Optical Paper Formation Analyzer

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ABSTRACT

Formation may be generally defined as the small-scale variation of the mass [fiber] distribution within a sheet. Many studies had been done to understand and define this parameter. The term "Formation" as it suggests, is a full statistical description of how the paper is formed or equivalently how the fibers are arranged. For a well formed sheet, It is necessary that the fibers are as much well dispersed as possible, have a minimum of alignment or orientation, have uniform consistency and are uniformly distributed with respect to their length, breadth a weight. This paper analyses the various methods of interpretation and quantification of this property through image capture and statistical analysis techniques. CEERI Centre, Chennai has developed this Formation Analyzer indigenously and the four main parts of the system development, Viz., Illumination system along with light intensity control unit, personal computer with VGA or SVGA with color monitor, monochrome CCD camera and frame grabber, proprietary image analyzing software are explained in detail in the following sections. This indigenously developed instrument with the latest available image analysis techniques combined with the computing power of the personal computer thus helps the paper maker in judging the formation based on statistical analysis of the captured image of the sample paper.

INTRODUCTION

Fomation may be generally defined as the small-scale variation of the mass [fiber] distribution within a sheet. many studies had been done to understand and define this parameter. It was shown that about 75% of the basis weight variance is due to imperfections in manufacture and about 25% is due to randomness of the process. Hence it is clear that there is room for improving the quality of paper through formation measurement and control. An improvement in formation leads to better print-ability and greater strength.

It should be undestood that formation is not a primary functional property of paper and it affects other functional properties such as opacity, stiffness, smoothness, porosity, run-ability, strength, etc. Almost all formation meters developed earlier are calibrated either directly or indirectly to yield the best possible correlation with a subjective evaluation by the human eye. However there are features that escape the human eye and still affect the functional properties. These features are also to be addressed to by the paper maker and an electronic instrument would help him to do so.

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equivalently how the fibers are arranged. For a well formed sheet, it is necessary that the fibers are as much well dispersed as possible, have a minimum of alignment or orientation, have uniform consistency and are uniformly distributed with respect to their length, breadth & weight.

The entire sheet characteristics are based on the physical properties of the fibers, the fiber network structure and the orientation. Variations in these properties cause change in average basis weight. Though large-scale variations could be effectively controlled with today's technologies, it is very difficult to use them to control small-scale local grammage variations (for areas less than 1 mm^2) and this non-uniformity affects the above-mentioned functional properties to a large extent. A Formation Analyzer, which can detect these small scale defects and variations is the most appropriate answer.

This indigenously developed instrument with the latest vailable image analysis techniques combined with the computing power of the personal computer thus helps the paper maker in judging the formation based on statistical analysis of the captured image of the sample paper.

DEFINITION

There are no widely accepted standards for the measurment of "Formation". Formation is generally defined as small-scale variation of the mass (fiber) distribution within a sheet. The upper limit of the small-scale size is defined as 100 mm and the variation is called "basis weight" variation and corresponds to paper making problems such as pump pulsation and/ or mechanical vibrations. Below 100 mm, the variation in the mass corresponds to the stock approach design, head box operation and/or forming section set-up and activity.

METHODS OF FORMATION ANALYSIS

Formation is a loosely interpreted term in the paper industry and many different expressions and strategies are followed depending on the requirement of information. Find below a number of such measurements and strategies, all of which are useful in some way or other. The user could choose appropriate method according to the needs.

STANDARD DEVIATION

Perhaps the simplest way to define formation index may be, is the standard deviation of the amplitude of intensity of the captured pixels in a transmitted light image. Greater the value of the deviation, poorer is the formation of paper. However this does not take into consideration, the size or shape of the flocs in paper.

REGRESSION ANALYSIS

Regression analysis is performed on a transmitted light image and a relation between optical density (OD) and basis weight distriubution is established. Threshold levels of references with known values of optical density are measured, from which the corresponding calibration curve is generated. The area under the curve may be used to calculate the mean OD and the standard deviation.

FAST FOURIER TRANSFORM METHOD

Frequency domain techniques are powerful approaches to the quantification of formation. The 2D FFT (Fast Fourier Transform) is used to analyze spatial periodicity of the mass density distribution. The power spectrum when transformed into a wavelength spectrum, is called the **'Formation Spectrum'**. This describes how the relative grammage variance (normalized with respect to the mean grammage) is spread over different floc sizes. The power spectrum also indicates the size of flocs with respect to another sample.

