Journal of
Information Technology & Software Engineering

Mulaveesala, J Inform Tech Softw Eng 2013, 3:2
DOI: 10.4172/2165-7866.1000e119

Editorial Open Access

Thermal Non-destructive Testing and Evaluation: Coming of Age

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Introduction

As a specialized tool for Non-destructive Testing & Evaluation (NDT&E), Infrared Thermography (IRT) [1-10] involves as a remote mapping of temperature over test sample for finding out its surface and subsurface features with the emitted radiation from objects in the infrared band of the electromagnetic spectrum. It is a fast, remote, and safe non-destructive testing and evaluation (NDT&E) method for surface and sub-surface defect detection in various solid materials. Since most solids conduct heat, IRT largely owes its emergence and potentiality for defect detection in variety of materials such as metals [5], composites [6,7,11] and semiconductors [8,12]. IRNDT has numerous applications in the area of aeronautics, space, electrical, electronic, bio-medical and mechanical industries [5-27]. Of the various possibilities of thermal NDT implementations Infrared Thermography (IRT) or Infrared Non-destructive Testing (IRNDT) has, gained wide acceptance in NDT & E methods due to its merits. Various methods and techniques have further been developed by various research groups all over the world to improve and widen the use of IRT for non-destructive characterization [1,7,10,11,14,15,16,21,23,26]. This editorial is to present an overview on existing work and to describe the most relevant experiences devoted to the use of IRT methods for NDT&E.

Active Infrared Non-destructive Testing

Widely used active thermal non-destructive testing methods for surface and sub-surface feature extraction are: pulsed thermography (PT) [7], stepped thermography or time resolved infrared radiometry (TRIR) [10], lock-in thermography (LT) [1] and pulsed phase thermography (PPT) [2,15].

In PT, the examined material is warmed up (cool perturbations can also be used) with a short duration high peak power pulse (optical, eddy current, ultrasonic pulse, etc.), and the thermal response is captured by an IR camera [9]. The resultant sequence of infrared images recorded indicates defects in the material located at various depths. In practice, this technique requires high peak power short duration heat sources and has the additional drawback of being sensitive to surface emissivity variations and non-uniform heating over the test sample [1,3].

Stepped thermography is similar to pulse thermography except that the duration of the excitation pulse is long. Unlike in PT, in stepped thermography the increase in sample surface temperature is monitored during the active heating. The temperature variation (rate of change of surface temperature) with time gives the information about the subsurface features of the test sample. This technique is also named as time resoled infrared radiometry (TRIR) [10]. Unlike PT, TRIR can be carried out even with low peak power heat sources.

In contrast to pulsed and stepped thermography, lock-in thermography is based on thermal waves generated inside the specimen under study. This uses mono-frequency sinusoidal thermal excitation at an angular frequency of ω, which introduces highly attenuated, dispersive thermal waves [2] of the same frequency ($\omega/2\pi$) inside the test specimen. The excitation frequency in LT is chosen to be dependent on the sample thermal properties and its geometrical dimensions. Lower the frequency of the thermal waves, deeper the penetration of thermal wave into the test specimen. From the recorded image sequence (by an IR camera), in the stationary regime of heat cycle, information about the phase and magnitude of the reflected thermal wave is derived [1,3]. The phase angle images have advantages of being less sensitive to local variations of illuminations and variations of surface emissivity over the sample [1]. Further phase images are capable of probing deeper depths compared to the magnitude images [1,3,11,12]. Since in a single run there is limited depth resolution of the lock-in thermography test due to fixed driving frequency of the excited heat sources, thus in order to get good resolution for various defects at different depths inside the test specimen it is necessary to repeat LT at different excitation frequencies [13-25].

