Image analysis technology opens a new perspective on paper formation

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ABSTRACT
Camera technology and image analysis are developing at an increasing rate, extending to numerous new areas of application. The imaging formation measurement of the paper web is a new significant solution that has evolved from this technology. The challenge includes handling the relatively high paper web speeds and the web’s varying optical transmittance properties. It must be possible to obtain high-quality images from most paper and board grades, under all circumstances. This requires the use of state-of-the-art camera and illumination technology. Imaging-technology-based formation measurements are already available in the market. However, the information reported by these measurements is generally confined to the calculation of individual quality index figures that indicate overall formation variation. Nevertheless, it still remains difficult to use only a single figure to deduce why formation variations occur so as to be able to optimize the process. This is due to the fact that formation is an outcome of several factors, as raw materials, process equipment and process operating point all leave their “fingerprint”. It is probably easier to list items that are not affecting to formation than ones that are. To facilitate formation optimization, a new approach is introduced: dividing the formation-related image information into mutually independent descriptive sub-components. This will further highlight what has actually changed in the formation in question, thus making it easier to decide upon subsequent corrective actions. The formation components’ functionality is indicated by on-line measurements.

INTRODUCTION
Over the past few years, camera technology has advanced rapidly. Exposure rates and resolution capacity have increased, physical size reduced and the selection of types and models expanded, with the price range becoming reasonable. A significant number of related applications have been adopted in various industries: monitoring, quality control, and robot control on automated production lines, among others, are run-of-the-mill phenomena today.

Numeric information is obtained from an image through mathematical analysis. Analysis of this type is calculation-intensive since a single image may contain large amount of elements. Thanks to the increasing capacity of conventional computers, we can currently carry out increasingly complex analysis with cost efficiency. Dedicated processors that are designed for image analysis purposes are also available in the market. These execute analysis algorithms with superior efficiency, compared to conventional processing environments. To enable the analysis of camera-captured images in real time, the camera must be directly connected to the processing unit through a high-speed digital data connection. The interfaces used in cameras and image analysis systems are being standardized, which means that combining the various manufacturers’ devices into a functional solution has changed from virtually impossible to moderately difficult. Among others, this area is currently undergoing rapid development.

Before camera technology can be successfully applied to the imaging of a moving paper or board web, a number of challenges must be solved. The moving web must be “stopped” for the exposure, while eliminating the basis weight variations’ effect from the amount of penetrating light.

The speeds of modern paper machines approach a level of 2,000 m/min. At this rate, the paper web moves 33 meters per second. To achieve optimum image resolution, the image must be exposed for a few microseconds. Board grades have lower web speeds but provide a different type of challenge: their basis weights are significantly higher. A sufficient amount of light must penetrate the product to achieve an appropriate formation image. The cameras’ improved sensitivity alleviates the problem, but in order to be able to image the heaviest grades, the light source is of major significance.

Conventionally, xenon tubes have been used for illumination purposes. These emit light pulses of a regular length with a (almost) regular power level. The amount of penetrating light must be optimized at the camera end. This technology may restrict the range of the basis weight being measured. In order to cover an extensive basis weight range without compromising the resolution, the most recent technologies are required, using which the light intensity and the pulse length can be adjusted independently from one another.

Imaging technology applications have been available for a few years for formation measuring purposes. In general, these applications are based on the use of laboratory equipment. In laboratory conditions, the measurement technology is not so challenging, compared to on-line environments, due to the use of stationary samples for measurements. The first on-line measurements for formation imaging purposes have appeared in the market over the last few years. A common feature of most imaging-based formation measurements is that a single key figure is calculated to represent the entire formation image field. In other words, a so-called formation index value is reported to the user. The index value shows the process operator whether the measured formation has changed, in other words, whether the numerical value in question has increased or decreased. Process operators use this value to decide upon required further action, based on their work experience and knowledge of the process in question.

Additional information on the formation characteristics and the related changes would probably facilitate the decision-making process concerning corrective action. The idea of “splitting up” the optical formation phenomenon into independent components has been suggested. Thus, the measurement could more efficiently indicate what has actually changed in the formation.
INTRODUCTION
OPTICAL FORMATION
CHARACTERS

Optical formation is created through the combined effects of several components during the paper process. This means that the formation is not a single phenomenon but the result of several superimposed phenomena. Consequently, its quantitative analysis has proved to be extremely challenging. Each of the sub-processes involved, such as raw materials, web forming, pressing, etc., has its effect on the various paper formation features. Suitable methods enable the examination of sub-process functions, which takes place through studying their “fingerprints” in final product. Modern image processing texture algorithms are used to divide optical formation into illustrative components, a few examples of which are examined below, with the aid of images captured by this novel on-line analyzer, and results.

