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# Performance Analysis of On-Line Camera-Based Web Inspection Sensors: A Pilot-Scale Experimental Study

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# PERFORMANCE ANALYSIS OF ON-LINE CAMERA-BASED WEB INSPECTION SENSORS: A PILOT-SCALE EXPERIMENTAL STUDY

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## ABSTRACT

Camera-based web inspection sensors have been available in the paper industry for many years. However, in recent years because of a market demand for high-quality paper products, the need for real-time flaw-detection systems has increased significantly. In addition to flaw-detection capabilities, these systems should be capable of doing defect classification (*e.g.*, relative to size and type of flaws) as well as defect localization (providing information on location of flaws). The technique employed in flaw detection and measurement principles used in common systems are based on laser, CCD (charge coupled device) camera, or infrared technology. The study was designed to determine the capabilities of commercially available CCD camera-based systems. A CCD camera-based commercial sensor was installed on a pilot paper coater machine with the production speed capability of 1524 m/min (5000 ft/min) that could accept paper rolls with a width of 76.2 cm (30 inches). Various paper grades consisting of newsprint, coated paper, coated board, and linerboard which had typical grade-related defects were provided by various paper mills for testing. The purpose of this manuscript is to describe the operational principle, capabilities, and performance of various sensors used in paper industry in detecting various flaws and defects and to provide a summary of the results obtained using a commercial sensor.

***Key Words:*** Paper Manufacturing, Pilot Scale Experiment, CCD Camera, Flaw Detection

## INTRODUCTION

Web inspection sensors that are used for detection of flaws and imperfections in paper materials have been available in the paper industry for several decades. However, in recent years because of the high demand for specialty papers and high quality products and coated papers (*e.g.*, paper used in graphic printing), the need for real-time flaw-detection systems have increased significantly. The sensor systems are used for detection and classification of flaws or defects in paper materials during production (*e.g.*, on-line and in real-time). The paper manufacturers are interested in identification of the type and size of flaw size and defect localization which means that the sensor should provide information on location of flaws and defects in paper, so decision on acceptance or rejection of the product can be made online and during manufacturing of the paper products. The measurement principles and basic method of flaw identification of the common systems are based on laser, CCD camera, or infrared technology.

The laser-based systems use a fast rotating polygonal mirror to produce a moving laser spot on the web along the cross machine direction. The transmitted light through the web is detected by fiber optics sensors and analyzed to determine the presence of flaws or defects on the moving web. These systems may be sensitive to the speed and vibration of the moving web [1]. The CCD camera-based systems are equipped with array sensors of light-sensing picture elements called pixels. Most standard CCD inspection systems use 1024 or 2048 pixel linear array cameras in their systems. The light incident on the pixels generates electric charges proportional to the light intensity. The CCD camera systems use either fluorescent or incandescent lamps for their light source and an automatic gain control system may be used to compensate for variation in illumination of the light source. The lamp intensity, distance from the camera to the paper, web speed, and rate of data collection by the sensors can influence the defect-detection capability of the system. The infrared systems use an infrared light source and discrete photosensitive elements for detection of defects. In general, these systems are primarily used for detection of flaws in uncoated papers. Among the advantages of these systems are ease of installation and the capability to detect rapid changes along the machine direction [1].

At the Institute of Paper Science and Technology (IPST) at Georgia Tech, and with collaboration of a sensor manufacturer (RKB Optoelectronics, Syracuse, NY) and a paper manufacturer (Appleton Paper, Appleton, WI), we have performed a pilot-scale experimental analysis of an on-line web inspection system to determine its capabilities and performance in detecting various flaws and defects [2]. Originally several commercial systems were proposed for the evaluation. However, during the course of the project tests were conducted only on one system. Several vendors expressed interest in participating in the study and in general, newer/smaller vendors that had a smaller share of the market showed more enthusiasm in participating. However, because of many factors such as economic constraints by the vendors (specifically limitation in funding for research and development), technical difficulties in preparation for the test trials, specific concerns about the testing procedures and evaluation criteria by some vendors (*e.g.*, proposed defects and flaws to be detected, etc.), issues related to rapid changes within some vendor companies (consolidations, discontinuation of a product, etc.), and uncertainty about the benefit-to-risk ratio in participation, commitment for participation by the major vendors could not be obtained. The RKB Opto-electronics was the only sensor manufacture that participated in mill trails. Although the results presented in this study are based on pilot-scale experiments with this sensor, the finding that can be applied to other CCD based camera systems are presented in this manuscript.

