# Analysis of Thermographic Patterns using Open CV

## *Case Study: A Clinker Kiln*

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Abstract: The core of the cement production process is the clinker kiln. Proper operation of the kiln depends on factors such as the timely monitoring of its thermal behavior under different operation conditions. This work includes a systematization of empirical knowledge of skilled kiln operators, linking it with the analysis of thermography images of the kiln using Open CV. The paper includes an integration of interventions implemented by the operators, in terms of a log described in natural language. The work highlights potential uses of the knowledge of experienced operators, when this is combined with techniques based on image analysis and artificial intelligence.



## 1 INTRODUCTION

A cement factory consists of several areas of different processes that influence the final cost of production. The area between the preheaters section to the cooler, which includes the clinker kiln, is undoubtedly the most important among the cement production processes (Deolalkar, 2009). Figure 1 illustrates the elements of that area. The control actions performed on the kiln have much influence on productivity levels and the quality characteristics of cement. Therefore, it is vital to maintain appropriate operating conditions, including real-time monitoring of thermal behavior of the walls of the kiln. In many cement installations, the operators that control the kiln typically decide their actions on empirical grounds, that have improved based on experience or verbal knowledge transfer.

This paper contains a proposal that allows systematizing empirical actions taken by operators, based upon graphical information of the thermal reading of the kiln walls obtained from a thermograph. The data capture is done via Open CV (Open CV, n.d.), which also facilitates the analysis of its graphic content. Also, the relationship between thermal images and description of the actions taken by the operators is done in natural language, in a log. In addition, a validation process through a decoding algorithm and extraction of information stored in the thermograph is performed using Open CV. This allows generalizing the methodology to existing industrial thermographs.

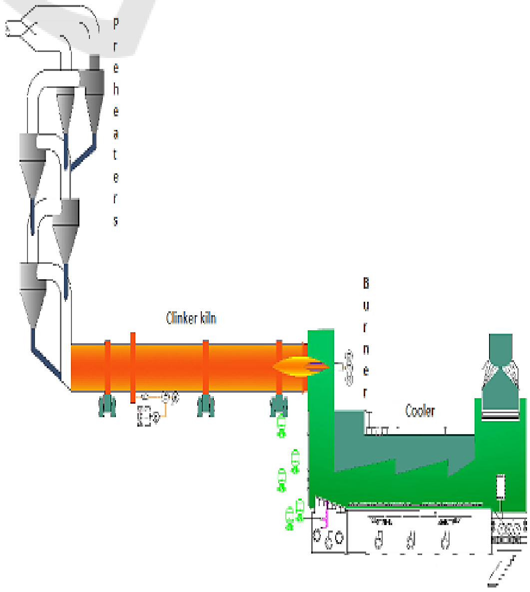


Figure 1: Illustration of the area between the preheaters to the cooler.

The analyzed information facilitates the search for patterns of operation of the kiln that permits establishing rules of inference, relating process variables, thermographic patterns and the log. This result represents a step forward to build a rule-based

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decision support system, with online reading of the thermography images and the values of the process variables, to enhance the operation of the kiln.

## 2 EXISTENCE OF UNSTRUCTURED EMPIRICAL KNOWLEDGE

The gap between experience and phenomenological understanding of the processes make the control actions taken in the kiln "reactive", based on a mind map of past experiences. On this map there may be “holes” (ie. Tendency to not quite remember the entire context where the new experience was developed) and a systematization of knowledge is therefore paramount to support decisions about the operation of the kiln. For example, in a study conducted on the considered plant, a Piping and Instrumentation Diagram (P&ID) of the considered area was built. This diagram included seventy-seven variables in the preheater and oven and eighty variables in the cooler. Figure 2 illustrates the part of the P&ID that corresponds to the clinker kiln. In a given operational condition, the operator only considers a small map of variables; empirically determining those affecting in higher degree the action to be taken. In this way, a system for establishing relationships among variables of the process with control actions would greatly help in the kiln operation.

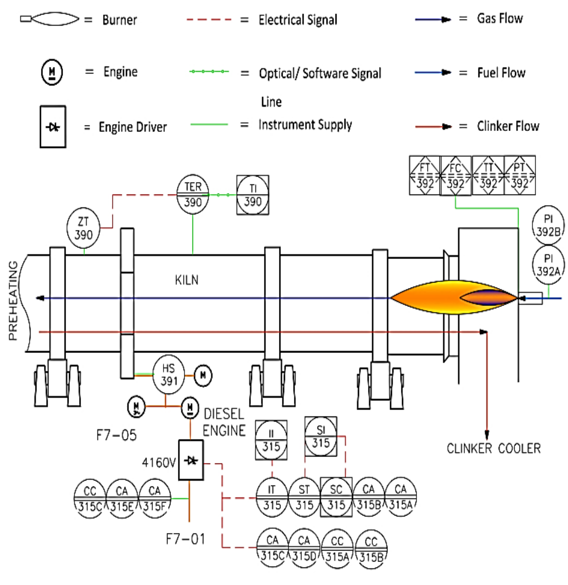


Figure 2: Clinker kiln P&ID.

