Automatic image-based detection of paper fiber ends

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ABSTRACT

Understanding the properties of paper fibers and paper fiber bonds can be really significant in improving the quality of paper. The problem in gathering measurement data from individual paper fibers is the lack of reliable and efficient research instruments. Also, without automation the yield of experiments will be low and the results will depend on the skills of the operator. This paper presents an image-based method to automatically detect the endpoints of paper fibers. The method will be utilized in automatic control of a novel and tailor-made paper fiber manipulation and measurement platform. Performance of the method is extremely promising with adequate speed and very accurate results.

Keywords: paper fiber, image processing, endpoint detection, binary image, Matlab, microrobotics, automation

1. INTRODUCTION

The properties of papermaking fibers affect the properties of the paper, and thus understanding the fiber properties can have a great impact on improving the quality of different paper products. Fibers are typically 0.6 − 7 mm long and 16 − 70 µm thick wood cells[1 − 3] and they are one of the main components of the network structure of paper. For estimation of the microscale properties of pulp and paper, researchers and engineers are currently using mathematic models[4]. Traditionally, average bulk parameters based on sample portions of the fibers under study are used in determining the mechanical properties of papermaking fibers, e.g. tensile and shear tests[5]. Currently, the main drawback in fiber research is the lack of suitable measurement data in an individual fiber level. New measurement data and especially data-driven controlled mechanical treatment of individual paper fibers could direct to drastic enhancements in the properties of fiber products. Recent advances in microrobotics and microsystems technology provide new tools and methods to manipulate and to characterize micro- and nanoscale samples such as living cells[6] and carbon nanotubes[7], and also promote microassembly approaches[8].

To overcome the disadvantages of the methods currently available in industrial and academic fiber research laboratories – such as laboriousness, need for extensive manual preparation and very low yield – our group has developed a microrobotic platform for manipulation and mechanical characterization of individual paper fibers[9]. Presently, the platform is teleoperated. To raise the throughput and reliability, the platform should be automated. The first step towards automation is identifying the coordinates of individual paper fiber ends. The challenge stems from the attributes of paper fibers. As paper fibers are natural fibers, they do not have a known fixed geometry similar to synthetic fibers. This paper presents an image analysis algorithm to automatically identify the coordinates of individual paper fiber ends from an image. The coordinates are used in automating the microrobotic platform for paper fiber characterization.

The rest of the paper is organized as follows: Section 2 gives a short insight to the microrobotic platform used in manipulating and characterizing the fibers, Section 3 presents the algorithm for the endpoint detection and Section 4 shows some results of the algorithm. The conclusion is drawn in the end.

2. HARDWARE PLATFORM

This section briefly introduces the microrobotic platform for paper fiber manipulation and measurements and describes the imaging devices and conditions. The platform and the imaging conditions are discussed in own subsections.

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2.1 The microrobotic platform

The microrobotic platform in use has a *Stacked Gantry Crane* configuration. In this configuration, there are two tailored SmarAct microgrippers (1 & 2), and a SmarAct XY-Table (3) with a SmarAct SR-1908 rotary-table (4) and a Femtotools FT-S540 micro-force-sensor (5) mounted on its top. The camera and optics used in teleoperation are placed above the platform. Figure 1 illustrates the components of the microrobotic platform.

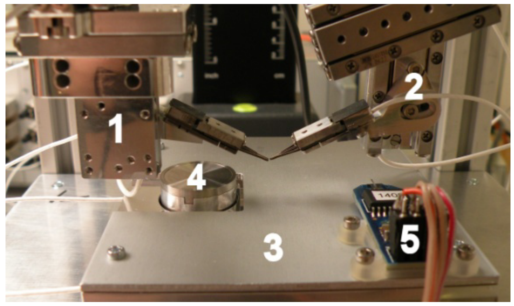

Figure 1. The microrobotic platform for fiber manipulation and flexibility measurements. The microgrippers (1, 2), the XY-table (3), the rotary-table (4) and the micro-force-sensor (5).

The paper fibers are initially in a wet state (i.e. immersed in water) and they are placed on the rotary-table for measurements. The microgrippers are used for picking up the selected paper fiber from the both ends and lifting it in a synchronized manner. This is shown in Figure 2. Then the microgrippers move the paper fiber towards the micro-force-sensor for measuring the bending stiffness of the fiber.

Figure 2. Image sequence illustrating grasping the fiber with the microgrippers.

The design and implementation of the microrobotic platform as well as experiments performed for measuring bending stiffness of paper fibers are extensively explained in [9].