With a funding from the Measurement Technology Committee (MTC) of the American Forest & Paper Association (AF&PA, Washington, DC) we conducted this study using a 60 cm to 76 cm (24 inch to 30 inch) web handling system capable of machine speeds up to 1524 m/min (5000 ft/min). At this maximum speed, inspection systems must be capable of detecting a 1-mm (0.0394 inch) diameter hole. Also, all systems must be equipped with a minimum of two cameras. The sensor was installed on a pilot paper coater machine with the production speed capability of 1524 m/min (5000 ft/min) that could accept paper rolls with a width of 76.2 cm (30 inches). Various paper grades consisting of newsprint, coated paper, coated board, and linerboard which had typical grade-related defects were provided by various paper mills for testing. IPST at Georgia Tech provided papers containing some predetermined (calibrated) simulated defects.

## MATERIALS AND METHODS

### The CCD Camera based Web Inspection Systems Used for the Experiments

A sensor manufacturing company called RKB optoelectronics provided a demonstration web inspection system to be used in pilot-scale experiments and we performed the experiments in a paper mill in Wisconsin called Appleton Papers. The system is designed to be interfaced with various camera/lighting systems to detect dirt/holes, streaks, creases, spots, coating streaks, and/or scratches commonly found in the production of various web materials [3]. The system tested was the Model 33030A™ Video Web Inspection System that uses CCD camera-based technology as the sensing platform. It had two configurations, one for discrete defects and one for continuous streak detection. During the tests, RKB was responsible for all engineering, documentation, installation supervision, commissioning, service, and all other work to ensure all sensing requirements were met. A schematic of the system used for discrete defects detection at Appleton Papers is shown in Fig.1.

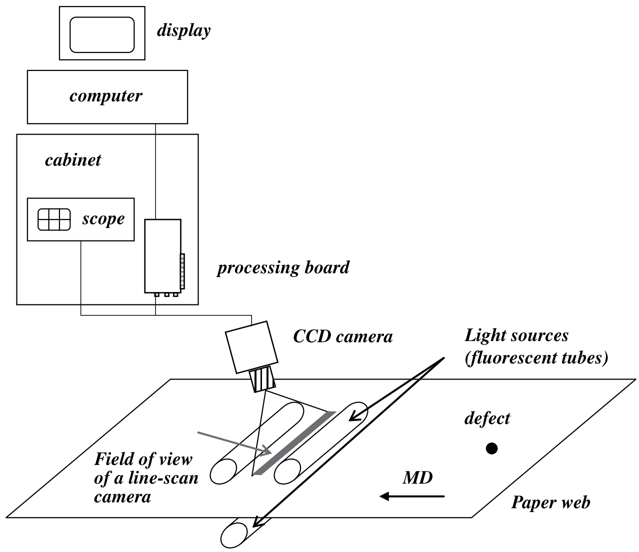


***Figure 1.*** Diagram of the system used by RKB for discrete defect detection.

The Model 3030A™ Video Web Inspection System is equipped with a data acquisition program and provides production personnel with information on defect fault types, sizes, quantity, and location. An operator is able to display all appropriate information in various formats by using touch-sensitive key buttons or point-and-click functions. Information concerning reel production, fault distribution, profiles, and history is accessible in color-coded graphs. The system can work with both reflected and transmitted light for defect detection. The principle of a line-scan camera is as follows: a lens periodically takes images of a line across the web surface using a linear array of CCD pixels. The quantity of light collected by each pixel is independent from the other pixels. An increase or a decrease of the energy collected by a pixel above or below a fixed threshold indicates that a hole (bright spot) or a dark spot is present on the web surface. If more than one pixel experiences a decrease or an increase of energy at the same time, then the defect can be classified into a small, medium, or large size depending on the number of pixels affected. The schematic diagram of the system used for streak detection is similar to the one used for the defect detection and it uses the same type of frame, cabinet, and computer (Fig. 1), however, different cameras and light sources are used for this system [4].

## Differences between the Line-scan and the Area-scan Camera Systems

Line-scan cameras are based on one-dimensional linear array sensors, while area-scan cameras are based on two-dimensional array sensors. Since the linear array is just one row of pixels, it can be thought of as one television (TV) line that is repetitively re-swept while observing the same precise geometric position in space from the optics point of view. The camera is stationary, but the subject can move rapidly under it without loss of visual information. Since it is only one TV line that is not locked into standard television field and frame rate conventions, the line-scan camera output can be updated very rapidly (for this evaluation, a 1024 pixel line scan camera that re-swept every 56.8 μsec was used). The line camera finds its application niche in industrial inspection where autonomous moving phenomena must be captured. The broader commercial application is in bar code readers.

