1. Introduction

This issue revolves around keywords (i.e., non-destructive testing, advanced image processing, defect detection, heat transfer, measurement uncertainty, thermographic numerical simulations, infrared vision, defect depth retrieval, qualitative and quantitative analyses, and infrared thermography) that are connected to each other. In particular, infrared thermography (IRT) is the core of the issue. It is thought to be a promising method because it can be useful to settle questions concerning, e.g., material analysis, evaluation and characterization [1–11]. The word “material” is here understood in its broadest sense. The participation of leading scientists guides the reader and new users towards “a world seen at infrared”. In particular, this issue introduces some of the most recent advances of thermal and non-thermal imaging in various research fields, as well as innovative ideas developed for different applications. It focuses mainly on understanding, reading and discussing infrared images, by presenting many effective techniques based on advanced image processing to reach new level of comprehension [12]. In some cases, numerical simulations are validated by experimental analyses, while mathematical formulations forerun thermographic results [13–15]. Through clever approaches useful to analyze thermal responses, this issue can help readers and future generations of diagnosticians to become more familiar with knowledge frontier and foster an increased interest in the field.

2. Overview of the Accepted Papers

Considering the above, this special issue has aimed to collect latest ideas on relevant topics, and more important, to address present challenging issues with the use of IRT. There were 19 papers collected in this special issue. Various research topics have been addressed, mainly (but not limited) to any process temperature-dependent link to civil, mechanical, biomedical, aeronautical, aerospace, electrical, and electronic engineering, computer science, as well as artistic and architectural heritage.

In particular, Ferrarini et al. investigated the thermal performance of a typical electric radiant panel. In this work, a climatic room was equipped with temperature sensors and heat-flow meters to perform a steady state experimental analysis. For the dynamic behavior, a mathematical model was created and compared to a thermographic measurement procedure. The results showed for the steady state an efficiency of energy transformation close to one, while in a transient regime the time constant to reach the steady state condition was slightly faster than those that are typical of hydronic systems [16].

Gavrilov and Maev proposed an approach for separation of independent image patterns (archetypes) from a set of principal component images. The approach was demonstrated in the application of the inspection of composite materials, as well as the non-invasive analysis of works of art [17].
Meola et al. selected glass/epoxy for impact tests by changing, with respect to previous analyses, some parameters and by inline monitoring simultaneously with two different infrared cameras to share a high frame rate and spatial resolution at the same time. In addition, the same material was monitored during quasi-static bending tests, by showing that it is possible to learn from thermal signatures when glass/epoxy is either impacted or under quasi-static bending [18].

Moropoulou et al. retraced some of the IRT applications (both in the laboratory and in situ) performed by her research team at National Technical University of Athens (NTUA), Greece, over the course of time. All these data and accumulated knowledge and experience contributed to a set of recommendations, which enabled the team itself to compile a protocol for the application of this technique in a more standardized way. The successful application and integration of this technique was demonstrated in large-scale conservation projects [19].

The paper written by Ospina-Borras et al. presents the estimation of thermo-physical parameters $k$ and $\rho c_p$ in Guadua angustifolia kunth (Guadua a.k.) bamboo through non-linear least squares optimization and infrared thermography. A sensitivity analysis was carried out to determine how the temperature on the bamboo surface is affected by changes in the convection coefficient $h$, thermal conductivity $k$, and volumetric heat capacity $\rho c_p$. In spite of the non-linearity and high correlation in the parameters of the inverse heat conduction problem (IHCP), it was found that the estimation of such parameters is robust and consistent with those reported in the literature [20].

Sannikov et al. focused attention on the detection of corrosion working with IRT to heat up the rebar by resistive or inductive heating. It was found that, in both cases, monitoring the dynamic temperature distributions on the pole allowed for the evaluation of reinforcement quality. In fact, the magnitude of temperature anomalies and their behavior over time depend on the presence of corrosion products, air gaps, and the quality of contact between rebar and concrete [21].

Steenackers et al. wrote a paper in which a numerical model of a bicycle frame was updated and optimized by the surface temperature distribution captured with pulsed thermography. The results were compared and benchmarked against frequency response function (FRF) measurement data as a reference. The chosen temperature decay measurement used as reference data was of key importance. In fact, the goal of the manuscript was to compare both measurement results and model predictabilities after performing finite element model updating with respect to accuracy and speed [22].

Theodorakeas and Koui investigated a carbon fibre-reinforced polymer (CFRP) consisting of internal artificial delaminations of various sizes and depth locations by means of optical pulsed thermography for the retrieval of quantitative depth information. The main goals of the work were the evaluation of the produced depth estimation accuracy from two contrast-based depth inversion procedures, as well as the correlation of the acquired results with characteristics such as the location and size of the detected features and with analysis parameters such as the selection of the sound area.

A quantitative analysis was performed in both the temporal and frequency domains. The results showed that the two different analyses provided efficient depth estimations, with frequency domain analysis demonstrating greater accuracy. Finally, predicting errors were observed in both cases and the factors responsible for these errors were defined and discussed [23].

Zhang et al. applied thermographic non-destructive inspection methods to evaluate and characterize basalt, jute/hemp and bagasse fiber composite panels. Different defects were found in terms of impact damage, delaminations and resin abnormalities. In particular, pulsed phase thermography (PPT) and principal component thermography (PCT) were used as post-processing techniques. Ultrasonic C-scan and continuous wave terahertz imaging were also carried out on the mineral fiber laminates for comparative purposes. An analytical comparison of different methods was given [24].

