Rhombodity Paper Summary

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The online Rhomboidity Measurement System employs sophisticated image acquisition & processing techniques to determine face contours of the billet with sub-pixel accuracy. The key features of RMS are the construction of a gaussian penalty function for selection of suitable 4-lines combination that precisely fits the billet face and use of a highly efficient and accurate statistical indicator, based on KL-Divergence measure, to estimate the rhomboidity even in presence of partial occlusion of billet face by scales.

Introduction:
The higher diagonal difference greatly impacts the quality of billets to be rolled at various mills. Rhomboidity at or over 4% leads to billet twisting in the roughing stands of the rolling mill.

- "Distortion measurement in casting", describes a contact type mechanism to determine the Rhomboidity. In the invention, the authors Kegham M. Markarian & Robert Sobolewski [3] propose to use pair of contact rollers supported by respective guide arms. The feedback about the respective positions and the separation between the rollers, Figure 1, is used to determine the Rhomboidity index.
- A related technique was proposed by Marcus Schmid & Adolf Fuchs [4], US4087918A, wherein the proposed apparatus for measuring the geometry of the hollow mold compartment of continuous casting molds comprised of a measuring head displaceable essentially in the direction of its lengthwise axis and having three impacts or contact elements,

Relevant Theory & Mathematical Prelimineries:
- The **Hough transform** was originally developed to recognize lines [5] and has later been generalized to cover arbitrary shapes [6, 7]. The advantage of the Hough transform is that the pixels lying on one line need not be contiguous. This can be very useful when trying to detect lines with short breaks in them due to noise, or when objects are partially occluded.
- A point in hough space represents a line.
- The algorithm for detecting straight lines can be divided into the following steps:
  1. Edge detection, e.g. using the Canny edge detector [8].
  2. Mapping of edge points to the Hough space and storage in an accumulator.
  3. Interpretation of the accumulator to yield lines of infinite length. The interpretation is done by thresholding and possibly other constraints.
  4. Conversion of infinite lines to finite lines.
- The Hough transform itself is performed in point 2, but it further requires finding peaks, corresponding to the lines in the image, in Hough accumulator matrix. While searching for 'true' peaks in that space several constraints are used to remove detection of very short lines, noise etc.
- **Kullback-Leibler divergence measure ?????** (Not clear)

System Description :
- Conventionally, Rhomboidity is defined as below: R= (d1-d2)/(d1+d2) x 100
  Where d1and d2 are the length of the opposite diagonals of a rhombus. Rhombodity at or over 4% leads to twisting of billets in downstream processing.
- Once billet rest signal is received, system captures the image of the billet face and further using Hough transform determines all the possible lines in image, say N. Exhaustive search is performed on all possible combination of 4 lines, IJK , to find its suitability for fitting an (almost) quadrilateral face. Gradual penalty function based on Gaussian distribution has been devised for this purpose and found to work extremely well under the given conditions.
- The penalty scores are based on various parameters determined by known geometry of the billets. For example, distance between parallel lines, angle between perpendicular lines, total area enclosed inside the 4-line combination etc. Once the fitting contour is obtained, it is further fine-tuned to define the true billet face boundaries and from there all the measurements including DD are obtained.
- statistical method where histogram shape of DD measurements of individual strands was taken into account and the abnormality index was calculated based on the shape difference of histogram of a strand with respect to shape of an ideal histogram.
- The ideal histogram shape is obtained by having measurements of the billets which are known to be free from any rhombic distortions. The KL-divergence method has been used for calculating the shape difference between histograms. This method induces 20 minutes delay in the decision process but is more than acceptable for all operational purposes.

Algorithm & Results:
The stepwise procedure adopted to determine billet rhombic index is as described below.
1. Image Acquisition & Billet Face Localization: ??? (not clear)
2. Edge Map & Lines Detection: Adaptive edge detection is needed to account for the variance in the brightness levels and hence the gradient values inside the image. We have used canny edge detector with varying threshold levels based on the illumination conditions to ensure reliable edge detection.Hough transform has been used to find lines in the image. It works on the edge map obtained by the adaptive canny edge detector. For noisy data, Hough transform is statistically superior than least square line fitting. t. Further, out of total number of detected lines, N, a set e was constructed that consists of all possible 4-line combinations.
3. Best Fit Quadrilateral Search:

- Here, we now introduce our Gaussian penalty function for giving scores to each 4-line combination according to their appropriateness for fitting the face contours of billet. From, each 4-line combination the following parameters are extracted,
  X= (l1, θ1, l2, θ2, l3, θ3, l4, θ4, A) where A represents the area enclosed.
- A multivariate Gaussian penalty function with following parameters is used to provide scores to all 4-line combination:

$$\begin{cases} \mu = (130,90,130,90,130,90,130,90,16900) \\ \Sigma = \begin{bmatrix} 1 & 0 & \dots & 0 \\ 0 & 1 & \dots & 0 \\ \vdots & \vdots & 1 & \vdots \\ 0 & 0 & \dots & 1 \end{bmatrix} \end{cases}$$

9×9 Identity Matrix

- Let x Type equation here. be a candidate for evaluation, putting its value in the following function with known mean (μ) and covariance matrix (∑) , the probability of that observation being generated from the Gaussian defined by above equation can be used as the score for the 4-line combination to best define the billet face.The scores thus obtained are normalized between (0,1) using below equation.

$$P(\bar{x}|\mu, \Sigma) = \frac{1}{\sqrt{2\pi|\Sigma|}} \exp(-\frac{1}{2}[\bar{x}-\mu]^T \Sigma^{-1}[\bar{x}-\mu]$$

Results :

- Based on the comparison of scores the best one is chosen.
- The Covariance matrix, ∑ although, for instance, describes a unit-variance, symmetrical Gaussian and penalizes deviation from μ equally for each direction, other implementations can use lesser θ variance. This will introduce less tolerance for variations in θ as compared to the face lengths values. Similarly, strict measures can be applied for the A(Area) variable to ensure the enclosed area tolerance remains in acceptable limits. These are design choices for implementation.

Conclusion & Way Forward:

Billet entanglement & burrs, residual molten steel lumps resulting from improper torch cutting, still pose challenge in accurately determining the Rhombic distortion index for some of the billets. Although, statistical methods like KL-divergence has been used to address such issues, however, the uses of stereoscopic imaging system can be investigated further to determine billet rhomboidity.