

Measurement of randomness in fiber distribution in paper using computer vision

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ABSTRACT *An automatic system for data acquisition and analysis has been developed for measuring the randomness of fiber distribution. The method is based on measuring the entropy of the image of the paper as gathered by a conventional computer vision system. The system measures both overall and local fiber randomness.*

KEYWORDS

Analysis
Anisotropy
Fibers
Image analysis

The properties of paper depend on the degree and type of fiber orientation, among other factors. The exact measurement of the degree of fiber orientation has been dealt with either by the measurement of strength anisotropy or by the use of laser diffraction techniques (1-3).

It is arguable that the method of measuring strength anisotropy bears a straightforward relationship to the spatial distribution of fibers. Experiments to determine this relationship are difficult to perform, however, and the method is not likely to be suitable for an on-line measurement system.

The laser diffraction method, which is meant mainly for laboratory work in the quality control department, could conceivably be used for on-line monitoring of a localized, limited area of the paper. Incorporating such a device in a paper machine control system has its drawbacks, however, mainly stemming from the limited average lifetime of a laser.

To have an on-line system to measure fiber randomness, a method is

needed that directly measures fiber randomness as the paper machine is running, using equipment with a long life cycle. Our work is aimed at developing such an automated system for acquiring and analyzing data. Our method of measuring the randomness of fibers in paper is based on the concept of entropy, in which the orientation of fibers is directly linked with the state of order.

This method performs a direct measurement of randomness through computing the entropy of the image (4) of paper as gathered by a simple, common, computer vision system. The equipment does not contact the paper and measures the whole field of view. Both the hardware and software components are long lasting.

To illustrate the use of the concept of entropy in measuring the randomness of fiber distribution, we report here the results obtained for the entropy of a kraft paper, which has a high degree of randomness. We also report the results for a printing paper,

which presents a much more ordered distribution of fibers.

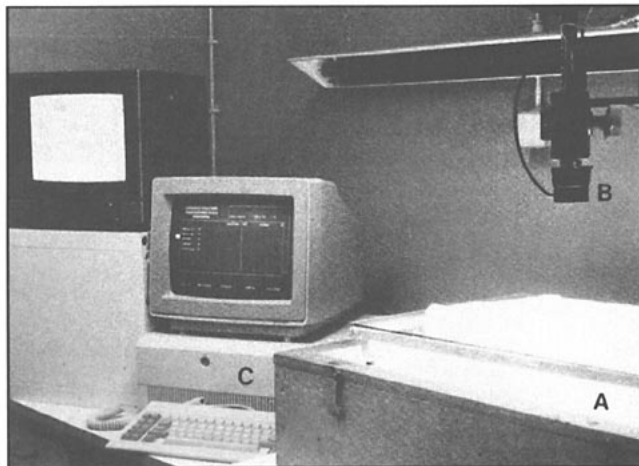
Entropy as applied to paper—a brief history

Thermodynamic entropy

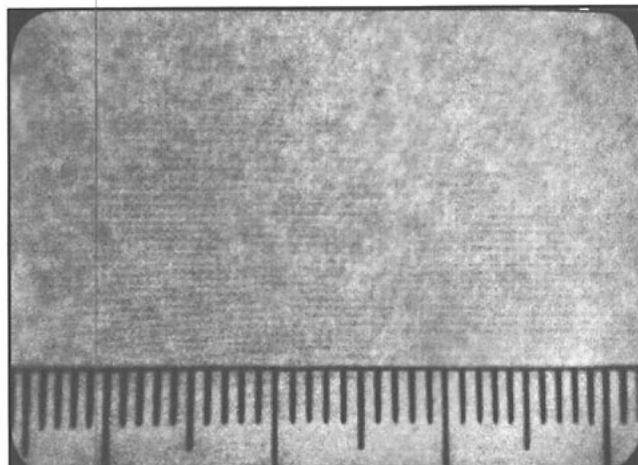
At the peak of the industrial revolution, Rudolf Clausius discovered a new quantity and invented a new word. The name for this quantity was the result of joining up "en" from the word "energy" with the Greek word "trope," which means "evolution." This new word, "entropy," was to signify a quantity of energy that is not accessible in any system undergoing a physical transformation. Any physical system left to itself would show a tendency for an increase in its inaccessible energy. In other words, its thermodynamic entropy will grow. Of course, this cannot happen when work is being performed on the system.

