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Characterization of Paper Pulp Fiber using Image Processing Techniques

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Abstract- **Paper industries around the world have been growing rapidly. In paper making industry, wood is the raw material used for producing paper. Properties of wood used for making pulp suspension affect the quality of the end product. When properties of fibers are measured accurately, pulp suspension of required quality can be prepared which will enhance the quality of the produced paper.Properties like length, width, kink and curl of paper pulp fiber, affects paper quality factors namely porosity, tensile strength, tear resistance, absorbency and paper formation. In this paper, Image Processing based analysis and characterization of paper pulp fiber are discussed which are very essential in product quality control.**

Keywords- kink, curl, tensile strength,porosity

I. INTRODUCTION

Image Processing is a branch of signal processing in which input will be a 2D image or video and the output will be images or parameters describing the image. A digital image is a binary representation of a two-dimensional image. Digital Image processing is the processing of digital image using computers. Digital Image Processing is used in variety of applications. Image processing techniques are used for robotic vision, autonomous robot navigation, inspection and assembly and also for medical imaging and analysis. Other applications include satellite imaging, acoustic imaging, finger printanalysis,biometrics etc. Industrial application of image processing includes monitoring and quality control of production process. Image processing technology finds its application in various industries such as steel, sugar, paper, cement, textile etc.

In this paper,Image Processing based analysis and characterization of paper pulp fibers properties will be discussed.In paper making industry, wood is the raw material used for producing paper. Variations in the wood property can cause inhomogeneous property of the wood pulp.Consistent paper quality is a result of how well fiber quality is managed. Even though fiber is a naturallyavailable raw material, its properties can be altered in various stages of pulping process.Characteristics of thewood pulp affect the property of the fiber.Properties like length, width, kink and curl of the paper pulp fiber are calculated to analyze the quality of the produced paper.In the production process, fibers can be damaged as it runs through various stages of pulp making. Some fibers can be mechanically disintegrated to form small segments called fines. Presence of excessive amount of fines affects the mechanical strength of fiber. Fiber length and width have large impact on paper quality factorsnamely, tensile strength, folding endurance, improved formation etc. Large variations in fiber curl and kink affect the tensile stiffness, tear index, porosity, absorbency etc. Thus measurement of paper pulp fiber properties is important in product quality control.If the fiber properties are analyzed in the wet stage, chemicals can be added and pulp suspension of required property can be prepared. If the fiber properties are known in advance, it will help to control mixing of raw materials. Thus uniform pulp quality can be obtained. Alsowastage of raw materials can be prevented which leads to increase in yield.

II. FIBER CHARACTERISTICS

Fiber morphology refers to the structural appearance of the fiber. Morphological properties of the fiber analyzed are fiber length, width, fiber kink and fiber curl[5].Fiber length is defined in terms of two parameters namely fiber contour length (L) and fiber end-to-end length (l).Fig.1(a) shows fiber with two definitions of length.Fiber contour length is defined as the along edge length and fiber end-to-end length is defined as the distance between end points of the fiber. Since the fiber resembles the shape of a curve, the contour length is calculated by taking the sum of distances

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between the curve pointswhich is same as the perimeter length of the fiber.

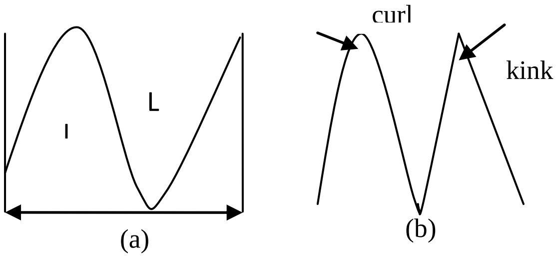


Fig.1. (a) Fiber with contour length(L) and end-to-end length(L) (b) Curl and kink of a fiber

Fig.1 (b) shows curl and kink regions of a fiber. Curl and kink indicates curvature details of the fiber. Curl defines deviation of the fiber from straightness and kink indicates small regions of the fiber with very high degree of curvature. Fiber curl defines degree of curvature and will not give information whether fiber curve changes slowly or suddenly. Fiber kink give information about deformations caused to the fiber, mainly mechanical damage.

Width of the fiber varies at each point in the fiber. So width of the fiber is the average width of the fiber. It is calculated by approximating it to minor axis length of an ellipse. Width of the fiber also affects fiber strength.