Variability

Fiber web variability is one of the key factors affecting the base paper’s visual appearance. Fiber web low variability indicates a good formation and a high variability one the opposite. This component is also an important contributor on paper printability. Variability is calculated as grey scale variability from captured sample. Figures 2 and 3 set out a comparison of two fiber web samples with different variability levels, followed by examples of different grades of board product.
Light/dark spots

Light spots are caused by local depressions in the paper. The otherwise uniform optical formation may include a number of depressions, even pinholes. Deformations of this type are caused by excessively intensive water removal, in conjunction with low basis weight values in particular. Two different samples containing a different value of light spots are compared in Figure 4 and 5 below. It is likely that the component that is used to describe light spots distinctly reacts to the occurrence of pinhole-type deformations. If light spots are dominating the image the spots value is positive.

Figure 5, Spot index = 9.94

Figure 6, Spot index = 17.90

Dark spots are flocs with thicker layer of fiber attached. More fibers forming a floc show darker on the image. Alternatively dark spots can be dirt particles from the process. This situation may happen during start up after shutdown. If dark spots are dominating the image the spots value is negative (Figures 6 and 7)

Figure 7, Spot index = -11.75

Figure 8, Spot index = -25.54

Figure 9, Different Spot Index levels on board.
**MD floc size, CD floc size and MD/CD floc shape**

The visual floc size within the paper is one of the important textural features in optical formation. The applied fiber composition (the average length of fibers) has the greatest impact on the floc size. The pulp beating degree and the water extraction process (turbulence and retention chemicals) are also important with regards to the floc size. The applied jet/wire ratio and the MD/CD stiffness anisotropy are observed in the form of floc size asymmetry between the MD and CD directions. Figures 8 and 9 set out a comparison of two samples that have a different floc size. It is observed that the base paper with a larger floc size gives a “cloudier” impression.

The floc shape is calculated as ratio of MD and CD floc sizes times 100.

![Figure 10, MD floc size = 1.51 mm, CD floc size = 1.83 mm and MD/CD floc shape = 82.40](image1.png)

![Figure 11, MD floc size = 2.58 mm, CD floc size = 2.71 mm and MD/CD floc shape = 95.20](image2.png)

**OPERATOR INTERFACE**

Introducing a new set of numeric characters to operators already dealing with plenty of information is a challenge. Special effort was put to develop a way to display this new information in meaningful and easy to understand way. Five formation characters are shown in polar plot form, which is found to be easy to follow among operators. Different sets of formation characters show as different patterns on display. History feature allows comparison to earlier measurement sets for follow up after process adjustments. Conventional profile and history trends are included in display set.

![Figure 13, Polar plot display of formation characters](image3.png)

Five images per scan are transferred to server for display and storage. With 20 second scan time and 60 minutes reel build up time some 1000 images are stored in served over one reel. Once reel is completed and numeric reel average character values are available, system selects an image representing reel average formation. This image is then displayed on a dedicated display among other images, each representing a reel average formation. A reference, grade dependent image is displayed in the middle for easy visual comparison.
PROCESS RESULTS

Sensor has been installed onto a size press of fine paper machine for some time now. After wet end modification on the machine a bump test on jet/wire was performed. Results show that variability correlates directly with jet/wire ratio at this operating point. Response on MD/CD floc shape is also quite clear. Increasing j/w causes jet speed to increase compared to wire speed. When the jet enters wire it slows down and flocs get compressed on machine direction, showing as reduction in MD/CD floc shape.

SUMMARY

The optical formation of paper is created through the combined effects of almost all the paper process components, including the complex interaction between various raw materials. Instead of using a single quality index, it is now possible to obtain a far more accurate and more practical perception of paper formation and its contributory factors than before. This is done through the analysis of mutually independent formation components. The simultaneous examination of on-line images and related calculation results makes it possible to determine which sub-process should be adjusted so as to improve the formation in question. Individual quality index values cannot be exploited in a similar fashion. They only indicate whether the situation has improved or not, after a change has occurred. Contrary to this, the formation components can be used to estimate, in advance, which sub-process should be improved, still retaining the possibility to use one of them as a quality index – the fiber web uniformity, for example, to evaluate the consequences of the change in question.

The imaging on-line measuring system has been used in production on a paper and board machines. The system has enabled the observation of various process situations’ effects in the visual form (images) and in the numeric form. Our experience indicates that the system is reliable and produces useful new information for the optical formation optimization purposes.