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Reduction of reflection and defect detection for metallic jobs using Superresolution Method on Hardware platform

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Abstract:
The quantitative inspection of metallic jobs is very crucial in manufacturing industries as not only the conventional approach of inspection can't achieve true outcome but the reflection of light from the metallic jobs also create the hurdles for proper inspection of defects in metallic jobs. Hence in this paper the automatic inspection with the help of image processing have been proposed for better inspection. The hardware friendly Raspberry Pi development board has been utilized for the automation using superresolution (SR) technique. The prototype implementation of SR method that achieves reflection reduction and detection of defects in the metallic jobs independently is implemented. The outer and inner defects of metallic jobs have identified along with reflection reduction. The prototype is implemented for this purpose with the help of image processing superresolution algorithm using DICWF filter bank wavelet transform to obtain superresolution reconstruction on real time Raspberri Pi development board. The coefficients of DICWF are dyadic and integer in nature that can be easily implemented on real time processor. Performance of the proposed real time system using DICWF for superresolution reconstruction has been evaluated based on subjective and objective results.

Keywords: Image superresolution, dyadic integer coefficient based wavelet filter, reflection detection and reduction, outer and inner defect detection, Raspberri Pi development board.

1 Introduction

In manufacturing industries proper inspection of metal jobs plays very crucial role to decide the quality of product. The traditional visual inspection of metal jobs by human being is time consuming and cumbersome process and it depends upon knowledge as well as patience of the job inspector. Therefore manual process becomes inconsistent and inaccurate which may cause errors during inspection. The defects of metal jobs such as pin-hole, cracks, weld point, coater drip and scratches cannot detected due to limitations of human inspection and involves errors. This leads to huge burden to industry in terms of cost. Hence many industries have been switching towards automatic inspection with the help of image processing for better inspection. The automatic inspection detects the problems arising in the previous stage of manufacturing process and can be corrected in the further stage of manufacturing. Many a time automatic inspection of defect detection in case of metal jobs is affected by the reflection. In the automatic inspection of metal jobs the reflection of light on metal jobs creates difficulty during image processing operations such as feature extraction, segmentation of image and template matching and it also adds the complexity to detect defects. Highly reflective metals like aluminum, gold, copper and silver having high reflection coefficient are often used in many industries like automobile industries, domestic electronics, communication and construction. These metals should have good surface quality otherwise the quality of final product gets directly affected. Defect detection process becomes tedious in case of such highly reflective metals because the light gets reflected from circular and straight edges that lead to add complexity in the defects detection process. Thus in this paper we have focused on prototype implementation of SR method that achieves reflection reduction and detection of defects in the metallic jobs independently. Various defects are present outside as well as inside the metal jobs. The detection of inner defects of rolled strips or rolled metal jobs caused due to drilling is very tedious. In this paper we have made an attempt to detect such types of inner defects along with reflection reduction that helps in identifying the defects easily. For this purpose we have implemented a prototype for an image processing superresolution algorithm using DICWF filter bank wavelet transform to obtain superresolution reconstruction on real time Raspberri Pi development board. The coefficients of DICWF are dyadic and integer in nature that can be easily implemented on real time processor. Performance of the proposed real time system using DICWF for superresolution reconstruction has been evaluated based on subjective and objective results.

Almeida *et al* [1] has proposed method to reduce reflection which is present in color image. Reflection identification has been achieved through two methods like thresholding and marking different portions. In thresholding, pixels having luminosity i.e. average RGB component values more than 250 are taken as reflections. In NICE-I images small and large white zones are present. Hence, there is a need of second method. It is used to mark portions which are white as well as very small which represents the reflection. Then each reflected pixel gets replaced with average value of neighboring darker half of the pixels. These pixels are situated in restricted circle around the reflected pixel. Original information covered by reflections cannot be recovered by this method. Farihan *et al* [2] has proposed LIPSVM (Line Intensity Profile and a Support Vector Machine) method. In this method, blue and green intensities are subtracted from higher intensity value i.e. 255. Pixel is said to be reflected if green and blue pixel intensities are less than red intensity of it. SVM is used for reflection classification. Afterwards, training and testing are performed. Reflected pixels are denoted by '1' while non-reflected pixels are given by '-1'. Every reflected pixel is replaced by four nearby neighbors from non-reflected area. Farmanullah *et al* [3] have proposed a method in which image is first converted into grey scale image. Then upper and lower grey level limits are found out. Threshold is calculated as T = (upper limit- lower limit-10). If grey value is less than T then pixel value is set to 1 otherwise set to zero to form binary image. Then complement of binary image is taken to get reflections as white spots. Experimentally it is observed that area of white dots related to reflections is less than 80 pixels. Each pixel in reflected area is replaced by lower grey level value. Boundary artifacts are reduced by applying median filtering on image after reflection reduction.