To produce a microscopic explanation for this new quantity, Ludwig Boltzmann in 1869 showed the existence of a direct relationship between

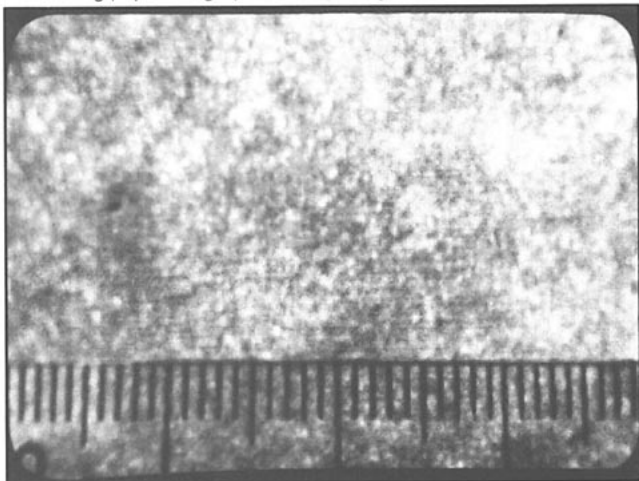
2. Setup of the experimental showing (A) the illumination stage, (B) the lens, and (C) the computer



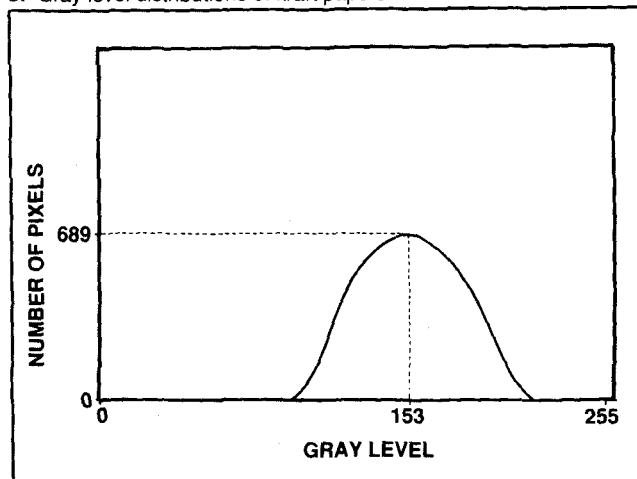
3. Kraft paper image (1 tick of spacing = 1 mm)



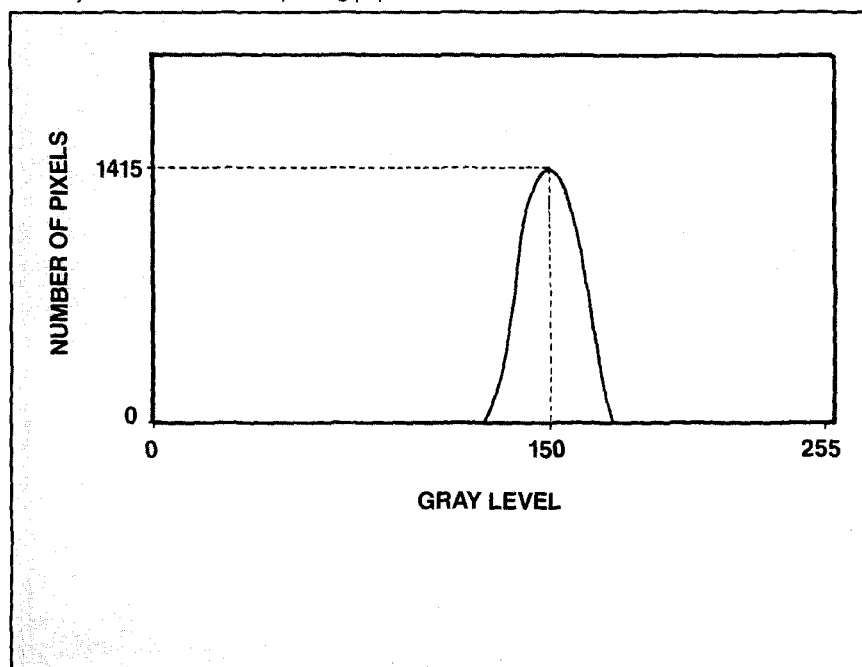
4. Printing paper image (1 tick of spacing = 1 mm)



5. Gray level distributions of kraft papers



6. Gray level distributions of printing papers



Method of measurement of fiber randomness

The theory

An optical system gathers the light transmitted or reflected by the paper and produces its image. The method is based on the calculation of the vision entropy of this image.

Computing the content of information or entropy of an image by any computer is a very fast affair. An image is composed of finite areas that constitute the picture's elements, and these areas are known as "pixels." Each of these pixels has a certain illumination. This illumination is the elementary message, x . By counting the number of pixels that have the same level of illumination and dividing this number by the total number of pixels in the image, the probability $p(x)$ of the level of illumination x is found. This probability is called the "gray level distribution."