III. PAPER PULP FIBER CHARACTERIZATION USING MORPHOLOGICAL OPERATIONS

Image processing methodology which process the image based on its shape is called Morphological Image Processing. These operations are described as the science of ‘form and structure’. It uses a structuring element for shape analysis and can be used for pre-processing and post-processing of images through filtering, thinning etc. The result of morphological operation depends on the choice of structuring element. Erosion and dilation are the two main and preliminary techniques used in morphological image processing. More complicated morphological image processing techniques can be implemented by combining the process of erosion and dilation. Dilation adds pixels to the object there by thickens the object whereas erosion removes pixels from the object and performs thinning of the image component[6]. Fig.3 shows the image processing steps used for the characterization of paper pulp fiber.

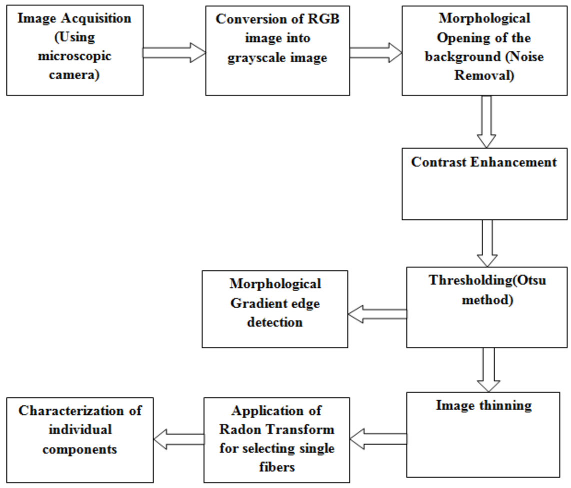


Fig.3. Design flow for paper pulp fiber characterization

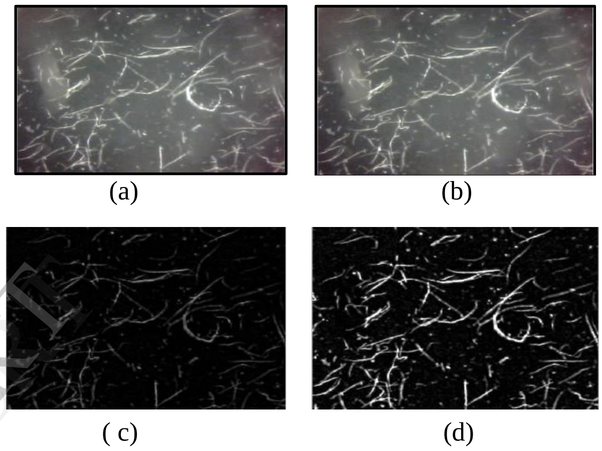


Fig.4.(a) Original Image of paper pulp fiber (b)Grayscale Image (c)Background noise removed (d)Contrast enhanced image

A.RGB to grayscale conversion

RGB color model consist of three independent color planes, namely red, green and blue which are the primary colors. Fig.4(a) shows the original paper pulp fiber in RGB color space.

The RGB image is converted into gray scale image for furtherprocessing. In a grayscale image the value of each pixel carries only intensity informationof that pixel.Fig.4(b) shows the grayscale image. A common method for converting RGB image into grayscale image is the luminance preserving conversion. An image in the RGB color model can be converted to a grayscale image preserving the luminance based on the following equation

$$Y=0.2126R + 0.7152G + 0.0722B \quad (1)$$

Where Y is the linear luminance which is the weighted sum of three linear intensities.

B. Noise Removal

Acquired image may contain noise due to improper lighting conditions, which can affect the image quality. Pulp suspension should be properly illuminated so that all the fibers are clearly visible. Noise created due to lighting imperfections can be eliminated by the process of morphological opening. The background information from the image is computedand this informationis subtracted from the original image to remove the background noise from the image.

Erosion and dilation are the basic morphological operations. Complicated operations like opening and closing are performed by combining the process of erosion and dilation.In mathematicalmorphology, opening is the dilation of erosion of a set A (which is the input image) by a structuring element B, which is formulated as

$$A \circ B = (A \ominus B) \oplus B \qquad (2)$$

Opening makes the contour of an object smooth and removes thin projections. Opening of the image is done by first eroding the image with a structuring element and dilating the result of this operation with the same structuring element. Effect of erosion on a binary image is to erode the boundaries of foreground pixels. Thus areas of foreground pixels reduce in size. The erosion operator takes two types of data for processing. The first is the image to be eroded. Second input is the structuring element.The structuring element determines the effect of the erosion on the input image. It is mathematically given by

$$A \ominus B = \cap_{b \in B} A_{-b} \qquad (3)$$

Dilation performs thickening on the binary image. It is mathematically given by

$$A \oplus B = \cup_{b \in B} A_b \qquad (4)$$

Same as erosion, dilation operator also takes two classes of data as inputs for processing. The first is the image to be dilated. The second input is the structuring element.Structuring element determines the precise effect of the dilation on the input image.Fig.4(c) shows the image with lighting imperfection corrected.