Sankowski *et al* [4] has proposed a method in which locations of reflections are detected first using reflections localization which gets followed by reflection filling in to remove the reflections. For reflection localization, grey scale image is obtained based on the luminance in-phase quadrature (YIQ) model in which threshold is calculated using maximum intensity in the image and average intensity of the image. Afterwards, localized reflections are filled using four neighboring non reflected pixels in the RGB image. Tieniu *et al* [5] have proposed method to remove specular reflections which act as brightest point in image of iris. In this method, binary reflection map is calculated using adaptive threshold.

Bilinear interpolation technique is used to fill the reflections. Xiaomin *et al* [6] found that difference between detail subbands and approximated subbands after interpolation. The interpolation of approximation subbands of the HR image does deviate with respect to original subbands while in detail subbands makes difference after interpolation. Based on this principle an algorithm has been proposed by author to learn four coupled principal component analysis (PCA) dictionaries to describe the relationship between the approximation subband and the detail subbands. It is observed that an algorithm based on PCA can be easily implemented.

Zhang *et al* [7] has applied L0 image smoothing method to a given low resolution image to obtain its low resolution smoothing image which preserved sharp edges. Besides, a low resolution error image was obtained by the difference between the low resolution image and the low resolution smoothing image. Shao Shuo *et al* [8] propose a multiframe superresolution reconstruction based on self-learning methods. First, multiple images of the same scene are selected to be both input and training images, and larger-scale images, which are also involved in the training set, are constructed from the learning dictionary. Chopade *et al* [9] proposed superresolution technique in which dyadic integer coefficients based wavelet filter bank is designed. The proposed technique has integer and rational coefficients. It makes hardware implementation for proposed technique easy as computational complexity is low. Don *et al* [10] establish the relation of reflective power and normal power of metal surface using surface scattering model. The profile of metal surface is computed using feature extraction and classification from the normal metal surface. Different classifiers are used to classified reflective metal and normal metal. Szydzik *et al* [11] presented high quality implementation of efficient superresolution on core FPGA processor. To maintain high quality they have used state-of-the-art software for implementation of superresolution technique. Bowen *et al* [12] implemented iterative back projection algorithm for superresolution on FPGA device. The sub pixel shifts method is utilized to put additional details of low resolution images caused by warping. Barreto *et al* [13] claimed in their research that their technique is able to produce one superresolved picture elements per cycle. In the architecture, 10 iterations are used to get superresolved image on FPGA device having operating frequency 58 MHz.

Angelopoalon *et al* [14] used development board having FPGA device for implementation of IBP algorithm for superresolution. This implementation gives 25 VGA 2x superresolved images at frequency 80 MHz. Goto *et al* [15] proposes superresolution method for regularization of total variation in television based on learning based approach. This method is implemented on multi-core processor. Numbers of option for surface inspection of available commercial products has been detailed out in [16]. These surface inspections are based on edge detection, profile analysis using multi resolution approach. Different types of defects and their causes have been identified in [17] by which solutions can be provided using different approach. In manufacturing industries, defect types as scratch, rust mark, emulsion mark, cracks and so on are always there. Cordelli *et al* [18] presented image resolution using inversion procedure of defects in metals using multi frequency eddy-current approach. The discrete geometric approach is used to find solution for forward problem of eddy current system.

In this paper detail explanation of prototype implementation of DICWF SR reconstruction on real time Raspberry Pi processor along with its application for reflection reduction and defects detection is presented. Section 2 presents a detailed description of the proposed method for reflection reduction and defects detection using superresolution along with various steps involved and its underlying principle along with algorithms. Section 3 deals with the results and discussions of the proposed system for reflection reduction and defects detection using superresolution reconstruction followed by conclusions in Section 4.

