.

Typical equipment for energetic studies in buildings generally includes a thermographic camera and a laser distance-metre, so maximizing their functions will optimize the results of a building survey.

This paper presents a working methodology for thermographic and geometric data acquisition in order to transfer to thermography the latest progress in image matching acquired in the photogrammetry field [7], especially destined to building inspection. With the aim of reducing data acquisition and processing, the methodology consists of the 3D modelling of building components from two thermographic images, two photographs, and two distance measurements, as images are subjected to an image fusion algorithm using IHS transformation [8], and then an image matching algorithm is applied to the fused images in order to reconstruct the surface under study.

2. METHODOLOGY AND RESULTS.

The proposed methodology was applied to the study of a building façade in Vigo (Spain), made of concrete and covered with small stones (fig. 1 (left)).

Image acquisition was developed using a thermographic camera NEC TH9260, and a visible camera Nikon D200, with a 20mm lens. Technical characteristics of these cameras are shown in tables 1 and 2.

CAMERA	NEC TH9260
Temperature range	**-20 to +500ºC**
Thermal sensitivity	**0.06ºC @ +30ºC**
Detector	**640 x 480 UFPA**
Spectral range	**8-14 µm**
Spatial resolution	**0.6 mrad**
Field of view	**21.7º (H) x 16.4º (V)**
Image frequency	**30 Hz**

Table 1 Technical characteristics of the thermographic camera used in this paper.

CAMERA	NIKON D200, 20mm lens
Sensor	**CCD 12Mpix.**
Format	**23.7x15.7mm(3872x2595pix)**
Weight	**830 g**
Storage	**Flash memory card**
LCD monitor	**2.5 in.**
Principal distance	**20mm**
View angle	**70º**

Table 2. Technical data of the semi-metric camera Nikon D200 with a wide angle Nikkor 20 mm f/2.8D lens, given by its manufacturer.

2.1. Data acquisition.

Given the fact that both thermal and geometric information have to be acquired, data acquisition must obey a series of requisites in order to make the whole process possible.

From the thermographic point of view, the survey should be carried out before sunrise, in order to avoid surface heating by direct radiation of the sun; and it must not have rained 24 hours prior to the survey, so that wet surfaces are due to interior dampness and not to rainwater [1]. On the other hand, with the aim of making the subsequent image-matching process possible, image acquisition must include two images of the object from the same angle, that are named overlapping pairs [9] due to their high overlapping surface (90-95%). What is more, image fusion requires the images to be fused be taken from the same point of view [10].

As a result, a thermographic and a visible image of the object were acquired from the same position; then, the whole system was moved 50 centimetres, in a parallel line to the façade under study, and image acquisition (thermographic and visible images) was repeated. This way, once image fusion of the corresponding thermographic and visible images is carried out, image matching can be developed for an overlapping pair.

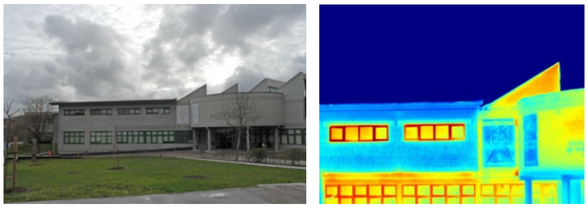

Fig. 1 Visible (left) and thermographic (right) images of one of the façades under study.

The final step of the data acquisition process is the measurement of the spatial coordinates (x, y, z) of four points in the façade that appear in both images. As it is not always possible to have a total station at disposal when doing a building inspection, this step can be substituted by the measurement of two distances in the façade that allow us the calculation of the relative coordinates of four points, as distance measurement is a common procedure in building inspection with a laser distance metre. These values are needed both for image fusion and for 3D modelling of the façade.

