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Machine Vision Based Approach for Automated Keypad Inspection

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Abstract: Humans have been traditionally tasked with quality control because it requires judgment. Hence when it comes to manufacturing and quality inspection, Machine Vision plays an important role. However, for the best quality, parameters like lighting, changes in colour, curvature, alignment, required time for flaw detection are various challenging factors. Defects on flat products like keypad labels can be hard for human inspectors to spot easily, reliably due to their random occurrence. It is very hard to scrutinize keypads with a very high degree of detail and different colours within a small area. Hence for the inspection of flaws or even small defects in the keypad, an automated system is required which will select the correct, non-defective samples and reject the defective samples. While working with the images for detection of faulty regions, image subtraction is to be carried out. This is possible if two objects are partially aligned. Hence the need for image registration arises. The main aim of this paper is to register multi-temporal images for minimizing the misalignment of the objects and computation of high correlation factor by Hough Transform based Parameter Extraction (HTPE) and Image Registration using Multilevel Pyramids (IRMP). In the presence of non-uniform lighting conditions the accuracy achieved is 75%.

Keywords: ***Image Registration, Keypad Inspection, Machine Vision, Quality Inspection***

1. Introduction

Industrial automation has a significant impact on the growth rate and development of the concerned product. There has been a significant amount of automation in 70-80% of the shop floors of product based industries [1]. This has not only eased the processes but has also improved the quality and quantity of industrial products. One such industry that has been dealt within the paper is the printing industry where thousands of Human-Machine Interface (HMI) labels are printed every week. The process of printing is completed in three stages which consist of mainly - (a) setting up the print type (b) actual printing, and (c) post processing labels. The type of print differs due to many reasons like the material quality on which it is printed, printing technology, etc. The common problems faced by any printing industry include blotting of ink, print offsets, colour variability, texture variability (to some extent), and various other defects that are inadvertent.

The defects that are the cause of printing process take a lot of man-hour time to analyse and discard the defective samples. This hampers the efficiency of the production line and the throughput too. The use of a machine vision based system overcomes the above drawbacks and eases the process too.

An autonomous computer vision system has been implemented in the paper which robustly detects the defects that are present in the keypad labels/HMI labels. As this is an industrial problem, the proposed methods are task oriented. The different approach that we have introduced is the multilevel pyramid structure for image registration along with hough transform for keypad labels with very small regions. The basis of quality inspection is the process of Image Registration using which a sample keypad is taken and compared with a reference image of

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the same defect-free label. Then an image difference is taken and the segments in which flaws are evident are mapped out. The accuracy of this approach is around 90% for image registration and 75% for defect estimation. The paper is mainly classified into two sections, section I describes the process of Image Registration, and section II describes the process of segmentation and defect estimation.

2. LITERATURE SURVEY

The literature survey is divided into two parts: (a) For Image Registration problem (b) For segmentation and flaw detection. The papers and conference proceedings for Image Registration are discussed as follows:

G. Hong and Y. Zhang [1] used a combined methodology of area and feature based image registration. However, the application was for high resolution remote sensing. For extraction of features, Wavelet based techniques are used and coarse and fine control point pairs are used for area based matching. A combination of both of the mentioned techniques gives an acceptable image registration. The drawbacks of this method are the computation time for calculating the required threshold and for estimating the correspondences between the data sets. Vishnu Naresh Boddeti et. al. [2] used correlation filters for object alignment. The relevancy was low but the methodology was interesting as filtering techniques were used to obtain alignment of objects for a fixed pose of the same object. Local appearances of vehicles were tracked by training using Histogram of Gradients (HOG) feature even in the presence of noise and background clutter. The advantage is that the method has a low computation complexity and can detect landmarks at ease. The alignment accuracy was also quite high. However, our problem definition is more or less in a controlled environment and without external noise or clutters.