2 Prototype of the Proposed System using Real Time Raspberry Pi

The block diagram of prototype implementation of proposed system for reflection reduction and defects detection using DICWF algorithm is as shown in Figure 1. The proposed system consists of Pi camera, small board computer (raspberry Pi development board) and display device. The Pi camera having resolution 640×480 with aspect ratio 4:3 is used to capture the image of the metallic jobs. Since the resolution of Pi camera is comparatively less it results into low resolution image of the metallic jobs. These low resolution images of metallic jobs are further superresolved to obtain high resolution images. The superresolution reconstruction algorithm using DICWF is implemented on Raspberry Pi development board which is interface with the Pi camera. The hardware of Raspberry Pi includes various modules such as processor/core, memory, input output peripherals and networking module. It has ARM1176JZF-S 700 MHz processor and RAM of 512 MB and supports to HDMI and analogue output. It interfaces most notably RS-485/232 serial ports, digital and analog inputs/outputs, CAN and USB devices which are widely used in manufacturing and automation industries. In the proposed system CRT is used as display device.

The experimentation is carried out on prototype of the proposed system for nearly 100 metal jobs which have reflection and defects. The experimental setup of proposed system using Raspberry Pi is depicted in Figure 2.

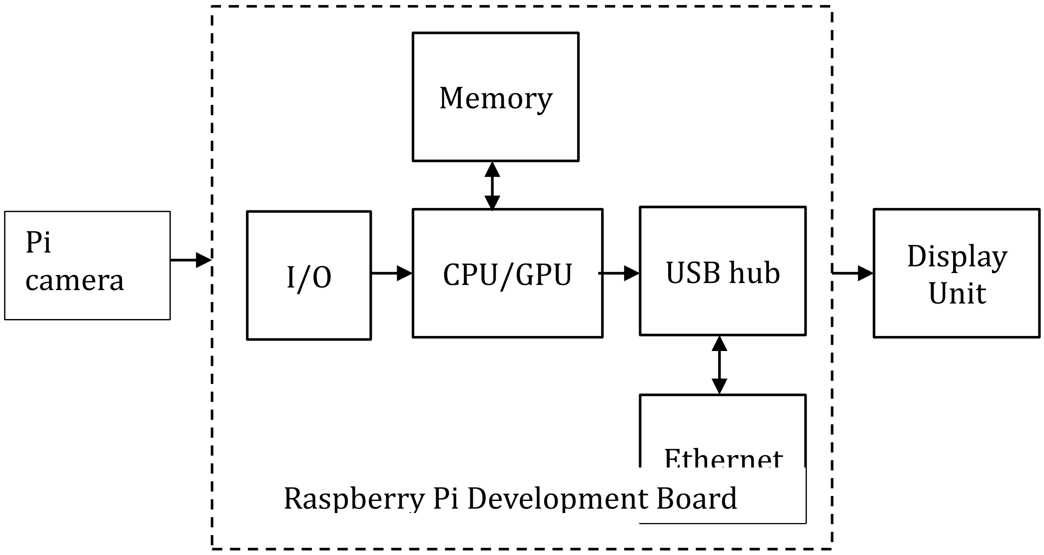


Figure 1 Block diagram of prototype implemented system on real time Raspberry Pi development board.

Figure 2 Experimental set up of prototype implemented system on real time Raspberry Pi development board.

This experimental setup has been used to carry out experimentation to reduce the reflection and to detect defects of metallic jobs. The various image processing operations such as image enhancement using superresolution reconstruction (DICWF), feature extraction (Blob analysis) and thresholding are used to implement proposed algorithm for reflection reduction and defects detection of metal jobs.

2.1 Reflection Reduction

The block diagram for reflection reduction using DICWF superresolution reconstruction is as shown in Figure 3. The images of steel material metal jobs are captured with help of Pi camera which is mounted on Raspberri development board. The reflection coefficient of steel material is high; therefore it reflects more light from its surface. As the resolution of Pi camera is low that results into low resolution images of the metal jobs. These low resolution images of metal jobs are further enhanced with superresolution technique using DICWF filter bank. The design of DICWF filter bank and its implementation for superresolution reconstruction is explained in detail in Chopade *et. al*. [9].