C. Contrast Enhancement

Contrast enhancement is done to increase the image brightness. Contrast enhancement is done by mapping the image intensity values to new values. Whileperforming intensity mapping certain amount of data is saturated at low and high intensity range of the input data.Fig.4(d) shows the contrast enhanced image.Different steps involved in contrast enhancement are as follows

- Normalization- This process involves dividing all the intensity values by 255
- Gamma correction-This process involves raising all the entries to the power 2 and then dividing all the entries by 2
- Linear mapping-This process involves converting the image back into original class

D. Thresholding

It is the process of converting the grayscale image into binary image. The method adopted for binarizing the image is Otsu thresholding. Otsu thresholding assumes that image contains two groups or classes of pixels namely foreground or background pixels. It calculates an optimum threshold so that their intra class variance is minimum.The intra-class variance is the defined as the weighted sum of variance of two classes. Otsu's thresholding method involves iterating through all the possible threshold values and calculates a threshold value which separates the pixels into two classes. So the pixels will either fall in foreground or background class.Fig.5(a) shows the result of thresholding operation on paper pulp fiber image.

E. Morphological Gradient Edge Detection

For the analysis of the paper pulp fiber characteristics, edges of the fiber must be detected effectively. Application of conventional edge detectors produced discontinuous edges. Edge detection using mathematical morphology produced continuous edges.

Then morphological gradient edge detection is performed which includes operations of dilation and erosion. Morphological opening and closing can also be done to obtain perfect edge detection.Morphological gradient edge detection is performed by performing dilation and erosion of the thresholded image[7].Edge detected image is obtained by taking the difference set of dilated and eroded domain of the thresholded image.Morphological gradient edge detection is given by Eq.(5).

$$E_G(A) = (A \oplus B) - (A \ominus B) \qquad (5)$$

Edge detection of paper pulp fiber using mathematical morphological techniques produced better results when compared to other type of edge detectors.
Fig.5(a)-5(c)shows the result of dilated, eroded and morphological gradient edge detection of paper pulp fiber image.

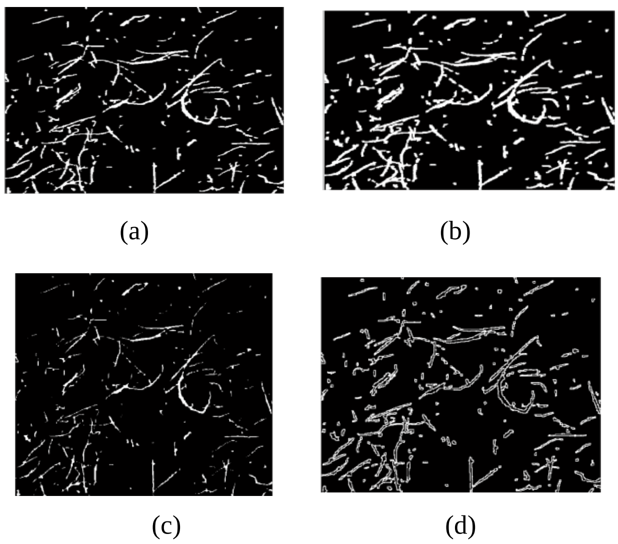


Fig.5.(a)Thresholded Image (b)Dilated Image
(c) Eroded Image (d) Result of Morphological Gradient Edge Detection

F. Thinning

Thinning is a morphological operation that is used to remove certain foreground pixels from binary images. The input and output images of thinning operation are binary images. For the purpose of finding the length of the fibers, the fibers must be made to one pixel width. Thinning operation is mainly done to find the fiber length. The thinning operation is related to morphologicalhit and miss transform. The thinning of an image I by a structuring element S is given by

Thinned(I,S)=I-hit and miss(I,S) (6)

The concept of thinning operation is to make certain foreground pixels to background pixels. Thinning operation is performed by placing the structuring element over the image and then translating the origin of the structuring element to each pixel position in the image.Fig.7(a) shows the result of morphological thinning operation. The pixels in the structuring element are compared with the underlying image pixels. If all thepixels of the structuring element exactly matches with the pixels in the image, then the image pixels which coincides with the origin of the structuring element is set to background pixel which is zero.