## 3 SYSTEMATIZED THERMOGRAPHIC MAPS AS A SOURCE OF KNOWLEDGE

Figure 3 corresponds to a thermal image of the kiln over its 58 metres in length and constitutes an important source of information. The thermography image reads temperatures in a range that varies between 80° Celsius to 500° Celsius, around the 360° of rotation of the kiln.

Empirically, it has been determined that an area with temperatures of 400° Celsius or higher for a long period of time would have higher risk of damage to the refractory and might cause a forced stop of the kiln.

*Capturing thermographic information with OpenCV*

Open CV (Open CV, n.d.) is software under the BSD license, which allows free use for commercial and academic purposes.

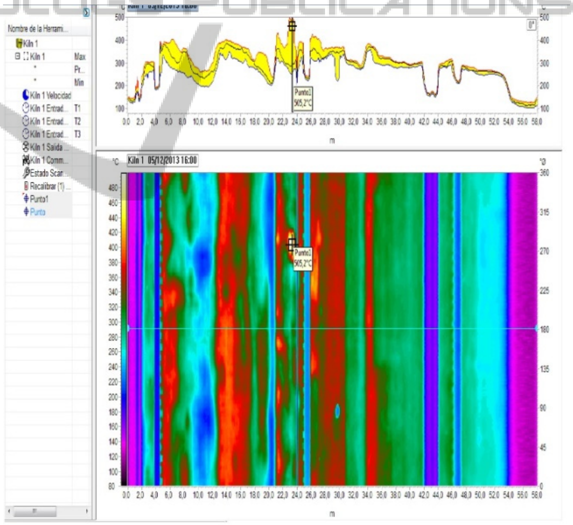

Figure 3: Thermographic image of the clinker kiln.

Usually, a thermography is presented from a propietary system as an image (see Figure 3). Thermographic systems store information in a confidential manner, i.e. they use algorithms of condensation, encryption, and others, which do not allow the extraction of information for direct analysis of their images. In addition, being proprietary systems, any possibility of integration with their databases can lead to malfunctioning of the system or could even be subjects to security risks.

In this proposal, regardless of the themographic system implanted in plant, the use of an interface under Robot (Oracle, n.d.) allows to capture the thermography image and to store it in an array of pixels which is subsequently treated under Open CV.

Through Open CV (.Mat, .Highgui) the information in the array of pixels is extracted and presented using SWT (ECLIPSE, n.d.) (Pulli, et al., 2012) (see Figure 4). Next, the necessary information is stored, so that it can be used for image analysis.

The post-processing allows locating longitude, latitude and temperature on any point of the extracted image; which determines values that will be used to search for patterns that describe thermal behaviors. The position of the matched pattern is stored in a database whose design allows for fast data recovery. It uses a standard indexation search method and facilitates the identification of refractory zones which may have been damaged for having been exposed to high temperature for large periods of time. The positions patterns storage allows for a semi-automated post-processing capability.

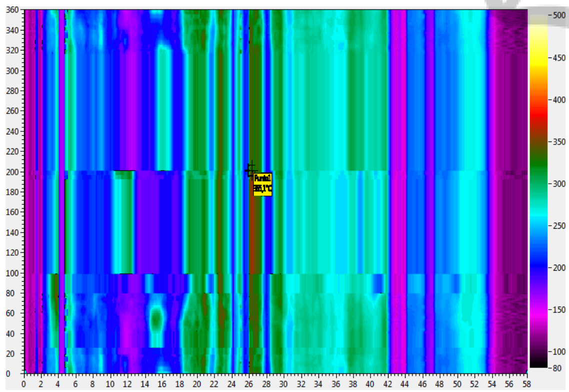

Figure 4: Image extracted from the Thermographic system and processed with Robot, Open CV and SWT.

### 3.1 Patterns Matching using Open CV with Bag of Words Approach (BoW)

The Probabilistic Latent Semantic Analysis (PLSA) (Fergus, n.d.) and the Dirichlet Allocation Latent Technique (Hofmann, 1999) used for text analysis were introduced in the visual domain methods (Blei & Jordan, 2003) (Fei-Fei & Perona, 2005) (Sivic, et al., 2005). In the code developed under Open CV there are implementations of PLSA, including all stages of pre-processing.

There are two possibilities to search for patterns that identify areas of high temperatures: use a loop that examines all the pixels in the images, or use a BoW approach.