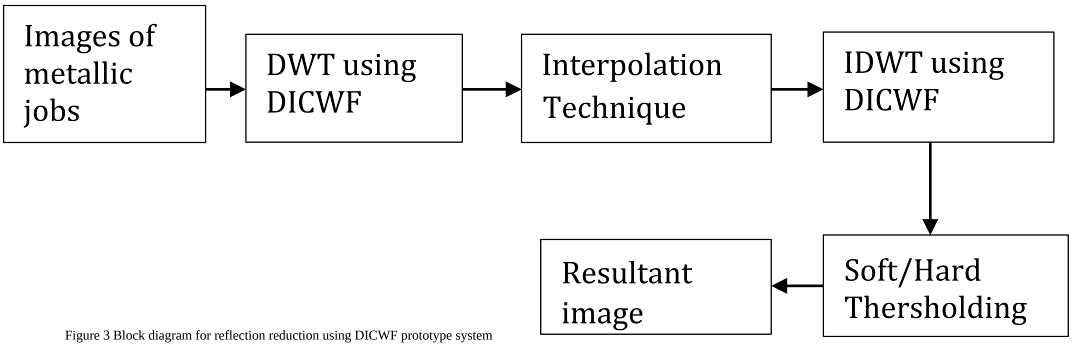


Figure 3 Block diagram for reflection reduction using DICWF prototype system

The low resolution image is decomposed at the first level by DWT using DICWF filter bank. As a result three detail subbands (LH, HL, and HH) and one approximation subband (LL) are obtained. The three detail subbands are interpolated by factor of *two* to obtain the high-resolution image. The superresolved image has been reconstructed with the help of these interpolated subbands and low resolved input image. Here we have used different interpolation methods such as linear, cubic and nearest to interpolate subbands for the enhancement of superresolved image. However it is seen that subjective quality of the superresolved image with these interpolation methods comparatively remains the same.

The superresolved image of metallic jobs contains light reflection portion which indicates highest intensity of the pixels. Therefore the reflection portion within the image is identified using intensity value of the pixels. For this experimentation purpose the threshold as 200 (empirically) have been used, so that the pixels having intensity less than 200 (8-bit grey scale image) are classified as non-reflected pixels whereas pixels having intensity greater than 200 are classified as reflected pixels. Further reflective portion of resultant superresolved image is reduced by filling pixels of reflective portions from the pixels of non-reflective portions. This may result as patches that are removed by using hard and/or soft thresholding in order to smooth the resultant image.

Hard thresholding represents ‘keep or kill’ operation. If threshold value is T then all pixel values less than threshold value T are made zero. Pixel values above threshold T are not altered. There are chances of information loss in hard thresholding. The following formula is used for hard thresholding.

$$A(I,T)=\begin{cases} I & \text{for all} |I| > T \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

where,

I is pixel intensity value, and

T is Threshold value.

Soft thresholding is an operation where threshold value is flexible with respect to pixel value of image. The following formula is used for soft thresholding.

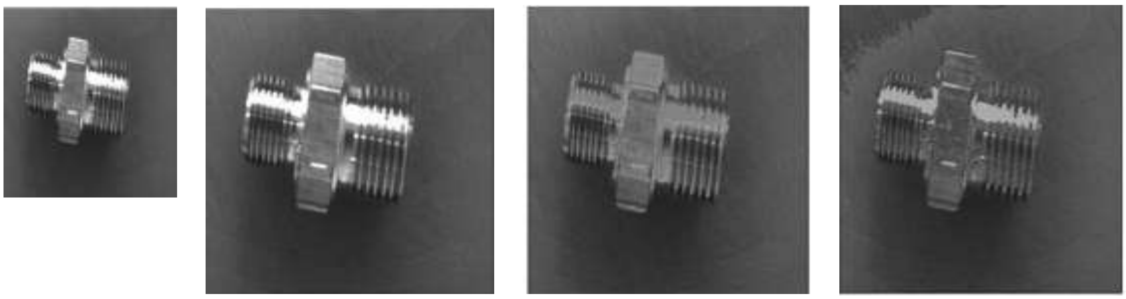
$$A(I,T) = \text{sgn}(I)......\max(0,|I|-T) \quad (2)$$

where,

I is pixel intensity value, and

T is Threshold value.

