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# Approaches to Data Reduction, Visualization and Analysis in Thermographic Signal Reconstruction

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**Abstract**

The Thermographic Signal Reconstruction (TSR) method has gained widespread acceptance for its ability to enhance flaw detection and quantitative measurement capabilities in active thermography through the use of logarithmic derivatives. However, in practice, analysis of TSR data often involves viewing an entire reconstructed image sequence as a movie, in order to identify regions of anomalous cooling behavior. In most cases, it is possible to convey all of the essential sequence information in a single image, or a small subset of images, expediting process of visualization by a human operator, or alternately, facilitating automated processing by a computer.

**1. Introduction**

Since its introduction in 2001, the Thermographic Signal Reconstruction (TSR) method has been widely acknowledged for its ability to enhance flaw detection and quantitative measurement capabilities in active thermography by exploiting the logarithmic derivatives of the signal [1]. TSR creates a noise-free replica of each pixel logarithmic temperature-time history by least squares fitting of a polynomial. The 1st and 2nd time derivatives of the replica are significantly more sensitive to signal changes associates with anomalous diffusion than direct viewing of the image sequence, or contrast-based processing methods. In addition to enhancement of flaw detection, TSR derivatives are relatively immune to shot-to-shot variations in excitation energy, or to heating nonuniformity due to emissivity variations on the sample surface. One of the most useful features of TSR is the fact that the derivative signals occur within a fixed and limited range, so that the derivative amplitudes have physical meaning that allow interpretation of even a single pixel, rather than an image.

In practice, interpretation of TSR data is often performed by a human operator who views the 1st or 2nd derivative sequence as a movie. While this process takes advantage of the excellent contrast detection capability of the human eye, it is time-consuming and imprecise, and subject to psycho-visual factors such as choice of color palette or thresholding of the dynamic range. Various alternatives to viewing a derivative movie sequence have been proposed, including:

1. Peak derivative or time images [2]
2. Viewing the polynomial coefficient images [3]
3. Projection of principal polynomial coefficients onto RGB basis components [4]
4. Pulse phase analysis of TSR processed data [5]

Technique 1 generates a reduced data set based an attribute of the signal, rather than the entire time sequence, while techniques 2-4 project the data onto an alternate set of basis functions, some of which may be eliminated without significant loss of information content. Each of these has been demonstrated to be effective in particular cases involving samples prepared samples. However, in actual NDT practice, data sets are often quite complex, regardless due to the presence of multiple flaws, experimental variables, but particularly due to the complex nature of many structures that require NDT. Often, the proposed methods described above are ineffective when presented with a cluttered data set with numerous internal features, both intentional and unintentional. In such cases, a reduced data set may not be sufficient for reliable interrogation.

## 2. The TSR Fingerprint

An alternate approach to visualization, first proposed in 2005, presents the entire 1st or 2nd derivative sequence, but transforms it to a different coordinate system [6]. The original logarithmic derivative sequence consists of a set of 2-dimensional images in which the grey level is the derivative value, so a point in the image represents the components x,y, $dT^{(n)}/dt^{(n)}$ and tme (t). If we consider the histogram of single image in the derivative sequence, its components are $dT^{(n)}/dt^{(n)}$ and N, the number of pixels with value $dT^{(n)}/dt^{(n)}$. Combing the histograms of every image in the sequence so that the x-axis represents time, the y-axis represents $dT^{(n)}/dt^{(n)}$, and the gray level represents N, we have transformed the coordinates of the sequence so that the entire sequence is represented in a single "fingerprint" image based on the relationship

$$F(x,y,\ dT^{(n)}/dt^{(n)},t) \Rightarrow G(t,\ dT^{(n)}/dt^{(n)},\ N) \qquad (1)$$

In making this coordinate transformation, we have reduced the dimensionality of the sequence from 4 to 3, at the expense of spatial information. However, any point in the fingerprint can be traced back to the pixels in the

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image it represents. While the fingerprint image is not visually intuitive to the casual observer, it offers an immediate view of the entire volume that has been interrogated, and confirmation that the experiment has been performed correctly. The resulting fingerprint is a single image that can be numerically compared to subsequent inspections using a cross-correlation operation. Comparison of fingerprints from different inspections does not require spatial pixel-to-pixel correlation, since the fingerprint is rotation and translation invariant.

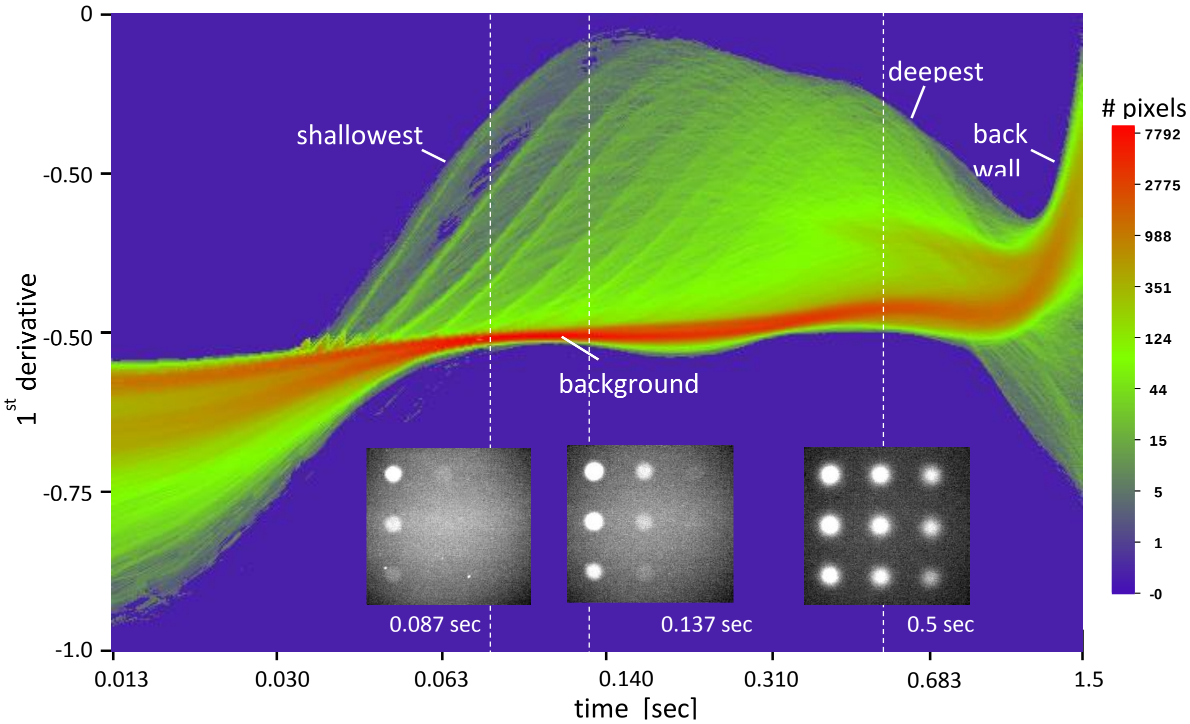


*Figure 1. TSR 1st derivative fingerprint of a 1.5 second flash thermography sequence of a steel plate with 9 0.5 in diameter back drilled holes at various depths. Unprocessed images are shown in grey scale (bottom)*

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