S. Richard [3] in his tutorial on image alignment and stitching focusses on various types of image registration like direct alignment (pixel based), feature based and global registration. In the feature based image alignment, David Lowes SIFT [4] (Scale Invariant Feature Transform) feature descriptors are used. We can even implement the same in our paper but the keypad labels are not scale invariant as the camera is at a fixed focus and the perspective is constant as well. Shams et. al. [5] paper is a good match to our problem definition and we have implemented most of the said registration steps using Hough Transform. But we have used Hough space to obtain the parameters of interest and register in spatial domain, not registered the image in Hough space.

Wei Chen [6] aligns tilt slices for 3D TEM Tomography using 2D Radon Transform. He has neither used fiducial markers nor the pixel information for registering purpose. 2D problem is reduced to 1D translation along two orthogonal axes. However, the algorithm is used for 3D reconstruction which is not what we want but we can try to implement image registration using Radon Transform as it might be an innovative approach as very few researchers have tried it including Wein Chen.

Christopher Paulson et. al. [7] have proposed a new approach to Wavelet based Image Registration to achieve a PSNR of 36.7 and RMSE below 4 which is used for remote sensing applications. The researchers use feature (Edges, Contours, Corners, etc.) based correspondences (Mutual Information, Cross correlation, Chamfer, etc.). They have used Daubechies Wavelets and feature correspondence using Template match is applied. This approach may be used as it resembles much of the problem definition and can be used to optimize the algorithm presented in the report.

Evangelidis and Psarakis [8] have proposed a very efficient alignment technique using Enhanced Correlation Coefficient (ECC) which is used in the project too. Using the reference image, a zero mean normalized vector is calculated and the same is calculated for the test image too. A Jacobian is calculated and perturbations are computed using the parameter vector. A threshold is set to terminate the process and the number of iterations is restricted as a measure to avoid infinite process just in case if the threshold value is never met.

Haiyong Chen et. al. [10] have proposed image alignment based feature matching algorithm for defect estimation. Forensic hash is generated for feature matching. As the keypad labels used in our experimentation have very small region structures, we have used multilevel pyramid approach for image registration.

N. Razmjooy et. al. [11] have proposed a real time mathematical method for potato inspection using machine vision. In the paper, images are kept in RGB colour space instead of converting into some other colour spaces like L*a*b* or HSV. The advantage is it uses a simple mean value of RGB as a descriptor for thresholding and segmenting the images. The defects are estimated by morphological operation and supervised classification.

E. Lughofer et. al. [12] focusses on online image classification by Machine Learning (ML) approach where the regions of interest are extracted from contrast image and feature vectors are extracted to train the machine. The accuracy of this method is quite high and can replace human vision and can overcome drawbacks of the same.

Che-Seung and B. Chung [13] have worked on real time fabric inspection by machine vision with low cost and high efficiency using a Charged Couple Device (CCD) camera. Various morphological operations are applied as well as median filtering before the same. This approach can be modified to some extent to suit our requirements in the work. However, for binary operations, the size of the structuring element hampers the performance of the algorithm which is a major cause of concern, and hence buffering of frames is required.

Hameed and Wang [14] have proposed a method to segment an object using edge detection using Histogram Equalization and multi-filtering process. The limitation of this process in our work is that many stray edges will get highlighted in case the keypad label is full of texture or contains substantial text content. In case of a Midco keypad label, this method of segmenting could be used but then again it is restricted to a specific keypad and cannot be generalized for a database.

Y. J. Cha, K. You and W. Choi[19] have taken images of loosened bolts using a smartphone camera. From those images, they have calculated the damage-sensitive features, such as the horizontal and vertical lengths of the bolt head, using the Hough transform. Finally, they have used support vector machines for classification.

Jian Lian et. al.[20] have presented Deep learning based approach which produces the flawless image and the corresponding exaggerated version of the defect. A Generative adversarial network (GAN) in conjunction with a convolutional neural network (CNN) is proposed to assure the accuracy of tiny surface defect detection. J. Liu[21] also used GAN to estimate the defect feature distribution on the defective image and generate defective blocks in case of fabric. Testing samples we have used in experimentation are small in number which will be insufficient for training the network. Deep learning approach can be used for defect classification that can be the future scope of our work.