The experimental arrangement of PPT is similar to PT, but extraction of various frequency components in the captured infrared image sequence is performed by Fourier transform (FT) on each pixel of the thermogram sequence [2,15]. The phase images obtained from the Fourier transform in PPT shows all the merits of the phase images obtained in LT, (i.e. less sensitive to surface in-homogeneous emissivity and illumination variations). Theoretically, the short duration excitation pulse in PPT does launch a large number of frequency components into the test samples, but the higher order frequency components may not have sufficient energy to cause a thermal wave to propagate deep into the sample. In order to detect deeper subsurface defects in test sample, PPT needs high peak power heat source which may damage the surface of the test sample.

In order to overcome these problems of LT and PPT it is necessary to send the desired band of frequencies into the test sample. This is preferably done in a single run for improving resolution of the test without repeating the experiment at different frequencies. The thermal excitation should be intense enough to generate thermal waves of appreciable magnitude within the desired band of frequencies to be launched into the specimen.

In order to improve resolution for detecting defects lying at different depths in lesser time as compared to LT, without increasing the peak power of heat source as compared to PPT can be achieved by non-stationary thermal wave imaging. In this desired band of frequencies (decided by sample's thermal properties and it's thickness) are launched into the specimen, followed by adapting an appropriate signal processing techniques on the captured transient thermal response (during active heating) to improve the resolution and sensitivity of the test.

In the last one decade many efforts have been made to investigate the non-destructive testing applications of novel non-stationary thermal wave imaging techniques by various research groups, (Mulaveesala

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Received September 16, 2013; **Accepted** September 17, 2013; **Published** September 24, 2013

Citation: Mulaveesala R (2013) Thermal Non-destructive Testing and Evaluation: Coming of Age. J Inform Tech Softw Eng 3: e119. doi:10.4172/2165-7866.1000e119

et. al. from India and Mandelis et. al. from Canada) to widen the applicability of infrared imaging for industrial inspection [11,21,24]. Mulaveesala and co-workers were the first to apply the various high resolution non-stationary thermal wave imaging methods for the non-destructive characterization of fibre reinforced plastic materials [12, 21,23,27,28].

However, frequency modulated thermal wave imaging (FMTWI) [13,14,16], quadrature frequency modulated thermal wave imaging (QFMTWI), digitized frequency modulated thermal wave imaging (DFMTWI) [11,12], and coded excited thermal wave imaging [21,23] are some of the non-stationary thermal wave imaging methods. These methods, with its predefined excitation schemes play a vital role in IRNDT. Further application of specialized post processing methods will further strengthen the utilization of these methods.

Among the various widely used post processing schemes, correlation based pulse compression post processing approach has its own advantages over the widely used conventional frequency domain phase based approaches [18-25]. Pulse compression technique allows the usage of a moderate peak power, long duration modulated heat sources to improve the defect detection range and resolution capabilities comparable to that obtained with a short duration high peak power pulsed sources[18,19,21,23,25,26,27,28]. This can be achieved with a correlation based pulse compression technique by cross correlation of the temporal temperature distribution over the chosen reference pixel over the sample, with a time delayed, attenuated version of remaining pixels in the field of view. Temporal temperature responses from defective and non-defective regions differ in their attenuation as well as delay, depending on the local thermal properties of the material underneath the surface. Cross correlating the temporal thermal responses of the pixels with chosen reference, produces a pseudo pulsed response (compressed to a very narrow pulse) about a delayed time instant, with respect to the auto correlation of the reference thermal profile, corresponding to the variations in thermal properties (i.e diffusivity of material, effusivity of subsurface feature etc.). Pseudo pulsed response obtained from this correlation approach for captured temperature distribution to the imposed modulated incident heat flux provides advantages similar to obtained with high peak power short duration pulsed excitation.

Conclusions

It is essential to develop a fast, remote, whole field, quantitative and safe non-destructive testing & evaluation methods to provide more convenient, feasible and reliable testing capabilities for industrial inspection and condition monitoring. It is indeed my pleasure to recommend OMICS group of publications to share novel ideas, suggestions and constrictive criticisms rapidly on cutting edge image and video processing methods for industrial imaging technologies for high visibility.

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