G. Radon Transform for selecting single fibers

Radon Transform is an integral transform which is defined as the integral of a function over straight line. It is also defined as 'raysum'.It transforms an image in (x,y) domain to (s,ɵ) domain. Radon Transform is a linear transform which performs the following transformation. Fig.6shows the projection imaging geometry.

f(x,y)= g(s,ɵ) (7)

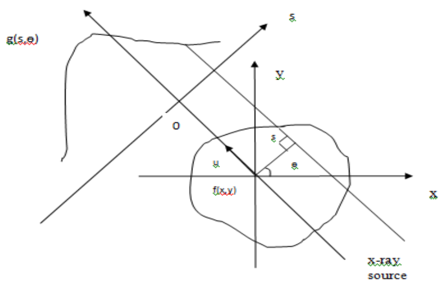


Fig.6. Projection imaging geometry

s=xcosɵ + ysinɵ (8)

A point in the projection g(s,ɵ) is the raysum along**s**=xcosɵ + ysinɵ. In order identify and filter overlapping and touching fiber sections and to select only single fibers from the image, the concept of radon transform is used.Overlapped fiber sections will have large intensity values when compared to single fiber sections.Then the fiber sections with large value of 's' with particular value of ɵ is removed from the image.The output image of this process contains only single fiber. Then the remaining part of fiber characterization is done on single fibers.Fig.7(b) shows the image of single fiber selected for characterization.

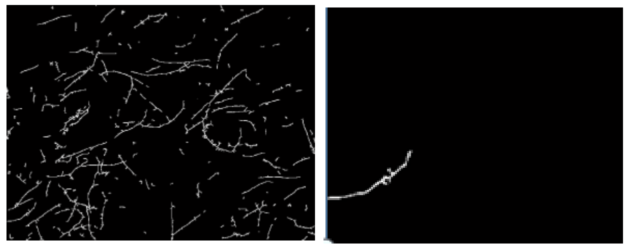


Fig.7 (a) Thinned Fibers (b) Single Fiber

H. Characterization of components

The characteristics to be found out are contour length of fiber,end-to-end length of fiber,width of the fiber,fiber curl and kink.Contour length is equivalent to the along edge length of the fiber which is same as the perimeter of the fiber.End-to-end length or projected length is calculated by taking the Euclidean distance between two extreme end points of the extracted fiber. Fibers will have varying width,therefore we must consider the average width of the fiber.This is equivalent to the minor axis length of an ellipse,if the shape of the fiber is considered as having elliptical shape.The mathematical equations for calculating these features are given below.

$$L = \sum_{i=2}^{n} \sqrt{(x_i - x_{i-1})^2 + (y_i + y_{i-1})^2} \quad (9)$$

$$l = \sqrt{(x_n - x_1)^2 + (y_n + y_1)^2} (10)$$

$$KI = \frac{2N_{(21-45)} + 3N_{(46-90)} + 4N_{(91-180)}}{L_{Total}} (11)$$

$$CI = \frac{L}{l} - 1 \ (12)$$

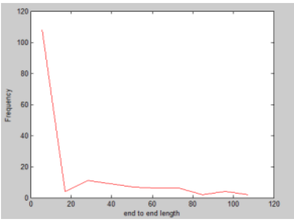
Eq.(9) represents the expression for calculating contour length(L). Eq.(10)represents equation for calculating end-to-end length(l). Eq. (11) represents the expression for calculating Kink index(KI). Eq.(12) represents the equation for calculating curl index(CI).Fiber kink and curl indicates the curvature details of the fiber. Curl indicates the degree of deviation of fiber from straightness. Kink indicates abrupt change in the curvature. Curl Index is calculated using the fiber contour length and kink is calculated by finding the number of pixels having orientations in specified directions. Fig.8 shows the values for various fiber characteristics.