2.2 Imaging conditions

The camera used in imaging is Sony XCD-U100 with Navitar 12x motorized zoom with 3 mm fine focusing (0.23x – 3.5x total magnification). The lighting system is Navitar Led Coaxial Illumination WHITE 5500K 4.8 Watt. Image acquisition software is a tailor-made Linux software. In the experiments, the paper fiber specimens were placed on the XY-table on a paper slice coated with a glass slide. This substrate was scratch-resistant and provided a good contrast between the fibers and the background. In the experiments, the substrate was not yet integrated to the rotary-table.

3. ALGORITHM

This section presents step by step the algorithm developed for the detection of the paper fiber endpoints. The steps discussed in more details in each subsection are segmenting to binary image, thinning the binary image and detecting the endpoints, omitting the undesired endpoints and providing the final result. The images were acquired using a tailor-made Linux software and Matlab was utilized as the development tool of the image analysis algorithm.

3.1 Segmenting to binary image

After acquiring the image, the first step is to segment the image to distinguish the fibers from the background. Figure 3 illustrates this with an image taken of paper fibers in a dry state. Matlab function `graythresh`, which uses Otsu's method for automatic thresholding is utilized in this step. The result is presented in Figure 3 B.

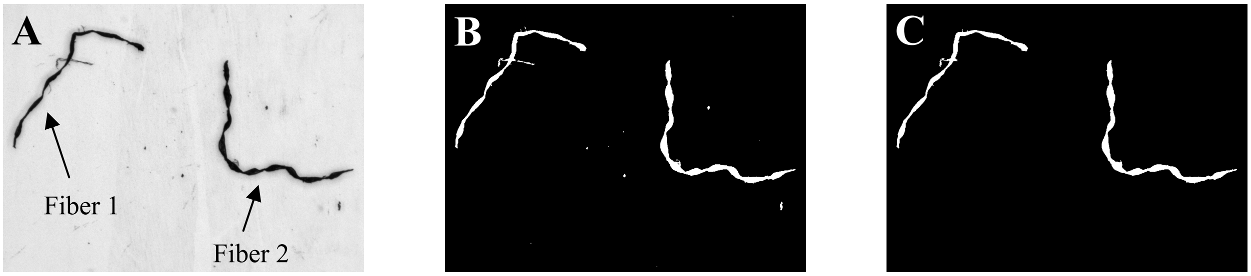

Figure 3. Image taken of paper fibers lying on a glass and paper coated holder (A), the same image after thresholding (B) and enhancing (C).

As it can be seen in Figure 3 B, also the trash and small pieces of the paper fibers lying on the glass can be seen in the binary image, and there are some small holes and cracks in the paper fiber areas. First, the holes are morphologically filled and then the connected components are detected from the binary image. Ellipses are fitted around the components of the image and their major axis lengths are compared with each other. It is assumed that there is at least one proper fiber in the image and it is the longest object there. Thus, all the objects with the major axis length less than 0.3 times the greatest major axis length found are discarded. The Matlab commands used here are `bwconncomp`, `regionprops` and `ismember`. The outcome is seen in Figure 3 C.

3.2 Thinning the binary image and detecting the endpoints

The next step is morphologically thinning the fibers. Here, Matlab's `bwmorph` function is utilized. However, due to the roughness of the fiber surface and the bundles of fibrils sometimes pointing out from especially mechanically pulped fibers, the skeletons of the fiber images have extra tails and thus many endpoints. This is illustrated in Figure 4.

Figure 4. Close-ups of Fiber 1 (A) and Fiber 2 (B) after morphological thinning of the image.

The endpoints of the skeletons are detected morphologically and arranged for each fiber by comparing to which skeleton they belong. The functions `bwmorph` and `bwconncomp` are utilized in this step. However, many undesired endpoints will remain**.** The wrong endpoints have to be separated from the real ones.

3.3 Omitting the undesired endpoints

Primary component analysis (PCA) is used for omitting the pseudo endpoints. The skeletons having more than two endpoints are selected and their coordinates are obtained. The coordinates detected for each object are represented in a plane formed by their eigenvectors using PCA. Figure 5 shows this step. The Matlab commands utilized here are `bwselect`, `find` and `princomp`.

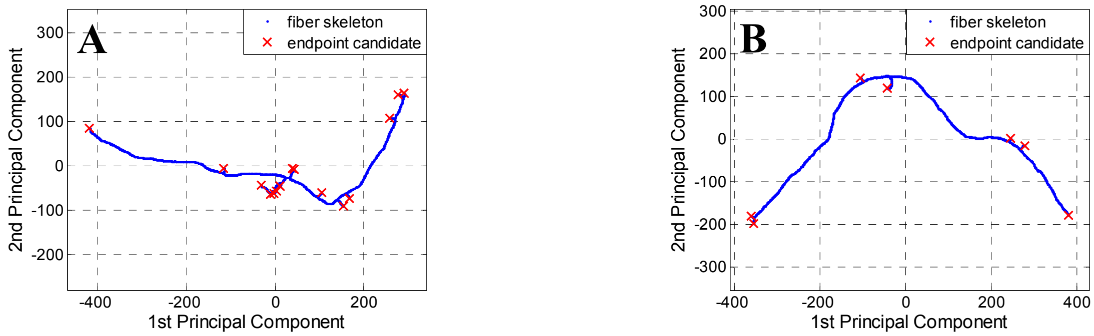

Figure 5. Points of the morphologically thinned fibers (Fiber 1 in A and Fiber 2 in B) plotted in the plane formed by their eigenvectors. The red crosses show the endpoint candidates.