EXTERNAL REPRESENTATION SCHEME

An approach that utilizes an external representation scheme can also be used to indicate formation. A region-growing algorithm is used to segment the image (using its boundary characteristics). Shape measures such as area and perimeter are obtained as a result of this algorithm. The number of flocs in the image is an indicator of the flocculation in the sheet.

The formation index **F = Total area of flocs/area of the image**

A greater index would be desirable for uniform paper. Another method could utilize the perimeter of the flocs and image perimeter to calculate the index. This is probably more desirable as it requires experience to obtain a threshold for discriminating large and small flocs.

COMPACTNESS

The term **'Compactness'** could be used to

distinguish between a floc and a region that could be designated as a fiber.

The compactness 'C' = (perimeter)^2 / (area)

SPECIFIC PERIMETER

The distribution of mass in sheet of paper is neither completely random nor perfectly ordered. Such a distribution is commonly termed as a texture. The first parameter called "contrast' is the overall variation in basis weight from point-to-point, which can get generally described simply as **co-efficient** *of* **variation.** The second parameter takes into account how the regions of different basis weights are grouped, whether in large flocs or small regions. In case of the second parameter, the most commonly reported index is the standard deviation of local basis weight or optical density. Such a measure does not however take into account the size distribution of the non-uniformity **(graininess).** This is generally computed by means of a Fourier analysis leading to power spectrum but it's interpretation is difficult for the non-expert.

The specific perimeter measurement lies midway and is a simple graininess parameter that is easily interpreted without recourse to Fourier analysis. An index may be used for assessing the graininess of such a texture. We define the **specific perimeter** as the total length of the median density contour per unit of viewed area. It is highest for fine grained and lowest for coarse-grained structures. One of the practical advantages of this method is that the measurement is insentitive to the photometric calibration of the instrument and the stability of the illumination. This is because the median signal strength can always be found, regardless of the scale. It was found that the specific perimeter computation is the best method for analyzing the formation of the paper.

PAPALYSER

The CEERI developed Formation analyzer "PAPALYSER" carries out the measurement of specific perimeter using an image grab and analysis. An area called the field of view is captured by video camera and its digitized signal is stored as an array of picture points. A threshold value of singal strength is determined such that one half of the picture points exceed the threshold. Using this threshold, the image is segmented, isolating those regions that are darker than the median. The perimeter of these regions is determined using standard image analysis procedures and is divided by the area of the field of view to yield specific perimeter.

DESIGN OF PAPALYSER

The method based on the light transmission coupled with computer based image analysis algorithms is used to determine the formation of paper. This method is fast, less expensive and accurate. The method involves the measurement of optical density of paper, specific perimeter, flock size distribution and formation index of paper. This index discriminates more sensitively between different qualities of formation than the standard formation number. The system consists of the main following components:

- Illumination system along with light intensity control unit
- Personal Computer with VGA or SVGA with Color Monitor
- Monochrome CCD camera and frame grabber

- Proprietary image analyzing software

OPTICAL UNIT

The formation is extremely sensitive to the intensity of background illumination and any non-uniformity would may bring in erroneous interpretations. The light box has been designed using a quartz halogen lamp with intensity control circuit. The light beam from the lamp is passed through a neutral density filter and series of diffusers to reduce the blooming effect and realize nearly uniform light intensity across the field of view, in order to illuminate the specific area of the paper sample under test. A filter to cut off the Infrared radiation is also used. The lamp assembly was housed inside the instrument box and a glass window of size 70 x 70 mm^2 helps to place the paper sample for receiving the illumination. The camera with it's eye piece lens was mounted directly over this glass plate at a vertical distance. Camera and lens mounting was covered completely to cut off any external light. Though the sample plane is 70x70 mm^2 the area of the image captured is 35x45mm^2 and the area of interest that is analyzed by the system is 30x40 mm^2. It is necessary to take care of short term intensity variations. Two different schemes are designed: 1. Semi-automatic intensity control system. 2. A fully automatic intensity control system.

Semi-Automatic Intensity Control System Approach is simple but effective to take care of any short-term intensity variations in the intensity of the illumination. A feed back multi turn potentiometer is

provided to obtain any required intensity. The lamp control circuit with feed back element has been implemented to take care of short-term variations. This setting is automatically maintained through a feedback phototransistor by sampling the light intensity being received by the CCD camera. This arrangement also helps to take the average intensity of the captured image closer to a Gray level of 128 when the sample is inserted after setting the average intensity to 128 before placing the sample.