From the obtained fiber characteristics of fiber end-to-end length, fiber contour length, fiber width, fiber curl and fiber kink, graphs were plotted showing the distribution of each characteristics. Fig. 10(a) shows the plot of end-to-end length of fiber against number of fibers.Fig.10(b) shows the plot of contour length of fiber against number of fiber.Fig.10(c) shows the plot of fiber width against number of fibers.Fig.10(d) shows the Curl

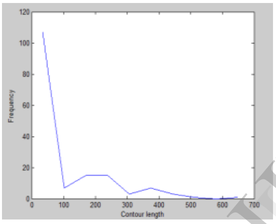
Index value against number of fibers.Fig.10(e)shows the kink value against number of fibers.

NO:	l	L	W	CI	KI
1	29.49	158.33	9.92	4.37	0.01
2	34.96	226.56	8.51	5.48	0.00
3	93.08	417.71	17.28	3.49	0.00
10	27.72	194.27	15.04	6.01	0.01
12	52.32	203.13	4.41	2.88	0.01
14	110.05	523.96	10.93	3.76	0.00
19	8.10	111.98	5.90	12.82	0.01
20	42.90	185.94	9.43	3.33	0.01
21	95.50	340.10	6.17	2.56	0.00
22	34.74	183.33	11.88	4.28	0.01
23	49.15	235.42	17.62	3.79	0.00
26	28.19	169.79	7.66	5.02	0.01
32	31.29	269.27	7.83	7.60	0.00
33	30.05	137.50	4.98	3.58	0.01
34	34.01	129.17	18.30	2.80	0.01
39	75.19	398.96	15.96	4.31	0.00
45	66.03	345.31	16.21	4.23	0.00
48	36.92	212.50	21.75	4.76	0.01
55	59.96	261.98	8.35	3.37	0.00
56	52.34	198.96	67.95	2.80	0.01
58	11.53	126.56	7.70	9.98	0.01
70	31.79	149.48	4.09	3.70	0.01
76	75.31	373.44	5.95	3.96	0.00
84	41.70	160.42	6.42	2.85	0.01
87	43.76	210.42	5.47	3.81	0.01
90	38.02	239.06	8.82	5.29	0.00
102	19.55	242.71	7.36	11.41	0.00
108	32.85	153.13	11.65	3.66	0.01

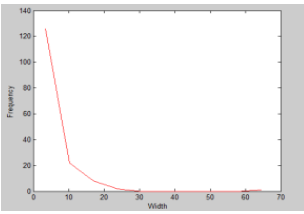
Fig.8. Fiber Characterization



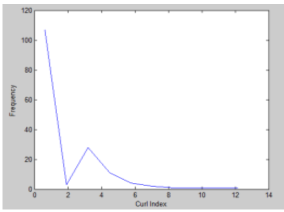
(a)



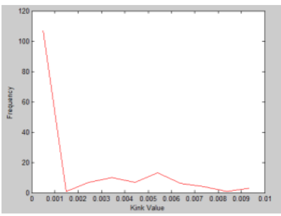
(b)



(c)



(d)



(e)

Fig.10:(a)Plot of end-to-end length vs number of fibers (b) Plot of contour length vs number of fibers(c) Plot of fiber width vs number of fiber(d)Plot of Curl Index vs number of fibers(e)Plot of Kink Index vs number of fibers

V. CONCLUSION

For the analysis and characterization of paper pulp fiber properties, the artifacts and lighting imperfections in the fiber image must be removed. A microscopic image of the pulp suspension is taken.It is processed by various image processing algorithms. Noise removal using linear and non-linear filtering operations does not provide satisfactory results.Application of conventional edge detectors introduced blurring effect on the image and this reduced the image clarity. Illumination imperfections in the image were corrected by applying morphological opening operation. Background information was computed using morphological opening technique and this computed information is subtracted from the original noisy image. Process of noise removal was followed byOtsu thresholding operation which produced an optimized result of binarized version of the image.The Otsu algorithm efficiently separated the foreground and background image classes. Process of thresholding was followed by edge detection process. Edge detection using first order derivative and second order derivative produced discontinuous edges.Edges detected using wavelet transform detected majority of the expressive edges but the individual fiber edges were not detected effectively.It formed clusters at the region of overlapping fiber sections.

Edge detection of fiber done using morphological gradient edge detection techniques produced continuous edges and the exact shape of individual fiber sections are analyzed. Then thinning process was performed to make the fiber edges one pixel thick. This was done to calculate the end-to-end length and contour length of the fiber.Then various morphological parameters of the fiberare measured using the mathematical formulas.Various fiber characteristics measured are fiber end-to-end length, fiber contour length,fiber width, fiber curvature details namely fiber kink and fiber curl. Future work will be focused on implementing the design in any Image processing hardware platform.

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