The main aim of the work written by Cristalli and Grabowski consisted in the analysis of time changes of features extracted from thermal images using the multivariate approach. The paper showed that if the principal component analysis (PCA), belonging to multivariate methods, is applied for quality control based on infrared images, then the minimum testing times can be estimated. In
particular, a detailed temporal analysis for an exemplary production line has been carried out, and future perspectives were given, too [25].

Galla described a proposal for the qualitative assessment of the condition of supercapacitors based on thermographic measurements. Necessary conditions to minimize the influence of disturbing factors on the performance of thermal imaging were also indicated. All the tests were conducted in conjunction with the classical methods based on capacitance (\(C\)) and equivalent series resistance (ESR) measurements; some selected results present the observed changes occurring in both. Limitations of the proposed assessment method, as well as the suggestions for its future development, were also described [26].

Jones described the advantages and enhanced accuracy that thermography provided to high temperature mechanical testing. In particular, this work demonstrated the superior visibility of test temperatures previously unobtainable by conventional thermocouples or even more modern pyrometers that thermography can deliver. The speed and accuracy of thermal profiling, thermal gradient measurements and cold/hot spot identification using the technique has increased significantly to the point where temperature can now be controlled by averaging over a specified area. Finally, the increased visibility of specimen temperatures has revealed additional unknown effects described in the paper itself [27].

Liu et al. proposed an improved dual-tree complex wavelet transform (DTCWT) optimized by an improved fruit-fly optimization algorithm (IFOA) and bilateral filter (BF) in order to eliminate the noise of infrared images without reference and noise models. In the experiment, the proposed method is applied to eliminate both additive noise and multiplicative noise, while the denoising results were compared to other representative methods. Finally, the proposed method was applied as a pre-processing utilization for infrared thermal images in a coal mining working face [28].

In [29], Mercuri et al. applied pulsed infrared thermography with the aim to provide stratigraphic information in different kinds of cultural heritage artefacts by analyzing the heat diffusion process within the sample after thermal perturbation. Moreover, the integration of such pulsed infrared thermography and three-dimensional shape-recording methods was proposed in order to provide a three-dimensional representation of the thermographic results. Finally, it was underlined how such a technique may be crucial to understand historical, technical and artistic points of view of the art master.

Oswald-Tranta focused attention on the induction thermography method useful to localize surface cracks in metals. It was found that the transformation of the temporal temperature development for each pixel to phase information made not only highly reliable detection of the cracks possible, but also an estimation of its depth. Finite element simulations were carried out to investigate how the phase contrast depends on several parameters. From the results obtained, generalized functions for the dependency of the phase difference on all the listed parameters were derived. They can be used as excellent guidelines to reach the goal of the paper described in the title. Several experiments were carried out; the results compared with the simulations showed very good agreement [30].

In [31], Peeters et al. assessed to what extent the less investigated InfraRed-B band (1.5–3 \(\mu m\)) can combine the information obtained from InfraRed-A (0.7–1.4 \(\mu m\)) and InfraRed-C (3–5 \(\mu m\)) bands and the related experimental setups. In fact, the application of the IR-B systems is relatively rare as there are only a limited amount of commercial systems available due to the technical complexity of the lens coating. In particular, four objects were studied in both reflectographic and thermographic mode in the IR-B spectral range and their results benchmarked with IR-A and IR-C images. For multispectral application, a single benchmark was made with macroscopic reflection mode Fourier transform infrared (MA-rFTIR) results. IR-B proved valuable for the visualization of several features; finally, potential pathways for additional applications such as pigment identification in multispectral mode or characterization of the support (panels, canvases) are indicated.

Tang et al. presented an efficient numerical approach for field infrared smoke transmittance based on grayscale images. The results proved to be of sufficient precision for engineering applications; in particular, the method greatly simplified the field trial process, thus improving efficiency [32].
The article written by Vantuch et al. described an experiment applying infrared thermographic measurements during long-term monitoring and fault detection in uninterruptible power supplies (UPS). The assumption that the battery overheats implied its damaged state was the leading factor of the experiments. They were based on real measured data on various UPS battery sets and several statistical examinations confirming the great relevance of thermal features with mostly over 90% detection accuracy [33].

Lastly, in [34], Wan et al. presented a saliency histogram and geometrical invariability-based method able to detect both bright and dark small moving targets effectively in infrared (IR) video sequences. Quantitative analyses demonstrated the detecting precision of the proposed approach; it can be up to 97%. In addition, the receiver operating characteristic (ROC) curves further verified that the method outperforms other state-of-the-art methods in both detection rate and false alarm rate.

3. Conclusions and Future Perspectives

The special issue summarized here has aimed to collect manuscripts representing “novel ideas for infrared thermography and its application to integrated approaches”. Very interesting and innovative works have been published after a rigorous peer-review process. The manuscripts deal with a number of technical issues consistent with the infrared thermography field. Science and engineering have been the two macro-sectors explored most by these authors. This demonstrates how such a technique, above all when combined with others working in different spectral bands, is able to support the decision-making responsibility of scientists in different areas of interest.

It might be expected that the contribution of infrared thermography in medicine will increase in the next few special issues as the new advantages of the latest algorithms introduced in the thermographic field are considered.

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