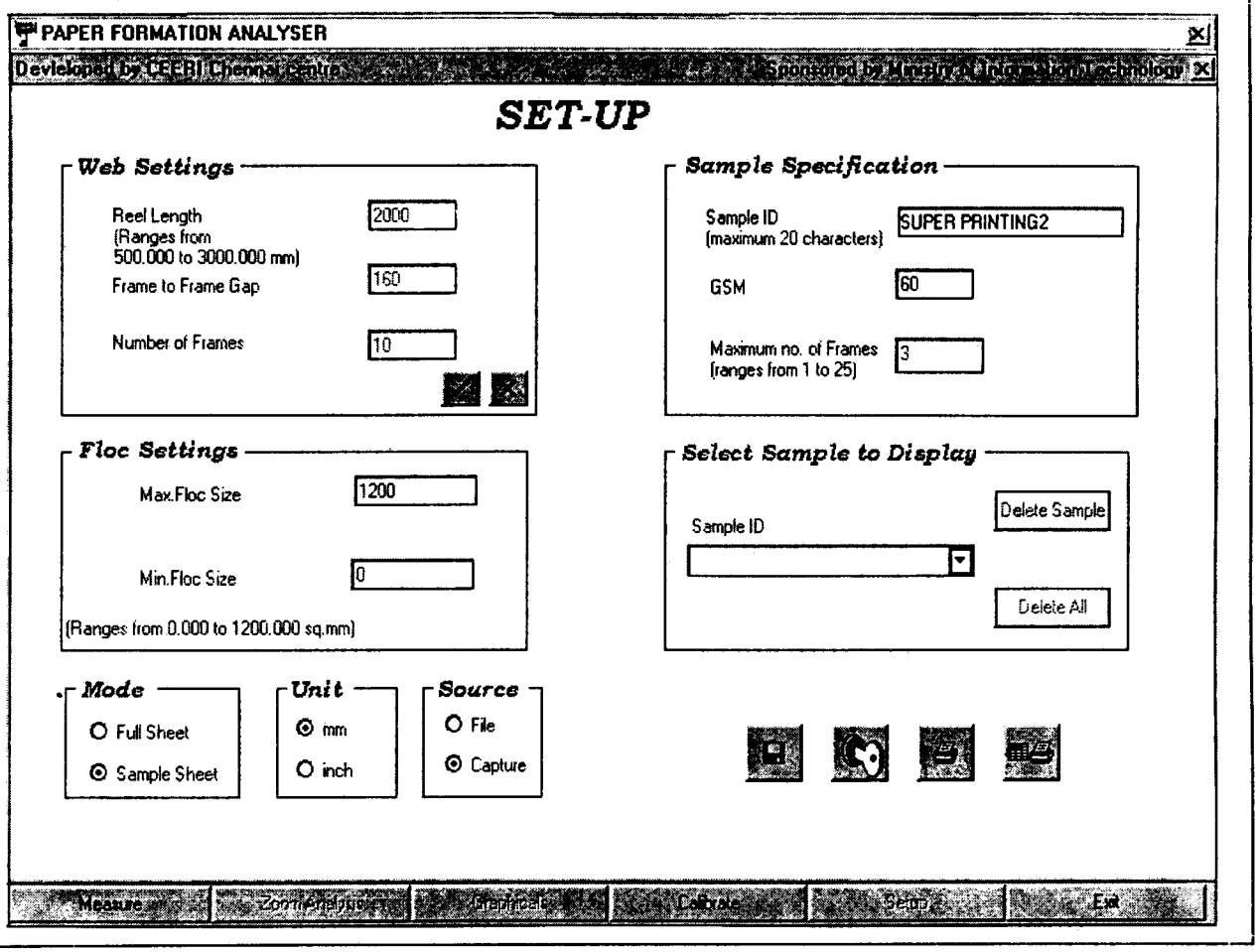
A Fully Automatic Intensity Control System approach totaly takes care of both short and any long-term intensity variations. This design does not employ any potentiometer for the adjustment and does not require even the feed back phototransistor arrangement for sampling the light intensity reaching the CCD camera. The system, on a click of the mouse measures the average intensity of the image, adjusts the voltage applied to the lamp, and sets it such a way that the average image intensity is broght to the present actual average intensity of the image too.

HARDWARE

There are two special purpose hardware to be added to the standard, commercially available personal computer system that works with window operating system. These are the frame grabber card and the D/A converter card. The frame grabber card interfaces CCD Camera. The images captured by the CCD Camera are transmitted to the frame grabber card which will convert the data into computer screen format. The proprietary application software of the instrument, with the help of suitable drivers will read the image for analysis. The interface software between the application software and frame grabber card is specific to the frame grabber card being used.