2.2. Image Fusion.

Acquired images are subject to an image fusion algorithm, which includes the following steps (fig. 3):

1. Temperature interval choice, in order to have a representative temperature scale for the two images needed.
2. Image registration by marking corresponding points in both images. Given that the transformation method for this step is the projective transformation, for which the relationship between the input and the output point is defined by equations 1 and 2, when a minimum of four pairs of points are marked.

$$x' = (x*h_1 + y*h_2 + h_3) / (x*h_7 + y*h_8 + h_9) \quad (1)$$

$$y' = (x*h_4 + y*h_5 + h_6) / (x*h_7 + y*h_8 + h_9) \quad (2)$$

Where h_1 - h_9 are the transformation coefficients; (x, y) are the coordinates of the points in the unregistered image; and (x', y') are the transformed coordinates of the points in the reference image (in this case, the visible image) coordinate system

2. Image transformation based on the marked points: thermographic image is transformed so that its characteristics (perspective, distortion) are the same as those of the visible image. Furthermore, the resulting full extent of the registered thermographic image is computed for filling in with white colour the pixels left to match the size of the visible image, since the visible camera has a detector thirty times greater than the thermographic camera, and consequently, its images cover a wider area.
3. Image conversion from RGB to IHS (Intensity, Hue and Saturation) of the thermographic image. This transformation is based on the following equations (3-5):

$$I = R + G + B \quad (3)$$

$$H = \begin{cases} (G-B) / (I-3*B) & \text{if } B = \min(R, G, B) \\ (B-R) / (I-3*R) + 1 & \text{if } R = \min(R, G, B) \\ (R-G) / (I-3*G) + 2 & \text{if } G = \min(R, G, B) \end{cases} \quad (4)$$

$$S = \begin{cases} (I-3*B) / I & \text{if } 0 \leq H \leq 1 \\ (I-3*R) / I & \text{if } 1 \leq H \leq 2 \\ (I-3*G) / I & \text{if } 2 \leq H \leq 3 \end{cases} \quad (5)$$

Where R, G, and B are the Red, Green and Blue colour channels; and I, H and S are Intensity, Hue, and Saturation values [8].

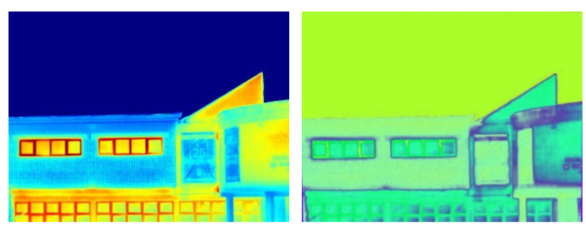

Fig. 2 Thermographic image of the façade under study, in the original RGB format (left) and after IHS conversion (right).

4. Image conversion from RGB to grey scale of the visible image.
5. Replacement of the I channel (intensity) of the thermographic image by the visible image in grey scale.
6. Image conversion from IHS with grey scale visible image in place of the intensity channel to RGB, by applying the inverse of equations 1-3.

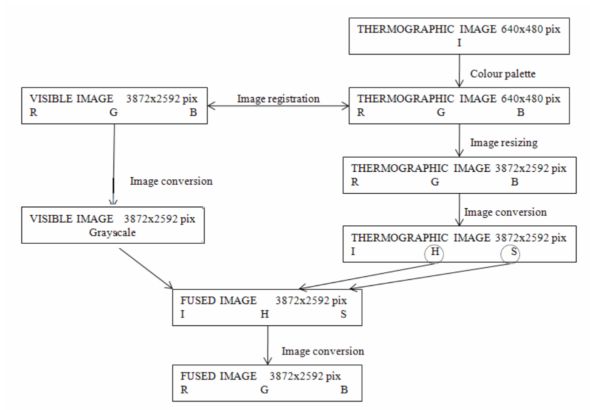

Fig. 3 Working sequence for thermographic and visible image fusion.

As a result of this sequence, a fused image is generated (fig. 4 and 5), with thermal information from the thermographic image and the geometrical resolution of the visible image. Thanks to that, fused images are more adequate for image matching processes.

Fig. 4 Fused image, resulting from the fusion of visible and thermographic images in fig. 1 with and IHS fusion algorithm.

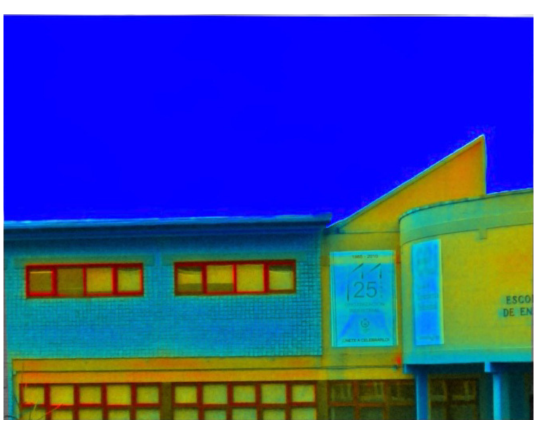

Fig. 5 Detail of the fused region.