Soft thresholding overcomes the drawback of hard thresholding. In soft thresholding, if the threshold value is T then all pixel values above threshold T are shrink by value T instead of making them zero. The intermediate resultant images after every step of reducing reflection for 'metal object-17' are depicted in Figure 4. The low resolved image of steel material metal job 'metal object-17' captured with Pi camera is as shown in Figure 4 (a). The captured low resolved image does not provide sufficient details hence it is enhanced with help of superresolution technique using DICWF as shown in Figure 4 (b). The resultant images after the application of hard and soft thresholding are shown in Figure 4 (c) and Figure 4 (d) respectively.



(a) (b) (c) (d)

Figure 4 Subjective results of reflection reduction with prototype system using Raspberry Pi development board: (a) Captured image of 'metal object-17' including reflection, (b)Superresolved image using DICWF (c) Hard Thresholding applied on superresolved image (d) Soft Thresholding applied on superresolved image.

Various steps involved in the algorithm of proposed superresolution technique based on DICWF for reflection reduction using Raspberry Pi processor are as follows:

*Step*1: Capture the image of reflective metal job.
Step 2: Apply Direct Wavelet Transform (DWT) using DICWF on captured image.
Step 3: Interpolate different subbands with interpolation techniques like cubic, linear, nearest.
Step 4: Apply Inverse Direct Wavelet Transform (IDWT).
Step 5: Get superresolved image.
Step 6: Transfer pixels from non-reflected region to reflected region.
Step 7: Apply hard and soft thresholding.

2.2 Defects Detection

The block diagram for defects detection using DICWF superresolution reconstruction is as shown in Figure 5. The images of defective metal jobs are captured with help of Pi camera which is mounted on

Raspberri development board. As the resolution of Pi camera is low that results into low resolution images of the metal jobs. These low resolution images of metal jobs are further enhanced with superresolution technique using DICWF filter bank in order to obtain superresolved image. In order to extracts the structural information from this superresolved image of the metal job, we have used Canny edge filter having less processing time. After detecting the edges Blob analysis is used to detect inner and outer side defects in the resultant image of Canny edge detection. Blob analysis uses certain spatial characteristics to eliminate the unwanted blobs that are the no interest regions and keeps only the relevant blobs that indicate the defected portion of the metallic job. Here, blob analysis is used to detect defects. So only blobs showing the defects are kept and other blobs are removed by setting limitations on the relative features in the algorithm. The intermediate resultant images after every step of detecting defects for 'metal object-65' are depicted in Figure 6.

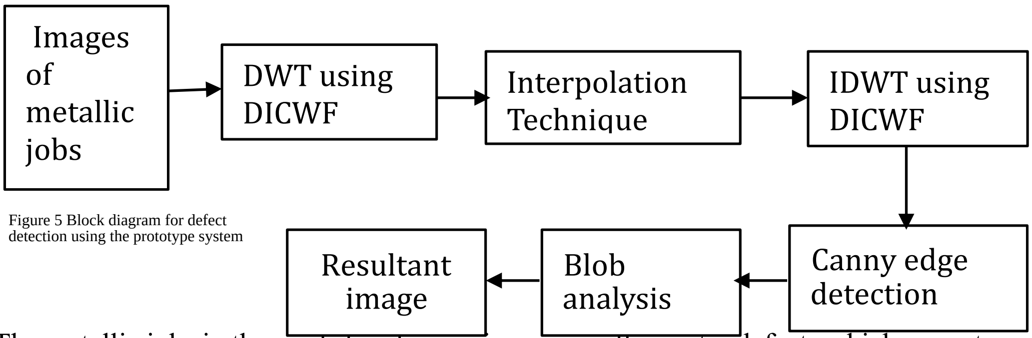
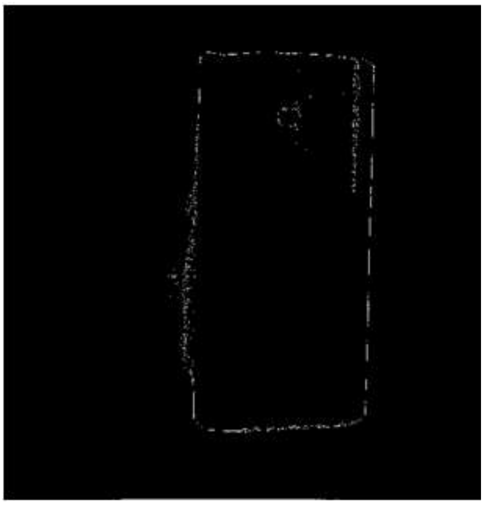