The D/A card is used only in the fully automated intensity control system and is not required for a semi automatic intensity control implementation. The application software analyzes the image and evaluates the average intensity available in the image. The intensity is compared against the users requirement and this difference is converted into voltage units and

6.1 SETUP



sent to the D/A card. The analog output is used to control the intensity of the lamp source. However in the case of semi automatic implementation, since the D/A card is not present, a multi turn potentiometer is available for setting up the required intensity level. The user will read the intensity of the image on the screen and adjust the potentiometer to get the required level. Thereafter the phototransistor which provides the feedback by sampling the light intensity reaching the CCD Camera helps to maintain the set level.

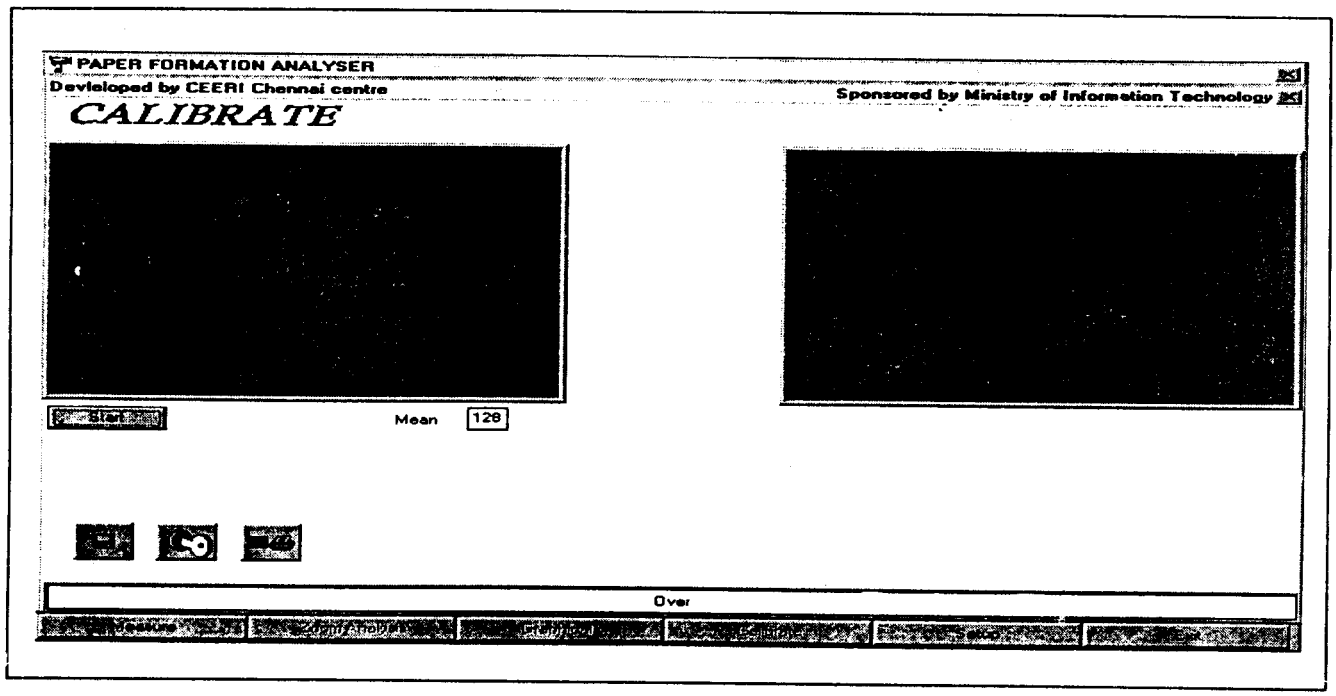
SOFTWARE IMPLEMENTATION

The system software developed under WINDOWS 95/98 is totally icon driven system. The complete operation is distributed onto five different pages for information as well as operation. The system software also maintains the data base in ACCESS format. The various pages are christened as 1) Measure, 2) Zoon Analysis, 3) Graphicals, 4) Calibrate and 5) Setup. Every page is provided with a **Dump** icon to enable the user to transfer the display page contents directly to the windows printer to generate a hard copy. It is the responsibility of the user to select the specific printer, currently connected to the computer system, as default printer, before using any print facility.