2.3. Image matching.

Once image fusion is developed for two sets of images (thermographic + visible) of the same façade, an overlapping pair is ready for image matching for 3D surface reconstruction. This process is developed using Photomodeler Scanner software, which uses a Dense Surface Modelling algorithm for searching identical image patches.

Fused images are introduced in the software, together with the camera calibration parameters that allow image orientation (table 3). In this case, as thermographic images have been rescaled and transformed into the visible images coordinate system, the fused images obtained have the same parameters as the visible images; therefore, modelling is processed using the Nikon camera calibration parameters.

Once oriented, the project must be scaled so that it incorporates real distances between its points. This can be done by introducing the coordinates of 3 known points or by indicating a distance between two points, either of the measurements being carried out in data acquisition step.

PARAMETER		VALUE
Focal length (mm)	Value	20.742566
	Std	0.007
Format size (mm)	Value	23.903x16.000
Principal point (mm)	X value	11.820142
	X std	0.006
	Y value	8.170093
	Y std	0.005
Radial lens distortion	K_1 value	2.723×10^{-4}
	K_1 std	4.3×10^{-6}
	K_2 value	-4.395×10^{-7}
	K_2 std	3.8×10^{-8}
	K_3 value	0.000
Decent. lens distortion	P_1 value	-8.575×10^{-6}
	P_1 std	3.7×10^{-6}
	P_2 value	-6.169×10^{-6}
	P_2 std	3.4×10^{-6}

Table 3. Calibration parameters of the camera Nikon D200 with 20 mm lens.

The next step consists of idealizing the project, which is done by re-mapping the images, pixel by pixel, removing any distortion introduced by the lens, modifying pixels to a square form and moving the principal point in the image to the image centre. This process is essential for the subsequent image matching procedure.

Once images are ready, image matching is developed using a Dense Surface Modelling algorithm. This algorithm searches out similar patches in a regular grid, and when a good match is found between the pair of photos chosen for matching, the correct location of the surface point in the space is computed. As a result, a dense point mesh is automatically generated, without manual point restitution (see [11]).

The generated point mesh is then processed in order to reduce noise, and triangulated, so that it is transformed from a point cloud to a solid model made of triangles. These triangles are textured with the fused images, so that the model has metric information given by the points coordinates and thermal information from its thermographic texture.

In order to facilitate direct measurements in the model, it is projected on a plane parallel to the façade, so an ortothermogram is obtained (fig. 6). This image works as a map, has its scale, and stands direct measurements of distances between points, together with direct temperature measurements.

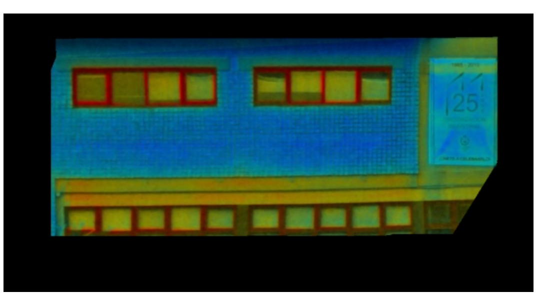

Fig. 6 Ortothermogram of the façade under study.

3. CONCLUSION.

As a result of the methodology proposed in this paper, different products are generated. First of all, image fusion is applied to the combination of metric and thermal information with the objective of generating thermographies with higher spatial resolution. As a consequence, resulting fused images present colour resolution from thermographies, which vary depending on the singularities of the object studied; and spatial resolution from photographs, which depends on the detector of the camera they are taken with, but is always higher than that of the thermographies. The fusion process is controlled by an operator, who marks control pairs in the images for image registration, and all the calculations are developed automatically, so that the operator's influence in the process is kept to a minimum.

Fused images can be subjected to an image matching algorithm for 3D surface recognition, so that, after image orientation, a point cloud is automatically obtained from the images. Image matching algorithms are one of the latest advances in photogrammetry and remote sensing, and now their applicability to fused thermographic images is demonstrated. The point cloud is processed to generate a solid 3D model with thermographic texture, and its subsequent ortothermogram.

These ortothermograms include metric and thermal information so that not only distances can be directly measured on them, but also surface temperatures. What is more, since thermography allows the detection of damp areas and air leaks, they are all accurately located given that the coordinates of all the points can be measured on the image.

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