Figure 5 Block diagram for defect detection using the prototype system

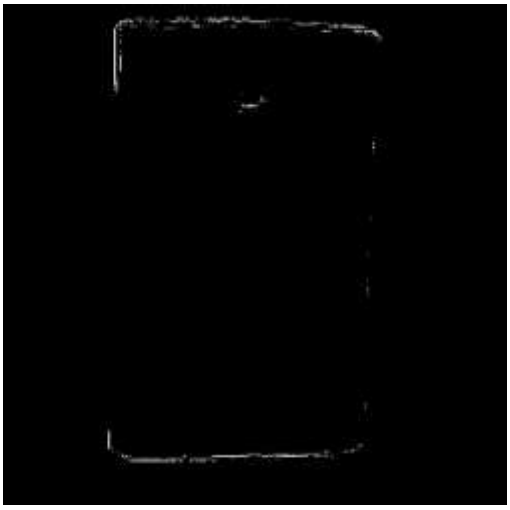
The metallic jobs in the workshop having inner as well as outer defects which cannot see naked eye has been used to identify the defects using our developed prototype system. Figure 6 (a) depicts the low resolution image of 'metal job-65' captured by the Pi camera mounted on the development board and used for further experimentation. The quality of the captured image does not provide sufficient details of defects. The resolution of this captured image is enhanced by superresolution technique using DICWF which increases the details of the defects within the captured image as shown in Figure 6 (b). The canny edge detection is applied to the superresolved image. The results of canny edge detection are shown in Figure 6 (c). It is observed that the boundaries and edges appear prominent in the resultant image. Further blob analysis is performed on resultant image to detect inner defect of metal job. The results of bob analysis are depicted in Figure 6 (d). The result of blob analysis shows white marks near the inner defects.

(a)

(b)



(c)



(d)

Figure 6 Subjective results of defect detection: (a) Captured image of ‘metal job-65’ (b) Super resolved image (c) Result of Canny edge detection (d) Inner-side defects detected by blob analysis.