By using a BoW approach it is possible to choose a pattern on one of the images of interest and search its repetition in the bank of images, obtained using an automated image capture.

The studied images, which can be currently obtained from the thermograph, are 350x330 pixels. However, the dimensions of the refractory areas which may be affected have a minimum length of 10 cm; as a result, image analysis should be based in affected regions of that size.

A disadvantage of using the BoW approach in Open CV is that coding is performed under MatLab®, whereas in the proposal free software is preferred.

### 3.2 Open CV Template Matching

The study of options for pattern analysis led to try other search alternatives. Under Open CV there is a Match Template function, with various methods of searching for similarities. The aim of these methods is to find a piece of specific image (Template Image) within an image source (Source Image). In the case of thermography images, this allows to determine the pattern of high temperatures, within the full image on the thermography of the oven.

The methods integrated into Open CV for searching patterns based on the Match Template function are:

```
method= CV_TM_SQDIFF
method=CV_TM_SQDIFF_NORMED
method=CV_TM_CCORR
method=CV_TM_CCORR_NORMED
method=CV_TM_CCOEFF
method=CV_TM_CCOEFF_NORMED
```

Each method is based on a mathematical formulation, which can be found in the documentation of Open CV (Open CV, n.d.), which allows formulating an algorithm for determining the most appropriate results, according to the characteristics of the desired images. In the case of thermography images, specific features such as its imprecise contours should be considered.

The tests were conducted on thermographic images obtained a day before a forced stop of the kiln, in a period of two years. Different methods of patterns search were used.

The methods implemented of the "matching" function, considered the template on the image search and tried to find the most similar. A disadvantage of using these methods in thermographic images is that hot spots showing the refractory wear may have different shapes. In spite of this, the necessary tests were carried out and obtained the following results: Figure 5 represents the source image, taken one day before a forced stop of the kiln. On the source image may be appreciated a small yellow area, which has been extended in Figure 6, and corresponds to the template image. This image symbolizes an area of high temperature on the wall of the oven.

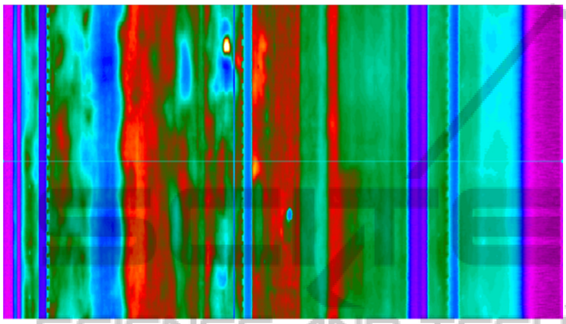

Figure 5: Source image.

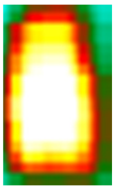

Figure 6: Template image.

After using the matching methods, the following results were obtained: Figure 7 corresponds to the result of applying the method CV_TM-SQDIFF, which provided a wrong pattern (upper left corner). None result were obtained by applying the method CV_TM_SQDIFF_NORMED, as it is illustrated in Figure 8. Figure 9 illustrates the wrong result from applying matching method CV_TM_CCORR, as seen in the upper left corner.

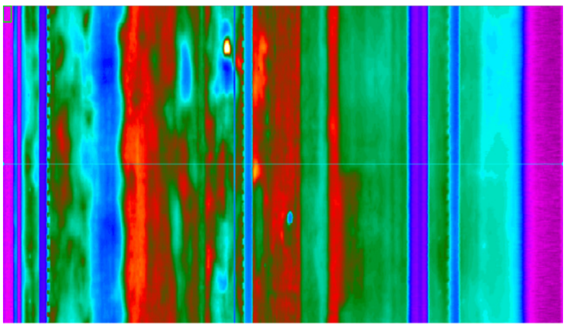

Figure 7: CV_TM-SQDIFF matching method result (upper left corner).

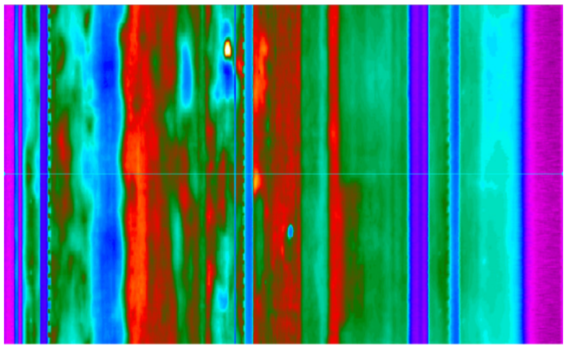

Figure 8: CV_TM_SQDIFF_NORMED matching method result (none pattern found).