3. METHODOLOGY

The paper uses two methodologies for the process of Image Registration: 1. Hough Transform based object perimeter extraction. 2. Image Registration based on multilevel pyramids. Two approaches are combined in the system because depending on the type of keypad label used, the approach varies. This is justified in the subsequent sections. The system is supported by a mechanical arrangement as shown in figure 1 which assists in the orientation and flow of the product line. Figure 2 shows the flow of the inspection process. The job/keypad type is initially selected by the user which prompts the user to load an image of a flawless keypad label which is used as a reference image for comparison with the test image. A sample keypad label without defects is shown in figure 3 while a defective sample is shown in figure 4. The images obtained undergo pre-processing stage if required. As industrial inspection standards are maintained during the process, pre-processing will be scarcely required. However, if the lighting intensity drops below a particular threshold an alarm is raised and pre-processing comes into the picture soon. This compensates for the brightness variability and ensures that the images have uniform grayscales throughout the process. The detailed operations will be discussed in consequent subsections.

Figure 1. Design of the inspection system

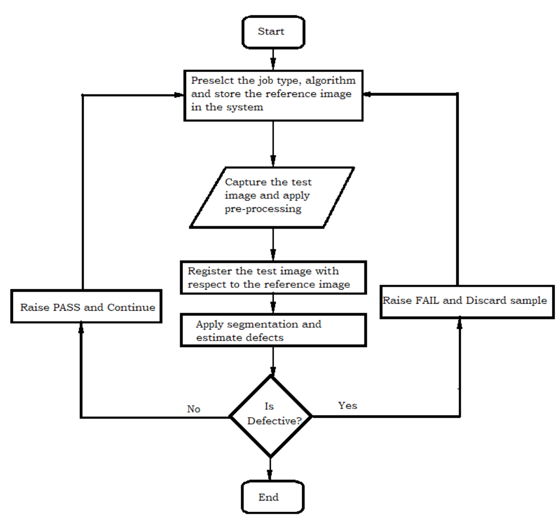

Figure 2. Proposed Methodology

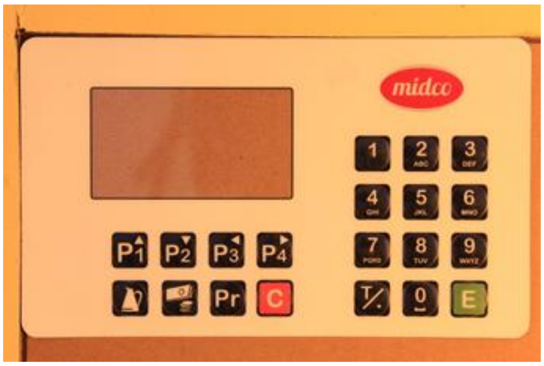

Figure 3. A sample keypad label without defects.

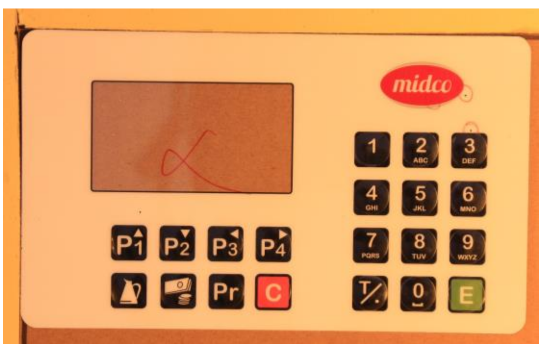

Figure 4. A defective keypad label

4. PRE-PROCESSING

Histogram Equalization is applied after image extraction using software based approach and exposure compensation is used in the optics to overcome the non-uniformity in grayscales. An ambient light sensor assisting the set-up is also proposed which senses the luminance and sends a signal to the system which decides the required level of pre-processing.