Choosing the leftmost and rightmost endpoint candidate as the real endpoint provides good results. The chosen endpoint is not necessarily always exactly in the end of the fiber as illustrated in Figure 5B. However, the results show that the determined endpoint coordinates are sufficiently close to the real end point coordinates in order to successfully grasp the fiber using the micrgrippers.

3.4 Providing the final endpoints

To acquire the endpoint coordinates of the final image from the coordinates obtained from Figure 5 A and B, the steps of PCA have to be inverted for the endpoints in the eigenvector plane. Figure 6 illustrates the fibers with the final endpoints given by the algorithm. As it can be seen from the figure, the results are satisfactory.

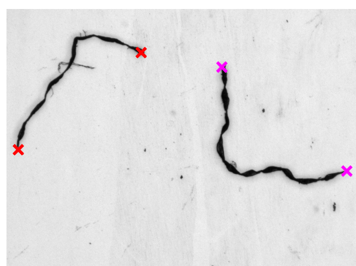

Figure 6. The original image with the detected endpoints of both fibers marked with the colored crosses.

The average runtime of the algorithm for a 1600 x 1200 sized 8-bit grayscale image is approximately 0.5 seconds. The number of fibers and other objects in the image is the most significant factor the runtime depends on.

3.5 Reconsiderations for the wet state

The fibers are inside a water droplet in the wet state, and therefore the thickness of the droplet should be as low as possible to enable good lighting and focusing. The form of the droplet and reflections from its surface easily make the lighting uneven. This complicates automatic thresholding. To overcome this, median filtering is used. The window size of 50 x 50 worked well with the images acquired. Median filtering slows down the process and that is why the imaging conditions should be improved to prevent the droplet from growing too big.

4. RESULTS

Experiments were performed to demonstrate the developed algorithm in detecting the endpoint coordinates of several fibers in the wet state. Three experiments with a different number of fiber ends to be detected were performed. Figure 7 shows the results with fibers in the wet state. As it can be seen, the success rate was 100% with the fiber concentration used, which is extremely promising.

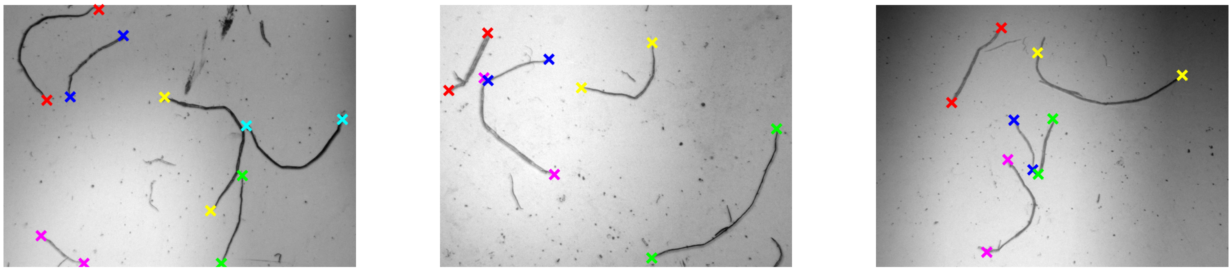

Figure 7. Fibers in wet state with the endpoints detected.

5. CONCLUSION AND FUTURE WORK

Knowing and being able to control properties of individual paper fibers is considered to be important in enhancing the quality of paper and other fiber products. In order to perform experiments and measurements in sufficient quantity for reliable results, a microrobotic platform for fiber manipulation and measurements has been developed. Still, an experienced operator is needed to complete the tests. In automation of the platform, machine vision and image processing have a crucial role.

An automatic image-based method for detecting the endpoints of paper fibers was presented in the paper. The endpoint detection is an important phase in automating the microrobotic platform for paper fiber manipulation and flexibility measurements. The algorithm is fast with a runtime of around 0.5 seconds for one 1600 x 1200 sized 8-bit grayscale image. The results are accurate enough for controlling of the microgrippers of the platform to grasp the fibers and the endpoints were detected for each fiber in each experiment. The substrate of the paper fibers still needs to be developed in order to enhance the image quality, eliminate the need for median filtering and make the fibers to remain at the same level. Also, the algorithm should be improved to be able to find and discard the fibers that are entangled to each other.

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