All the parameter limits, modes, units, type of samples etc. are set through this page. Most parameters also have their limits of operation.

The active paper length is set through **"Feeder Settings"**. This parameter is equal to the current paper length of the sample sheet. **"Frame to Frame Gap"** is the gap between two successive measuring frames. This could be advantageously set to the distance between two slices. The **"Number of Frames"** is the number of measurements that the system will carryout for the complete paper length (cross direction). The program automatically calculates the third parameter when **"Reel length"** and any of the other two parameters is set. The **"Floc Settings"** are very important and flocs that lie between these set limits only are accepted. **"Units"** window is provided to select the units of floc measurements and feeder settings either in mm or Inches.

There are two modes of measurements. **"Full Sheet"** mode will enable the system to automatically move the sample in the predefined direction and the speed. The paper is automatically stopped for data collection and analysis. The sample is then moved till the next frame arrives under the CCD camera for next data collection. **"Sample Sheet"** mode measurement is done with a sample either at one location or more than one location. In this case, the sample has to be shifted manually to the specific location of interest. The **"Source"** selection defines the image source for analysis. **"Capture"** captures the current images through the CCD camera and grab the image for storing and analysis. **"Sample Specification"** selects the sample under test. It is important to note that the image/data collected can be saved only if the Sample ID is unique. The list of the entire stored sample IDs



can be viewed by using the pull down arrow button. **"Print"** will print all the data available with the setup page in text mode.

CALIBRATE

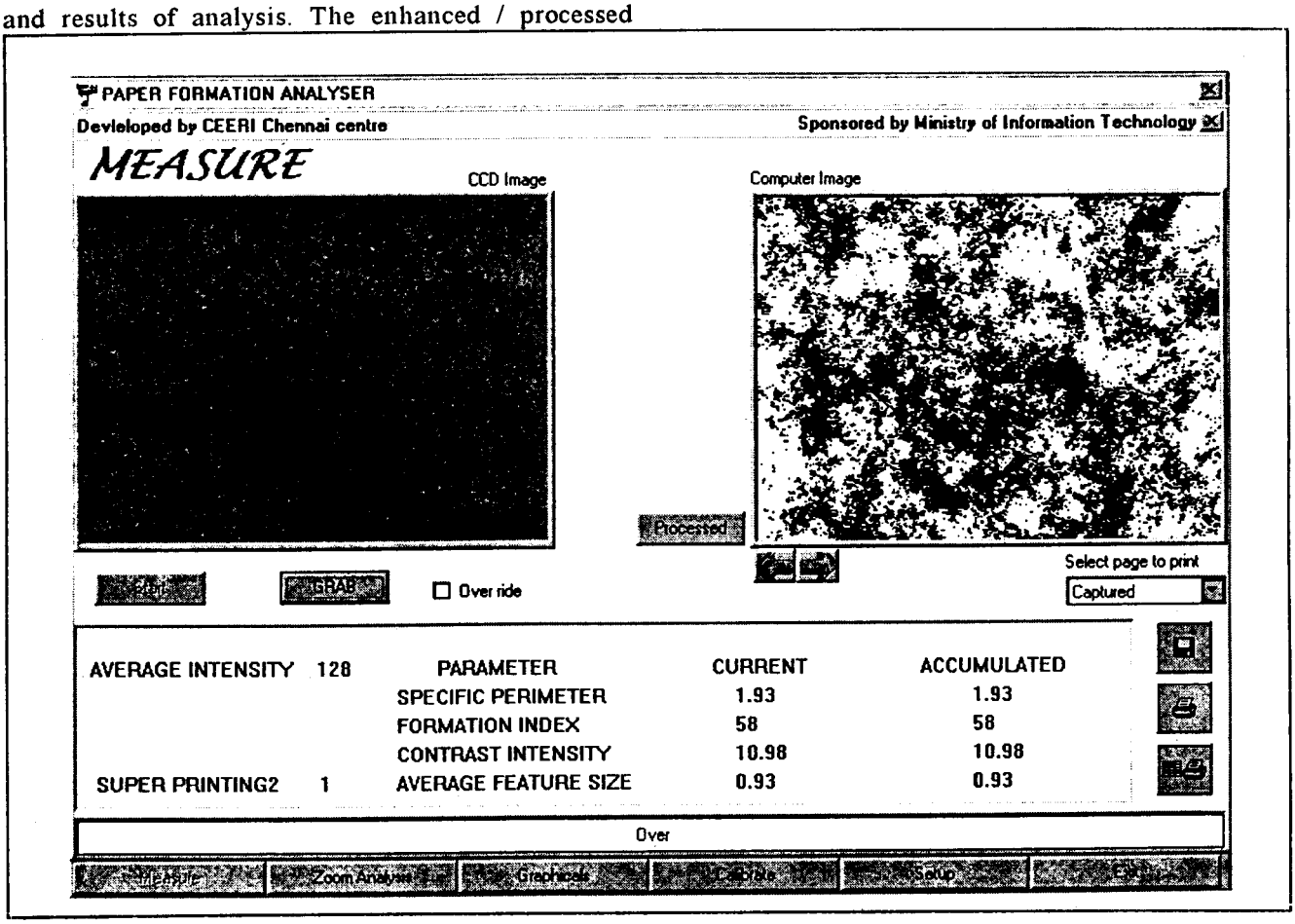
The **"CALIBRATE"** is carried out with out the paper sample, during the first use of PAPALYSER. this will also be required whenever lamp assembly is disturbed, reassembled or the lamp replaced. The **"Start"** initiates the calibration process. Initially the intensity level is required to be set between 128±2". Then the image is required to be linearised. The system can then store the linearisation mapping data. This data is used to correct the image during the process of formation measurement. This linearisation will take care of the problems related to the non-linearity that may be present in the CCD elements and non-uniformity that may be present in the image intensity across the image.