5. IMAGE REGISTRATION

Image registration is a process of geometrically aligning an image with respect to a fixed/reference image. The different types of image registration methods are multi temporal, mono modal and multi modal. The paper deals with a mono modal and multi temporal registration method which aligns the images captured from the same device at different time intervals. Many of the researchers have proposed various methods of image alignment using Hausdorff distance, Hough Transform, Multilevel image pyramids, Radon transform, etc. and used various metrics like mean squared error and mutual information. The image alignment is a measure of maximum or minimum of the metric value. In this paper, image registration is the base of quality inspection as the comparison of test image with the reference is carried out as an image difference to extract defective areas in the sample. Figure 5 shows the problem of misalignment in case of keypad labels. The paper emphasizes focus on a proposed method of image registration using Hough Transform and image registration using multilevel pyramids.

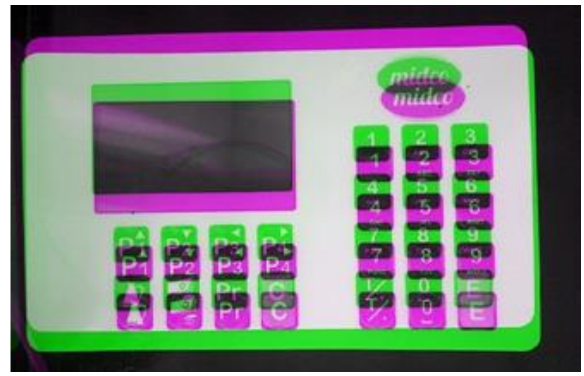

Figure 5. Misalignment between test and reference keypad labels

6. IMAGE REGISTRATION USING HOUGH TRANSFORM

Straight line Hough Transform is used to extract line segments of a keypad label that are predominant. This includes the perimeter of the label which can be used for boundary extraction. As Hough transform maps spatial lines to converging curves in parameter space (ρ, θ), this property is exploited to extract lines that belong to the range -2, 2 degrees (horizontal) and -88, 88 degrees (vertical). The range is predefined as a mechanical arrangement assisting the system will ensure the object is never out of the tolerable degrees of rotation. The steps are given as follows:

- The object to be tested is captured and straight line Hough Transform is applied using the equation below.

$$\rho = x \cos\theta + y \sin\theta \qquad (1)$$

- Let the equations of the four lines extracted be in the following form

$$y_{length} = mx_{length} + c_{length} \qquad (2)$$

$$y_{breadth} = mx_{breadth} + c_{breadth} \qquad (3)$$

where the coordinate (x, y) is the pixel location of the line, 'm' is the slope of the line at an angle θ and 'c' is the intercept corresponding to the keypad length and breadth respectively. The symbol 'm' for slope of the line is not changed in the equations but practically for length and breadth, the values will change.

- The object is extracted from the boundary and all the pixels/pad zeroes are blackout that are outside the object boundary. This ensures the proper alignment of the object and increases the accuracy of the system. This also ensures that the image dimensions remain uniform throughout the process.

- It is assumed that the above steps are applied to the reference image before the start of the process. In case this has not happened, a flag will be set reminding the user to process the reference image. This is an intuitive signal given on the Graphical User Interface.
- The test image is then rotated and translated exhaustively in the given intervals of theta and tx, ty. This affine transformation uses bicubic interpolation[15]. The metric used here is the mean squared error (MSE) and the minimum of the mean squared error will yield the translation and rotation matrix for Image Registration

$$MSE_k = \sum_{n=1}^{N}(I_{test} - I_{ref})^2 \quad (4)$$

In the above equation, k denotes the number of images which are obtained in the interval of 0.5^0. I_{test} is the test image while I_{ref} is the reference image.

- After aligning the test image with respect to the reference image, the keypad label is segmented in various regions depending on the properties they inherit. The detailed segmentation process is given in the next section.
- The segments are compared and estimated for defects that are present. The defects are estimated by auto thresholding the segments of the image. An image difference of the registered test image is taken.
- A blob analysis [16] helps to obtain the center of these defects in case they have a fixed geometry. Using the obtained coordinates, a hollow red circle is used to point the defect in the output image whose diameter is equal to the major axis length of the defect. This is for graphical representation only and is a part of the automated process.