Since area-scan cameras are based on two-dimensional arrays, they are extensively used in conventional picture-forming applications (TV) such as surveillance cameras, portable video cameras and recorders and studio equipment. Since the area scan camera has many TV lines (rows of pixels) across a two-dimensional geometry, it is possible to work with the subject's light over an area field of view and detect subtle line phenomena in the machine direction (MD) or the direction of motion of a continuous web during paper manufacturing. RKB has a patent on the technique of detecting defects on a continuous moving web of material, and more particularly, detecting defects in the form of streaks and scratches using area-scan camera technology [5]. This includes real-time inspection and detection of streaks and scratches that occur substantially parallel to the machine direction (MD). An energy source such as an incandescent lamp or bank of lamps generates energy that impinges upon or is transmitted through the web or sheet of material. The area type camera receives either reflected light or transmitted light and then generates video signals accordingly. The area cameras are disposed opposite the energy source or within a particular degree of the plane perpendicular to the plane of the web. The video signals are processed by the system to generate an enhanced signal to noise ratio that represents a streak or scratch on the web or sheeted material. Light transmission was used for detection of streaks using two interlaced two-dimensional cameras. Illumination was provided through four conventional fluorescent tubes.

## Test Setup and Description of the Calibrated Defects

Shown in Fig. 2 is a photograph of the RKB web inspection system. This figure shows the location along the line of the pilot coater where the measurements were taken. At this location the web is horizontally oriented at 1 m above the ground and perpendicular to the optical axis of the cameras. Shown in Fig. 3 is a view of the beginning of the pilot coater as a roll of paper being unwound during the experiments with the web inspection system. The line-scan camera uses three special very high output fluorescent tubes for the light source, two on the top of the web in reflection configuration for dark spot detection, and one on the bottom for hole detection. The distance from the line-scan camera to the surface of the web was 68.6 cm (27 inches).

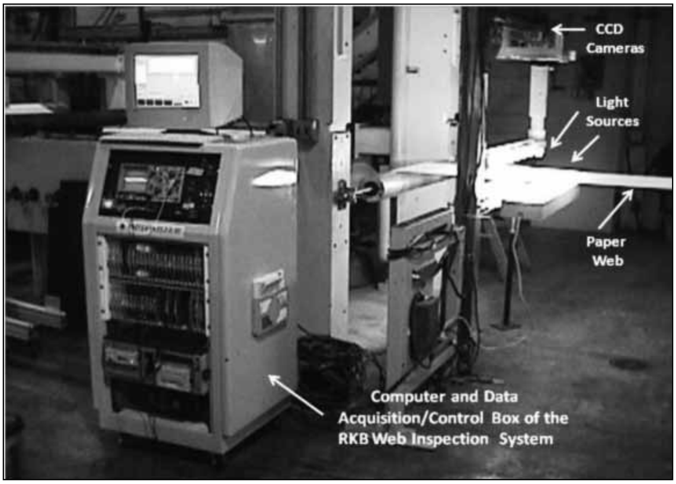


***Figure 2.*** General view of the RKB web inspection system demonstration unit used in the pilot-scale experiments.

The field of view (length of the line scanned across the web) was 34.3 cm (13.5 inches) and the sensor was a line 2.5 cm long, made of 1024 pixels. The field of view was less than the total width of the web of 76.2 cm (30'') because only one camera was available for discrete defect detection. Inspecting the whole width of the web would have meant a pixel size along CD of 0.6-0.7 mm which would have been too big compared to the typical size of the dark spots. All rolls were unwound, so that their external surface was facing the cameras.

Shown in Fig. 4a-4c are layouts corresponding to the calibrated defects. Each of the three defect sections shown in Fig. 4a was 9.14 m (30 feet) long with a printing width of 2.44 m (8 feet as shown in Fig. 4b). The defect sections were spliced in three places of a "defect free" roll. The calibrated defects were in the form of circular spots at various diameters in the range of 0.25 mm to 1.0 mm printed on a 400 dot-per-inch (dpi) wide-format printer using an offset bond paper provided by International Paper.

In order to run the test at a speed of 1005.8 m/min (3300 feet/min) and have a sufficient amount of run time for each test, these defect sections were spliced at the appropriate length of leader and trailer (Fig. 4a) which were expected to be defect free. Shown in Fig. 4b are the orientation of circular spots and location of the complex images in each section. Each horizontal or vertical line represents a series of circular spots placed at a predetermined spacing. For instance, for the two spot regions with a horizontal orientation, the spacing between each two spots along the horizontal direction was approximately 20 mm, and along the vertical direction was approximately 80 mm. The spacing for the spots with a vertical orientation was 90 mm and 30 mm along horizontal and vertical directions, respectively. Note that the spots were distributed along a 76.2 cm (30") distance which corresponds to the cross direction width of the paper. Shown in Fig. 4c are the images of the complex-shape objects, which were placed on the roll to evaluate systems with imaging capabilities.