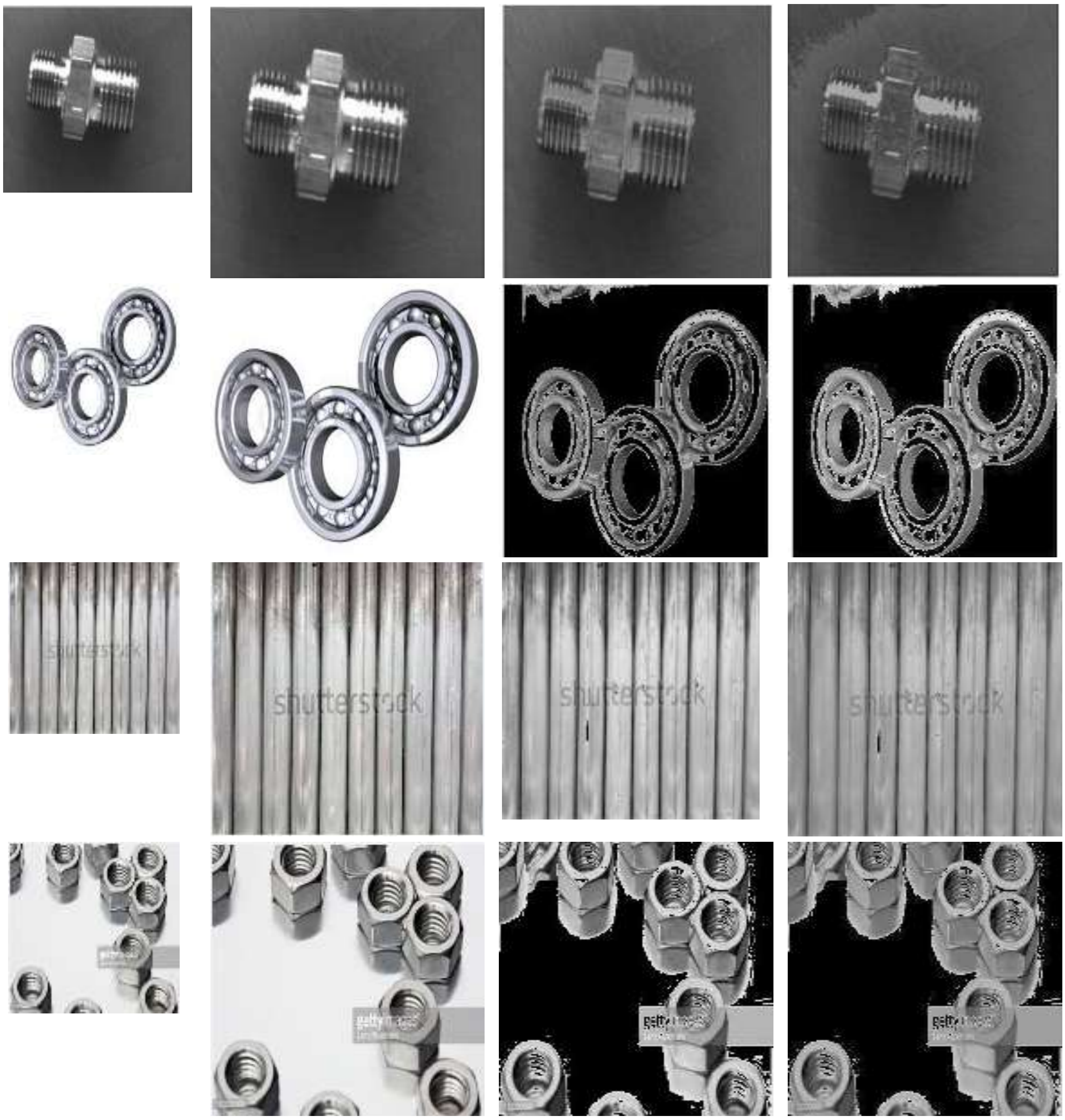
Various steps involved in the algorithm of proposed superresolution technique based on DICWF for defects detection using Raspberry Pi processor are as follows:
*Step*1: Capture the image of defective metal job.
Step 2: Apply Direct Wavelet Transform (DWT) using DICWF on captured image.
Step 3: Interpolate different subbands by factor *two.*
Step 4: Apply Inverse Direct Wavelet Transform (IDWT).
Step 5: Obtain the superresolved image.
Step 6: Apply Canny edge filter.
Step 7: Identify the defects using blob analysis.

3 Results and Discussions

The proposed prototype system has been developed using real time Raspberry Pi development board for reflection reduction and detection of defects. The algorithms based on superresolution reconstruction using DICWF have been implemented on ARM1176JZF-S 700 MHz processor with 512 MB RAM. The proposed system has been tested on 75 metallic jobs having reflection and 100 metallic jobs having defects. Performance of the implemented prototype system is measured in terms of subjective and objective parameters such as PSNR and RMSE. To understand the working of the proposed system, the resultant images during various operations of image processing have been illustrated and discussed in this Section. The proposed system for reflection reduction involves different operations of image processing such as image enhancement with superresolution reconstruction and thresholding.

The subjective results of various operations of proposed system are shown in Figure 7. The images of various metal jobs having steel material are captured with Pi camera. These images are low resolved image due to limitation of Pi camera is shown in Figure 7 (a). The captured images do not provide sufficient details hence it is enhanced with help of superresolution technique using DICWF. The output resultant images of superresolution are shown in Figure 7 (b). The hard and soft thersholding is applied to smooth the resultant image. The resultant images after the application of hard and soft thresholding are shown in Figure 7 (c) and Figure 7 (d) respectively. It is observed that captured images have more reflection while resultant images after processing have less reflection. It is also observed that reflection of metal has been reduced to a greater extent using hard thresholding method as compared to soft thersholding.