The defects are decided based on a proposed parameter called the Mean Error Content (MEC). This is the normalized count of white pixels/black pixels (in case of inverted image) present in the various segments of the defect image. The result after extracting the object using Hough Transform is shown in figure 6. Results are satisfactory as small regions are also correctly extracted. But if the image has small regions with continuous variations or not fixed geometry, then hough transform may not give an accurate result. Such a case is shown in figure 7 where hough transform fails.

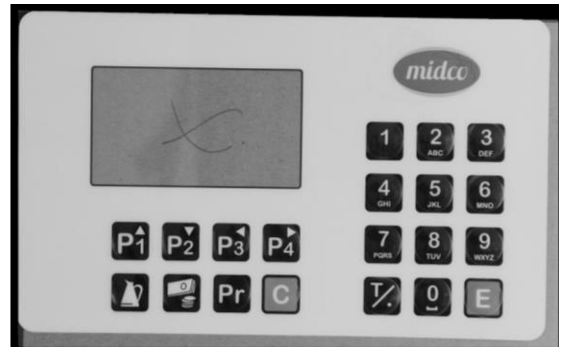

Figure 6. Result after extracting object using Hough Transform

Figure 7. A case where Hough Transform Fails

Multi-level pyramids is another popular method used for image registration. The disadvantage of using the Hough Transform based Image Registration is evident in cases of keypad labels which do not have a fixed shape/geometry and no straight lines exist along the perimeter. The method to be used for Image Registration is selected by the user from the GUI. This is the default method set for all inspection problems as it yields the results for keypads with fixed geometrical shapes too. However, the proposed Image Registration using Hough Transform works best for geometric labels. The detailed steps are given as follows:

1) Reference image is stored and the test image is captured from an imaging device.
2) A 3 level pyramidal decomposition of both the images is used and the test image is aligned with respect to the reference image using mean squares as the metric and steepest gradient descent as an optimizer [17].
3) Segmentation is done and thresholding based defect analysis is carried out similar to that of the method in the above section.

7. IMAGE REGISTRATION USING ENHANCED CORRELATION COEFFICIENT

The algorithm proposed by Evangelidis and Psarakis [8] is used because of its simplicity, robust alignment and computation time. The problem of brightness constancy [18] may not be encountered if an industrial grade inspection environment is set up. There is also an advantage of linearity and no nonlinear distortions are accounted for in the problem. The motion model is set as euclidean and the number of iterations is restricted to 500. The terminating value of ‘epsilon’ is set as 1E-7. The interpolation used in this method is bicubic interpolation whose pixel values are bounded by the size of the image and the grayscale range 0-255. In most cases, the termination is affected by the value of epsilon than the iteration count. The output obtained is a wap matrix of size 2x3 which is then used to align the images using an affine transform. The sample for which hough transform was unable to give accurate results, figure 8 shows good results with image registration using Enhanced Correlation Coefficient. Figure shows the result of subtraction process.

Figure. 8. Result of IR using Enhanced Correlation Coefficient

8. SEGMENTATION

After aligning the test image with respect to a flawless reference image, it is required that the keypad be divided into various segments to set various thresholds for the same. Fixing the thresholds is a crucial task as the segments will not have a fixed value of the threshold. After trying thresholding, it was noticed that there were certain regions that cannot be well segmented using Otsu thresholding technique. So it has been decided to segment the image based on the regions that are based on two parameters i.e. Brightness (3x3) and Roughness (3x3) parameters. The regions are sub-classified into 4 categories namely:

1) More bright, less rough.
2) Less bright, less rough.
3) More bright, more rough.
4) Less bright, less rough.

