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Passive multivariate thermography on the mitigation of corrosion under insulation

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Abstract

Corrosion under insulation (CUI) is one of the major concerns of oil and petrochemical installations as damage evolves invisibly under insulation layers and usually revealed on the occurrence of leaking or more catastrophic failure. Methods to early detect CUI and its causes is an urgent necessity to assure safety and performance of insulated process piping.

Oil and petrochemical plants are often considered explosive environments in which thermal excitation devices are forbidden. The present work aims then on the consolidation of a passive thermographic methodology to reliably detect moisture trapped under insulation layers that will cause corrosion.

The proposed methodology focuses on the thermal behaviour of the piping structure during process variations and interactions with the external ambient. The partial least-squares analysis showed promising performance on separating different physical phenomena and creating cleaner images for defect detection.

1. Introduction

Corrosion represents one of the biggest costs of industry where corrosion under insulation (CUI) is responsible for around half of it [1]. Shadowed by insulation, the damage evolves undetected and only discovered when leaks or more catastrophic failures occurs.

The water trapped in the insulation systems is the main driving force to generate CUI and methods for detection is of urgent necessity. Once trapped in the insulation, the water decreases thermal resistance while increases heat capacity of insulation systems [2]. When interacting with the process heat or ambient variations, the trapped moisture creates different thermal distributions on the piping surface that can be detected by infrared thermography.

But as in any other thermographic application, the inspection is disturbed by ambient reflections and surface conditions (mainly low and uneven emissivity) that insert noise on the thermal images and might compromise detectability.

Several data processing methods are consolidated on filtering noise in thermographic data being most of them applied to the active mode, where objects are thermally excited by an external heat source [3]. For the case of oil and petrochemical sectors, external heat sources are not allowed due to the explosive characteristic of these environments. The alternative then is to look for disturbances caused by the process itself, during shutdowns and turnarounds for example, and the interaction of the structure with the ambient aiming to detect abnormal thermal distributions.

Regression methods like Principal Components Analysis (PCA) and Partial Least-Squares (PLS) are known to be effective on separating subsets with different temporal behaviour inside a heterogeneous dataset, being the second one a more robust algorithm with less collinearity problems [4]. Both analyses can be used to separate the noisy disturbance of the external heat on active thermography, but also to separate temporal variations influenced by different variables on a passive approach [5].

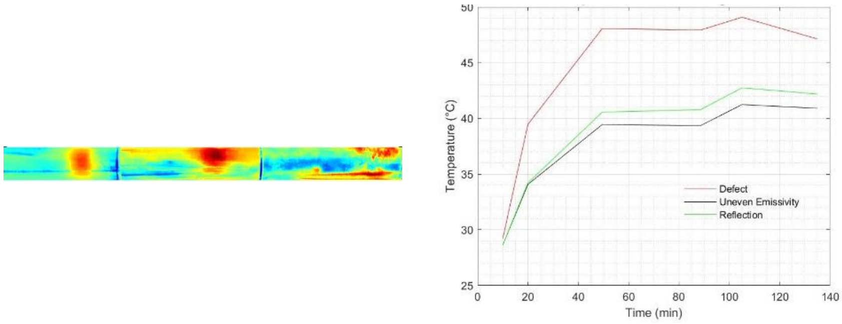
In the present work, the PLS method is applied to thermographic data acquired from an insulated piping containing trapped moisture. The regression method is capable to separate the data in components that can be related to different sources of contrast in the passive acquisition mode. The method appears to be a robust multivariate analysis that generates images almost free of noise and extends the applicability of thermography to considerably low levels of surface emissivity.

2. Materials and Methods

An insulated carbon steel pipe was monitored by an infrared camera whereas process and ambient variations were imposed. The insulation layer has three inserts of trapped moisture with different sizes positioned under aluminium claddings of three different values of emissivity (0.77, 0.53 and 0.46). A flux of pressurized hot oil passes inside the pipe.

As shown on figure 1, the temporal evolution is considerably different for regions delimited by defects and the ones influenced by ambient reflections or uneven emissivity. This situation is favourable to the application of regression methods based on variance of analysed data, like PCA and PLS, being the second one a more robust regression method when multiple variables are involved [4].

The PLS algorithm is applied to the raw or calibrated (emissivity and reflected temperature) thermographic images by means of an unfolding procedure. The number of the new predictors are adjusted by a cross-validation step where the residual error to the actual temperature values is reduced while the most part of the dataset variance shall be contained in the regression model [4]. The loadings of the PLS for each predictor are then converted to individual images where each one is most influenced by only one variable.



Angular Coefficients (°C/min)	
Trapped moisture	0.120
Reflection	0.097
Uneven emissivity	0.085

Fig. 1. *Calibrated thermogram, temporal evolution of three regions and corresponding angular coefficients*

3. Main Results and Conclusions

The proposed multivariate thermography method, based on the PLS regression, can separate the information influenced by different variables on distinct components. As a result, one can achieve images free from noise and containing almost only defective information, as shown in figure 2.

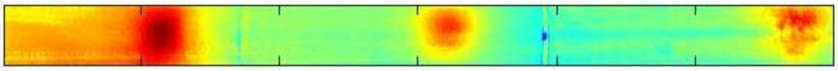


Fig. 2. *PLS component to reveal the trapped moisture defects*

A signal-to-noise ratio (SNR) analysis points to an increase of more than 20dB when comparing calibrated images and the proper selected PLS component. Another important achievement is the apparent decrease of the emissivity influence. Both results can be seen by the charts on figure 3.

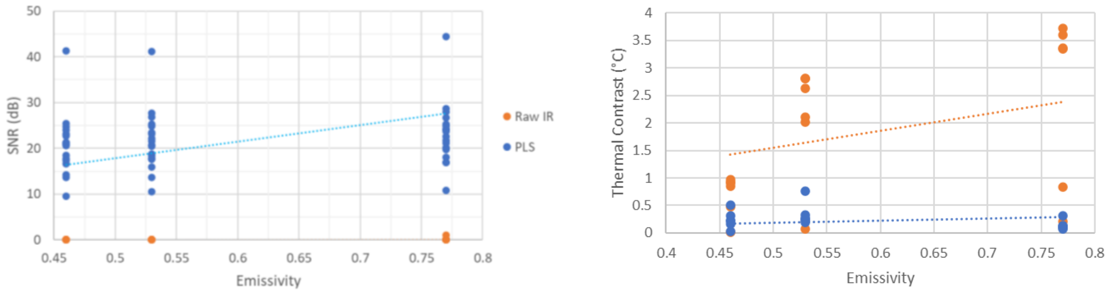


Fig. 3. *SNR comparison to raw thermograms and emissivity influence on thermal contrast*

The method was capable to achieve reasonable SNR results for emissivities as low as 0.46, which is considered a low level for industrial applications, indicating the potential of the method to extend the applicability of thermographic inspection. The number of acquired images and the minimum temperature change necessary to generate reasonable SNR values are still questions to be answered pursuing a deployable field inspection procedure and will be the target of the next steps of the study.

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