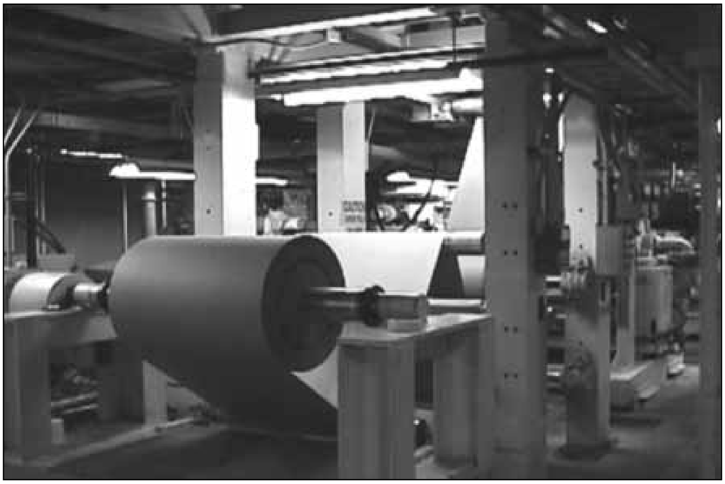

***Figure 3.*** View of the beginning of the pilot coater line. Roll is being unwound.

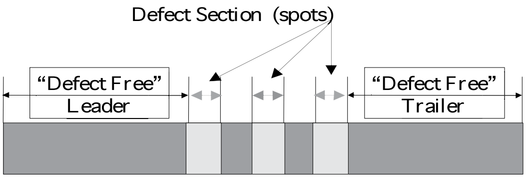


***Figure 4a.*** Locations of Three Defect Sections in a Roll.

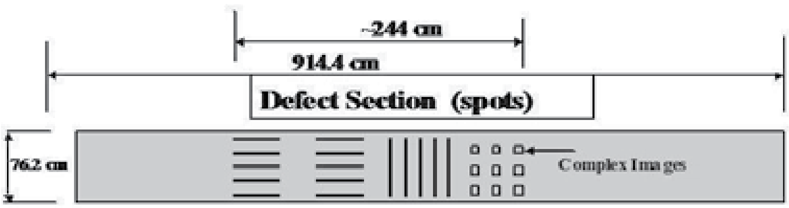


***Figure 4b.*** Orientation of Spots and Location of Complex Images in each Section.

***Figure 4c.*** Complex Shape Objects in each Sections.

## RESULTS AND DISCUSSION

To determine repeatability of the sensor in detection of the same flaws and defects, we conducted repeated tests of the same roll of paper for various paper types such as linerboard (use in manufacturing of corrugated boxes), newsprint (used in newspaper) and several other types of papers. In this section, results obtained from experiments with three types of paper will be presented. Figure 5 shows some typical defects observed in a 33-lb (~15 kg) linerboard. The paper industry refers to this type of paper as 33-lb linerboard because the thickness of the paper is such that the weight of each 1000 ft (304.8 m) length of the paper in a paper machine that is approximately 10 m wide is approximately 33 lb (~150 kg). The flaws detected for this paper were mainly dark spots, dark fibers or few light spots. The numbers above the graduation marks shown on Fig. 5 are in centimeters and the small graduations are in millimeters. The roll was rewound after the test each test and the test was repeated three times (identified as runs 1, 2, and 3).

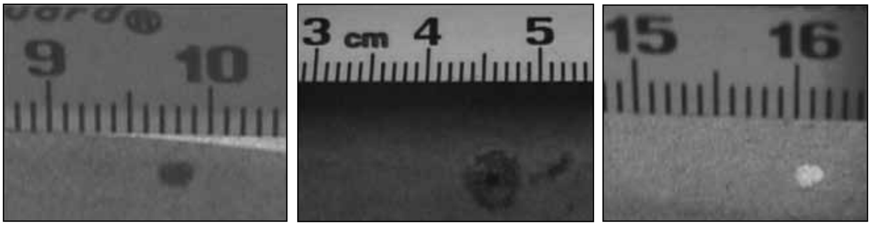


***Figure 5.*** Examples of defects present in 33-lb linerboard, dark spots and light spot.

In these tests we used a machine speed of 762 m/min (2500 ft/min). Outside surface was up and facing the camera. Since this paper was thick, only the dark spots facing the camera could be detected using reflected light. The dark spots facing the ground couldn't be detected, which is normal for this grade. Holes (appearing as bright spots) are detected using the transmitted light of the fluorescent tubes placed under the web.