A. *BRIGHTENSS*

Brightness is the measure of reflected light from the surface of an object. In this case, a neighborhood of 3x3 is considered and the pixels are averaged, the average value is the brightness parameter at that point. The point of separation between the bright and the dark regions is fixed at a grayscale value of 170.

$$\alpha(x,y) = \frac{1}{9}\sum_{i,j=1}^{9}(I_{test} - I_{ref}) \quad (5)$$

where (i, j) is the spatial coordinates of the difference image $(I_{test} - I_{ref})$ while $\alpha(x, y)$ is the parameter of brightness of the image. I_{test} is the test image while I_{ref} is the reference image.

B. *ROUGHNESS*

Roughness is the measure of texture content in an image. This parameter is used along with the brightness parameter to segment out the corresponding patches of the keypad label. Equation no. 6 represents the roughness parameter for a 3x3 neighborhood of pixels. The point of separation of roughness parameter is set to 12.

$$\beta(x,y) = \max(I_{test} - I_{ref}) - \min(I_{test} - I_{ref}) \quad (6)$$

where $\beta(x, y)$ is the parameter of roughness measured at spatial location (x, y) and it is measured in a 3x3 neighborhood.

Using Gray Level Co-occurrence Matrix (GLCM), features like correlation, dissimilarity, energy, entropy were also calculated for measuring texture contents in the image. As there were no significant differences in the results using GLCM, we used only roughness and brightness for segmentation. The result of the segmentation process based on these parameters is shown in figure 9.

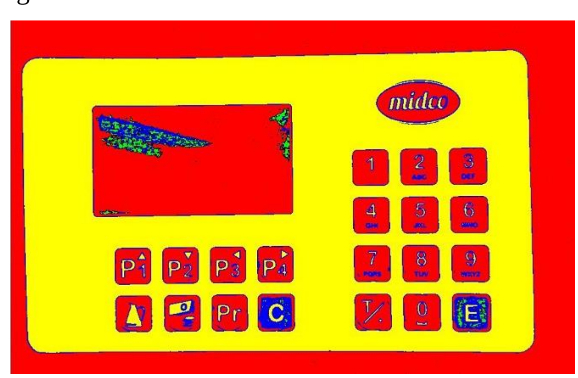

Figure 9. Result after applying Segmentation process

Based on the two abovementioned parameters, the process of segmentation produces an image classified into four main regions of interest namely:

1. Highly bright, low rough (yellow patch),
2. Dark, low rough (red patch),
3. Bright, moderate rough (blue patch)
4. Bright, highly rough (white patch)

9. DEFECT ESTIMATION

After segmenting the various parts of the keypad labels, the final stage in the inspection process is the estimation of the defects. This is achieved by taking an image difference of the reference image with the registered test image.

However, a major drawback with this approach is that after taking the image difference, there are certain portions like the boundary of the keypad buttons which are visible and do not suppressed completely. The result is shown in figure 10. It shows the result of image subtraction process for a false positive case.

Fig. 10. Extracted defective regions from the difference image

This can be avoided by re-subtracting the resultant image with a difference image of a non-defective sample and the reference image for registration. The resultant image after the re-subtraction process contains only the defects. After obtaining the defects, their corresponding spatial location is found out using numerical methods. The obtained coordinates are mapped in the defective keypad image. The defects which are large in size are grouped in one coordinate (preferably the central coordinate) and a single circle is drawn encircling the same. In the process, other false defects get highlighted too and can be avoided by ensuring industrial inspection standards during the testing process.

10. GRAPHICAL USER INTERFACE

The graphical user console provides the end user an interface required for testing the keypad labels. The user is asked to store the reference image for a particular job type i.e. the keypad label required for the process of Image Registration. User can select methods, metrics and optimizers for the inspection process. This is as shown in figure 11. The process can be then set to automated mode in which the mechanical arrangement synchronizes with the machine to load the test labels.