The objective results are further computed for the resultant images after application of soft and hard thresholding of the proposed system on 75 different metallic jobs. While computing objective results different interpolation techniques (linear, nearest and cubic) which is part of superresolution reconstruction has been applied. The objective results are shown in Table 1 and Table 2. It is observed that an objective result of cubic interpolation technique is better than other two techniques for both types of thresholding.



(a) (b) (c) (d)

Figure 7 Subjective results of refection reduction with Raspberry Pi: (a) Captured images with Reflection, (b) Superresolved images (c) Hard Thresholding applied on images (d) Soft Thresholding applied on images

Table 1 RMSE of the proposed system for different test images using various interpolation techniques with hard and soft thresholding.

Images /Techniques	Linear		Nearest		Cubic	
	Soft Thresholding	Hard Thresholding	Soft Thresholding	Hard Thresholding	Soft Thresholding	Hard Thresholding
Metal job 1	28.78	28.64	29.13	29.05	29.94	29.64
Metal job 7	27.56	27.03	28.01	27.99	28.79	28.15
Metal job11	28.15	27.78	28.56	28.32	28.97	28.66
Metal job 17	26.27	26.13	27.12	26.99	27.87	27.17
Metal job 27	27.12	27.06	27.46	27.35	28.01	27.90
Metal job38	28.16	28.04	28.45	28.23	28.73	28.47
Metal job 47	26.26	25.99	27.13	26.89	27.97	27.32
Metal job55	27.29	27.11	27.88	27.48	28.96	27.89
Metal job 69	25.24	25.01	25.89	25.78	26.12	26.02
Metal job 75	28.67	28.36	28.96	28.84	29.12	28.98

Table 2 PSNR of the proposed system for different test images using various interpolation techniques with hard and soft thresholding.

Images /Techniques	Linear		Nearest		Cubic	
	Soft Thresholding	Hard Thresholding	Soft Thresholding	Hard Thresholding	Soft Thresholding	Hard Thresholding

Metal job 1	18.16	18.19	18.24	18.26	18.67	18.69
Metal job 7	17.99	18.01	18.12	18.24	18.26	18.35
Metal job11	18.78	18.86	18.86	18.97	18.76	18.79
Metal job 17	17.12	17.32	17.35	17.46	17.56	17.77
Metal job 27	17.17	17.91	18.12	18.54	18.46	18.85
Metal job38	18.28	18.26	18.61	18.71	18.77	18.79
Metal job 47	17.27	17.52	17.55	17.86	17.46	17.77
Metal job55	17.27	17.51	18.02	18.24	18.36	18.45
Metal job 69	16.89	16.99	17.01	17.12	17.25	17.34
Metal job 75	18.26	18.29	18.24	18.29	18.77	18.88

Further experimentation is performed for the detection of inner and outer defects of the metal jobs. For this experimentation 100 metal jobs have been tested. The process of defects detection using the proposed system is illustrated and explained using sample 'metal job-65' in Figure 6. After carrying the experimentation on the 100 metal jobs containing defects, it is observed that proposed system works well for detection of defects. It is seen that the proposed system has detected defective portion of the metal jobs properly and accurately.

4 Conclusions

A prototype system of superresolution reconstruction using DICWF is implemented on real time Raspberry Pi development board for reflection reduction and defects detection. DICWF filter bank of superresolution technique has integer and dyadic coefficients hence it is easily implemented on Raspberri Pi development board and used for real time applications. It is observed that reflection of metallic jobs has been reduced substantially using proposed system. Soft thresholding provides smooth reduction of reflection from metal jobs. The linear, cubic and nearest interpolation techniques are used in DICWF technique to obtain high resolution image. The proposed system also works very well to detect defects of metallic jobs. The blob analysis facilitates to detect inner defects of rolled metal jobs. The proposed algorithms work efficiently on Raspberri pi processor which is used for real time implementation. The embedded system along with Raspberry Pi can be deployed in mechanical industries for quality inspection.

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