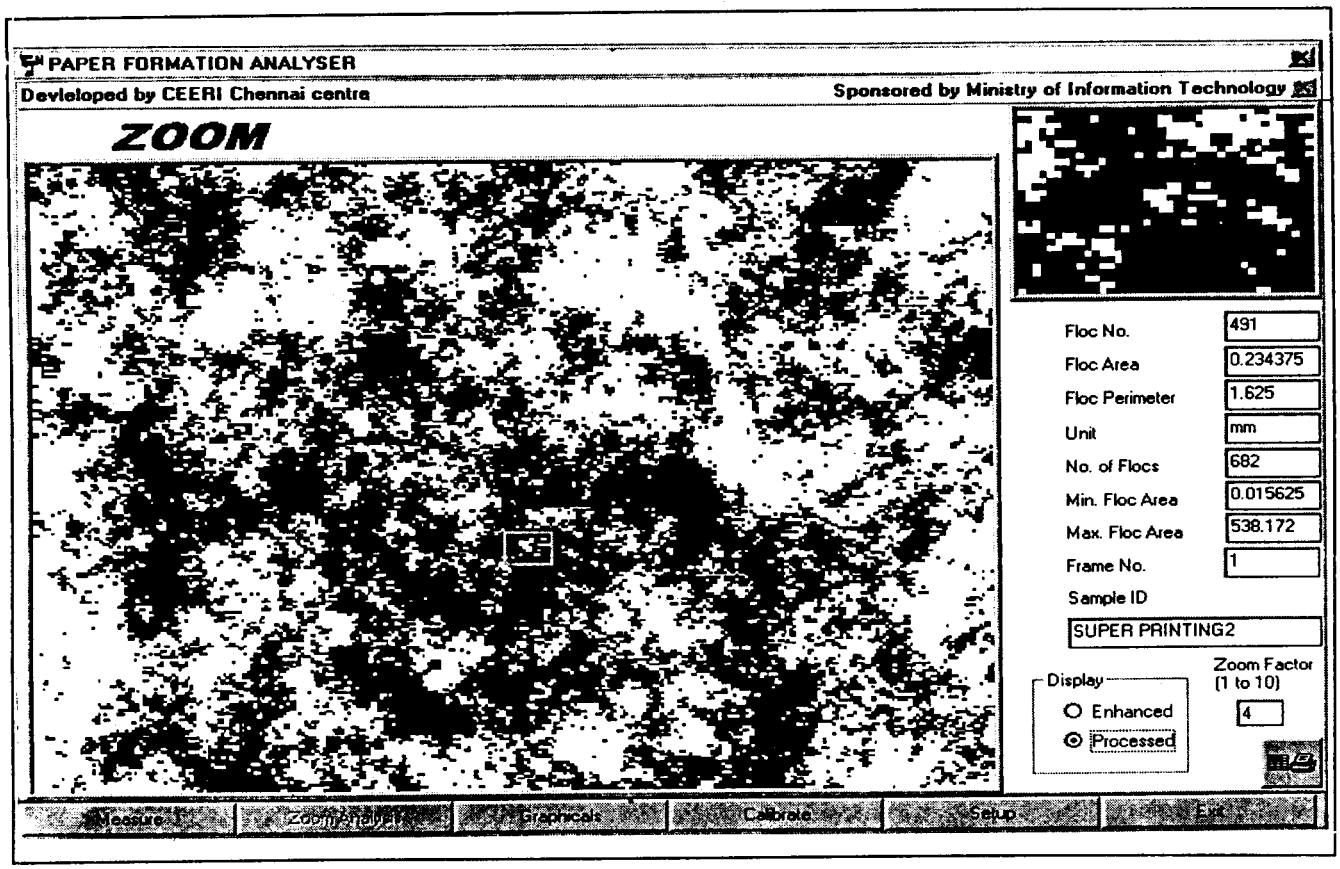
MEASURE

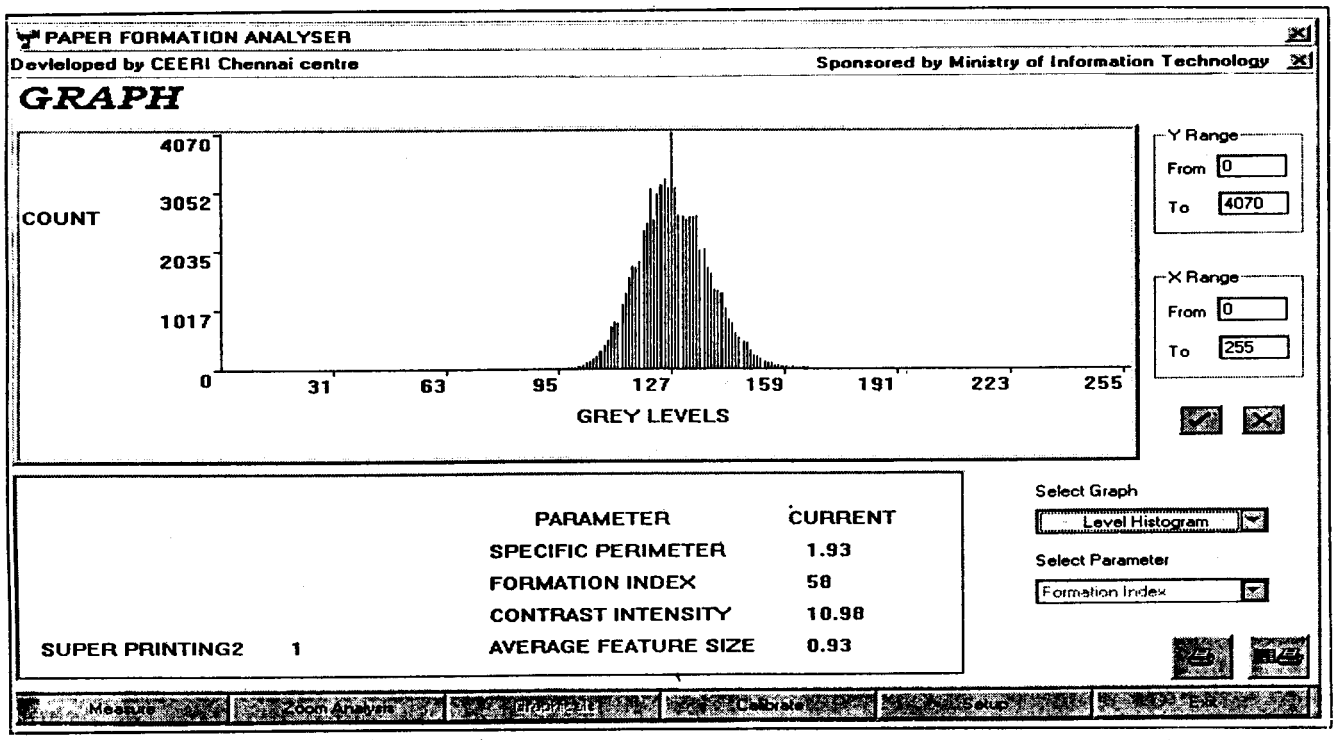
The **'MEASURE'** page displays real time image, the enhanced / processed image of the grabbed image and results of analysis. The enhanced / processed image will get updated on **"GRAB".**

In the continuous mode, the grabbing takes place automatically for every fixed duration as per by the data of **"Feeder Settings"** in the setup page. The data in the measured window is automatically updated for very grab both in single sample mode as well as continuous mode **"GRAB"** will initiate action to make sure of the average intensity to be between 128±, in non-override mode. Then the image is grabbed at intensity of 128± in non-override mode and any intensity in override mode, processed and liberalized and displayed. The parameter values are updated for **"Current"** and **"Accumulated"** in the measurement window. Similarly the formation is carried out in **"Full Sheet".** The system software will automatically measure all the regions as per the details programmed in the setup.