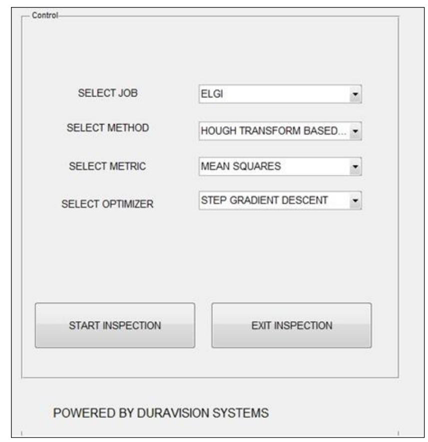

Fig. 11. An overview of the proposed Graphical User Interface

11. EXPERIMENTAL RESULTS

The Image Registration methods used in the paper align the test images to a good extent however every method has its own advantage and disadvantage. The method proposed using Hough Transform does not apply to keypad labels having irregular geometry, there is a loss of information when Multilevel Pyramids are used and there is a process of double subtraction that needs to be used to avoid false defect classification using Enhanced Correlation Coefficient. However, irrespective of the method used, the process of defect classification remains the same.

While 20 samples were tested, 5-6 pieces were wrongly classified, while 14-15 pieces were correctly classified. As the defects were too small to be classified, few defective pieces were PASSED. Hence the accuracy of defect estimation is about 70-75%.

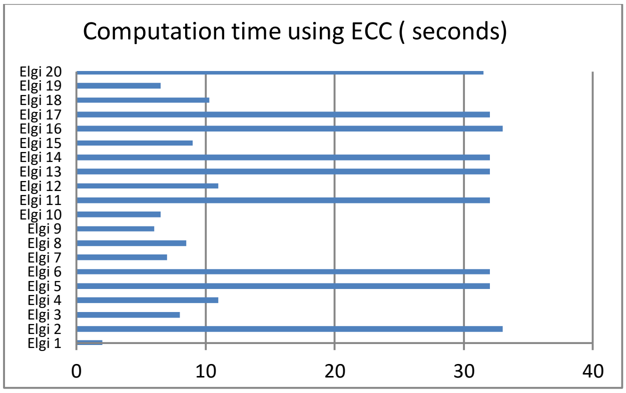

Figure 12. Computation Time for 'Elgi' dataset

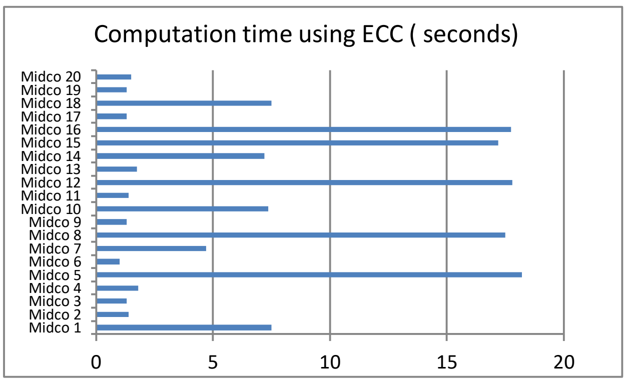

Figure 13. Computation Time for 'Midco' dataset

As seen in figures 12 and 13, the computation time in each of the images varies. This is because the alignment of each keypad label with respect to the reference image is not the same and the computation time is calculated on a computer that was utilized to some extent prior to the start of the process. The computation time will change depending on: 1. The misalignment of the test image with respect to the reference image. 2. The CPU utilization. 3. Specifications of the computer.

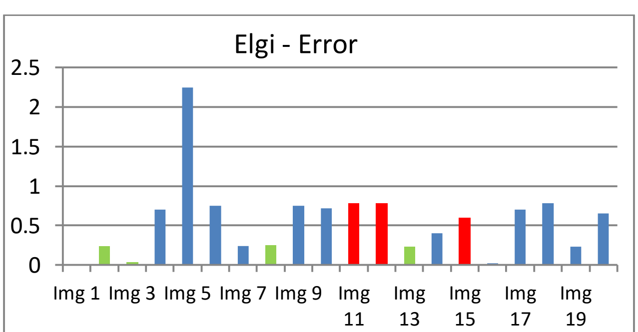

Figure 14. Error Content for 'Elgi' dataset

Figure 14 shows the error content of the Elgi keypad dataset of 20 images. When tested, the algorithm gave 70% accuracy with the threshold of Error Content as 0.25 and considering the grayscale defects, the accuracy is increased to 80%; overcoming the external conditions constraint and keeping lighting consistent, the accuracy is 85%. It is important to note that the computation time of inspection for each keypad varies depending on the misalignment that it has with respect to the reference.