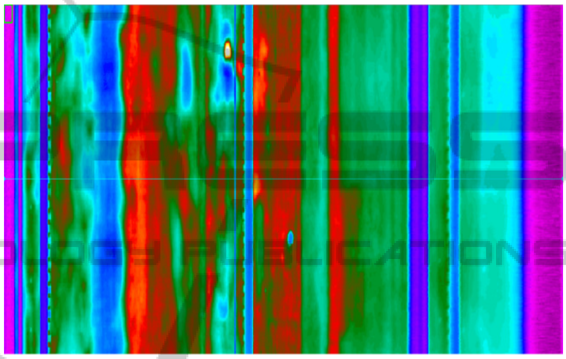

Figure 9: CV_TM_CCORR matching method result (upper left corner).

Figure 10 depicts a set of wrong results after using the matching method CV_TM_CCOEFF. Finally, the right pattern was found applying the matching method CV_TM_CCOEFF_NORMED, as it is presented in figure 11.

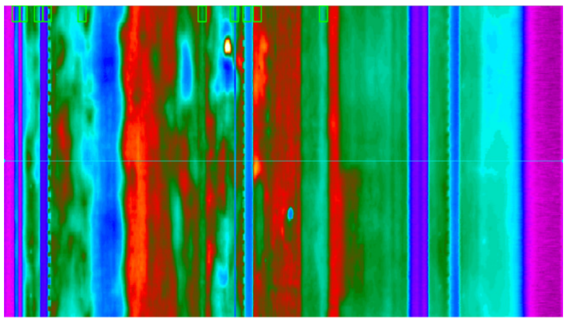

Figure 10: CV_TM_CCOEFF matching method result (a set of wrong patterns are found).

The previous results were checked with other sample data and allow to suggest that, given the particular characteristics of the thermographic images, the matching method CV_TM_CCOEFF_NORMED is the most appropriate to distinguish thermal patterns associated with high temperatures on the walls of the kiln.

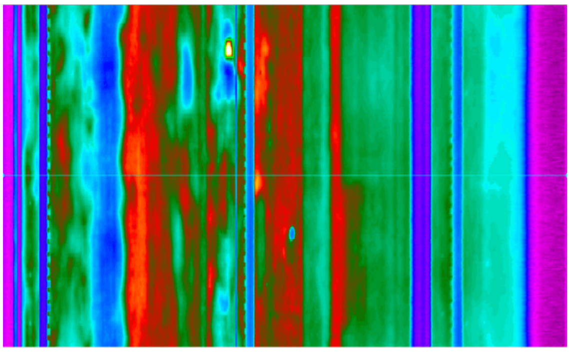

Figure 11: CV_TM_CCOEFF_NORMED matching method result (the right pattern is found).

## 4 ANALISING NATURAL LANGUAGE TO RELATE TO PATTERNS

While kiln operators have a log to describe operational conditions, manually every hour, it is required an analysis of this description to determine its suitability. Beyond that, log analysis is important to search for command patterns, taken by operators according to their criteria and personal expertise, to meet operational deviations. With this analysis it is possible to formulate decision rules, which were validated with elicitation sessions with operators.

This knowledge base and support from an artificial intelligence tool, allow determining which actions must be implemented based on conditions of the refractory, displayed on the thermography; for instance switch on a particular external air quencher fan or reduce the kiln angular velocity. Additional information to be used is the semi-automated historical analysis of the thermography. In order to infer from the log written in natural language, this work is testing MYCIN (Buchanan & Shortliffe, 1984).

## 5 VALIDATION OF RESULTS

To validate the information obtained under the Open CV application described in this article, a code was developed to extract information from the thermograph in an automated manner. The thermal information storage uses some "compression and encoding" techniques, especially to prevent the growth of the database in a disproportionate way. In the case studied here, the thermograph stores information in a hexadecimal format. Each hexadecimal data represents the temperature at a point on the kiln, longitude and latitude (x, y). To find the correlation between the stored value and the represented decimal value, a hexadecimal to decimal transformation algorithm, considering four cases of data compression, was designed. These cases allow saving space in the string that stores the thermography. Temperatures are expressed in degrees Celsius and to save space, normally the data is stored divided by 10. The algorithm varies with the used thermograph, but once decoded it was possible to connect various applications such as the one developed in this project. When the result of the transformation was obtained, it was possible to search for information directly and compare it with the images read by Open CV.

## 6 CONCLUSIONS

In this paper, empirical knowledge extraction from operators of a clinker kiln has been addressed, from computational perspectives. Firstly, a link to a set of thermal image readings was built, using a non-invasive approach in an industrial case of study. It has been possible to capture graphic information that has been processed and analyzed by a coupled system, without computational interference.

It has built an application to establish relationship between decisions made by operators and thermographic images, corresponding to the operating conditions under which these decisions are implemented.

The work has used images classification techniques based on a classification of texts approach. In particular, the BoW approach has been proved with satisfactory results.

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