There are two kinds of measured data, CURRENT and ACCUMULATED. The current data is the resultant due to the last GRAB while accumulated data is the result of all the samples so far collected for the current session. The accumulated data is the arithmetic average of all the current data of the grabbed images.







The processed or enhanced may be overcome. **"PRINT"** will enable printing of any of Captured Image, Enhanced Image, Binary Image, Report, **"SAVE"** will enable saving of the image. The arrow keys under the processed image may be used to bring up the previous or the next image collected in any mode.

ZOOM ANALYSIS

Zoomed image of the processed or enhanced image of the captured image is displayed. Any flock could be selected and further zoomed up to 20 times and displayed on a separate small window in the same display. All its parameters like floc number, floc area, & floc perimeter could be displayed. Further the other information on the total number of flocs, minimum & maximum floc area of the image and frame number are also displayed.

This page provides graphical information for multiple parameters like GRAY LEVEL HISTOGRAM, FEATURE AREA HISTOGRAM, FRAME PROFILES. Frame profiles include a) Formation Index, b) Percentage Contrast Intensity, c) Specific Perimeter, d) Average Feature Size.

The graph that is displayed for any selected parameter, would exist both for full sheet, single sheet modes that may be set in **"SETUP"** page. The ranges of X-axis and Y-axis are programmable.

SPECIFICATIONS OF PAPALYSER

- Sensor: ½" Monochrome CCD Camera of 640 x 480 pixels
- Standard C mount and 12 mm lens for focusing
- Feature size Maximum 100 mm
- Calibration Software
- Graphics Display Live & Captured images. Zoomed images, Feature zooming, Multiple histograms, Profiles, CD Prlfiles.
- Sensor Resolution 0.02 mm (approx)
- Repeatability error + / -1
- Quartz halogen light source
- GSM range: 15 to 175 GSM expandable to 350 GSM
- Power supply: 230 V, Single Phase
- Data base: MS ACCESS

CONCLUSIONS

The system has been developed by CEERI Centre, Chennai and it's performance has been verified with the results of similar systems available with a few paper mills. The results are quite satisfactory and the indigenously developed system would certainly b of great use to the Indian Paper industry in the sense that an imported system of similar nature would cost heavily. It is estimated that this system could be made available to the users at a fraction of the cost of imported systems. Further there is still scope for improvement by incorporating a few more of the different techniques of analysis. It is also intended to include Dust Count measurement along with this system, as a future addition to the system. The Centre is already working on this aspect and should be able to come out with a second model in about 6 to 8 months time. On the whole it is expected that the Indian Paper mills would get benefited by this new technology at a nominal cost and improve their product quality.

The Centre is already in the process of commercializing this technical know-how and a few enterepreneurs have shown interest in taking up the technology.

BIBLIOGRAPHY

1. "The NUI FORMATION Tester- An evaluation, Modification and Comparison with other Techniques", R. Daunals and R.G. Garner, Paper Physics Conference, 43-49, 1987
2. "Local grammage distribution and formation of paper by light transmission image analysis", Jean Philippe Bernie and W.J. Murray Douglas, TAPPI, Vol. 79, 193-202.
3. "How formation should be measured and characterized", Isko M. Kajanto etl., Nordic pulp and paper research journal, Vol. 3, 219-228, 1989.
4. "Light scanning system provides qualitative formation measurement", Otto j Kallmes and John A. Ayer, Paper physics Conference, 209-215, 1987.
5. "The Application of Image analysis to evaluate small scale basis weight variations in Paper", Peter Bergh and Philip Luner-Technical report of Empire state paper research Institute, USA.
6. "Paper Formation and Image Analysis", M. Shinozaki, Y. Tajima and S. Miyamoto-Technical report of New oji Paper Co. Ltd., Japan.
7. "Outline of an THI FUZZY logic formation control system", M. Yakabe, K. Ishibashi and S. Suzuki-Technical Report of Ishikawajima Harima Heavy Induatries company Ltd., Japan.
8. "Specific perimeter- a graininess parameter for formation and print-mottle texture", B.D. Jordan and N.G. Nguyen- Technical report of Nguyen pulp and paper research Institute, Canada.