Figure 15 shows the error content values for a 20 image Midco dataset. When tested for a threshold Error Content of 0.35, the algorithm gave 3 False Positives and 3 False Negatives with an overall accuracy of 70%. However, this accuracy is the worst case scenario especially for this dataset because the keypad label has undergone a post processing of the buttons which causes stray reflection from the buttons. This is removed with the help of an image mask (for masking the reflection).

Although the accuracy of experimentation is between 70% to 80%, it is acceptable for industrial process. Keypad inspection by an individual is a very time consuming process and also very minute defects on the keypad labels such as very small cracks, irregular surface, misaligned labels, etc. cannot be detected easily.

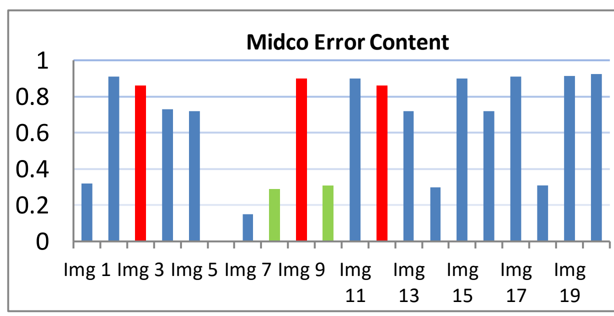

Figure 15. Error Content for 'Midco' dataset

However, the drawback of this method is that the error present in the buttons is not extracted at all. The error Content values marked in red color show false positives whereas the Error Content values marked in green color show false negatives in the figures.

12. IMPLEMENTATION CHALLENGES

The implementation challenges are classified into two parts like the paper i.e. Image Registration and Image Segmentation related challenges. The literature related to Image Registration was quite helpful in getting the knowledge of how Image Registration works but in the practical implementation of the same, various factors needed to be considered like the computation time of defect in real time, Image noise, and dependency on a single metric. While it was quite a task to reduce the computation time, the availability of a high end computer with a fast processor made it possible to reduce the time from minutes to seconds for each keypad label. The error metric used was mean squares error, however, for a noisy image, the registration result obtained was false and the defect estimation failed miserably as the core process of Image Registration had failed. In noisy conditions, the error metric should be changed (ex. Mutual Information, ECC, etc.). Sometimes, using Hough Transform based Image Registration, the perimeter of the object cannot be detected properly, and this may happen due to lighting inconsistency or the object falls out of the region of interest. Hough transform also fails in cases where there are many lines inside the object, in such instances, different registration method is used based on Image Pyramids or Image Registration based on Enhanced Correlation Coefficient (ECC). The distortions in the camera are removed in the initial stages however, an inspection of the imaging systems is often required to prevent the dimensional changes of the object during acquisition. If this is not ensured, the process of Image Registration may get hampered.

Image Segmentation was based on brightness and roughness parameters but the parameters failed to segment the object in presence of noise and inconsistent lighting conditions. Though the robustness has been tested in a rugged and inconsistent environment, this will not happen in practice as industry standards of inspection environment are maintained unless otherwise, a breakdown of the system has occurred. The threshold varies for every segment and every object under test. This has to be set before the inspection process by the end user. The value is set only after trials of various samples.

13. CONCLUSION AND FUTURE WORK

The paper focuses on a proposed method that could be used for image registration and in turn be used for inspecting objects using machine vision. However, the accuracy can be improved much further by using quarter pixel estimation and bicubic interpolation technique. This may cause a time overhead for the inspection process and could be avoided by using a powerful machine processor but this may again increase the cost of the product. The paper fails to classify the defects as defect classification requires a large database. Future work in the classification of defects can give rise to detailed statistical analysis of a production line's quality control data. Regional CNN's can be used for defect detection and classification.

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