As expected from a thick grade, we observed many more dark spots than holes in this linerboard grade. The black disks in Fig. 6 indicate that a dark spot has been detected. RKB could detect spots and holes that were different in shape and size. These defects are shown by a circular symbol. The color band on the TV monitor stands for the spot size. Blue, green, and red correspond to small, medium, and large, respectively. Representation of defects in this system is consistent with the Technical Association of Pulp and Paper Industry (TAPPI) standard [6, 7]. Holes and spots are represented by circles in which dark circles are used for spots and white circles correspond to holes. The numbers on the left side are a time counter that can be used for finding the position of the defect along the machine direction, knowing the speed of the machine.

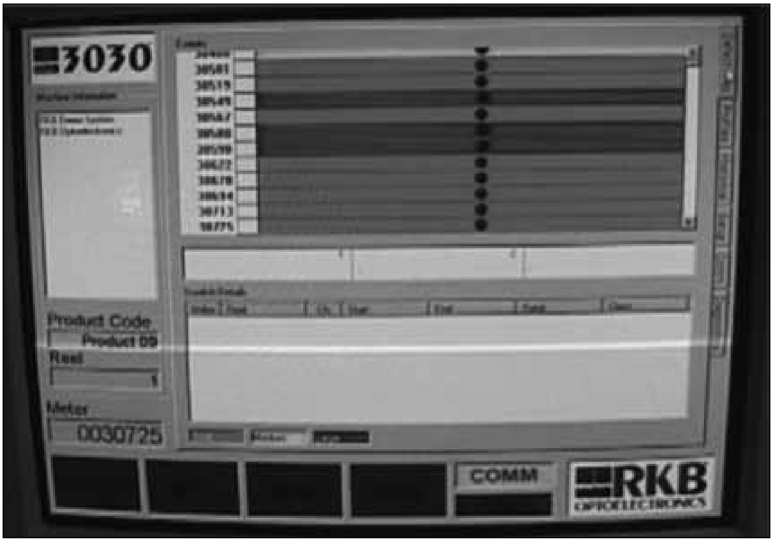


***Figure 6.*** View of the computer screen during the trial with the 33-lb (15 kg) linerboard.

Shown in Figures 7-9 are comparisons among the number of spots, holes, and total defects for three repeated runs using the 33-lb (15 kg) linerboard. Percent differences between the number of spots detected in runs 1 and 2 for spot sizes of small, medium, and large were 9.0%, 2.2%, and 8.2%, respectively. Considering problems associated with high tension and sheet fluttering that occurred during these runs, the percent difference is relatively small. Note that percent differences between each two numbers are obtained relative to the average values of these numbers. Results shown in Figures 8 and 9 indicate that for the hole sizes of medium and large (Fig. 8), and also the total number of defects (Fig. 9), there was a larger difference in number of defects detected in run 3 compared with the other two runs. In addition to differences in the amount of sheet fluttering, there was also a difference in the setting of threshold detection levels among these runs. In runs 1 and 2 the threshold detection level was set to 6.9 (10 being the most sensitive) while in run 3 the corresponding setting was 6.7.

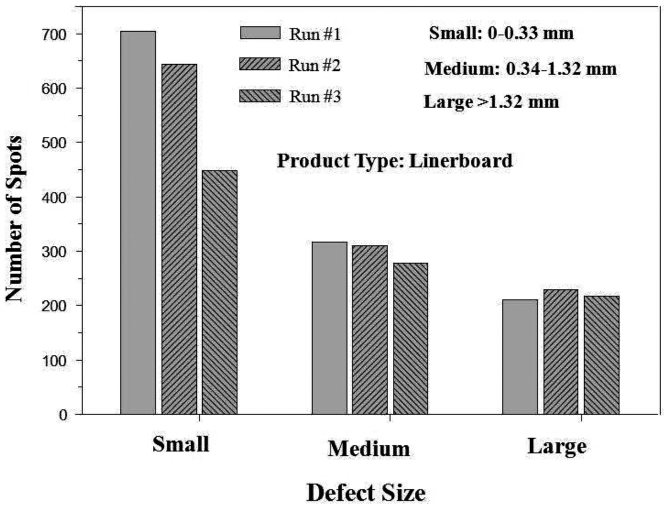


***Figure 7.*** Comparison among the number of spots detected in Linerboard for the runs 1-3.

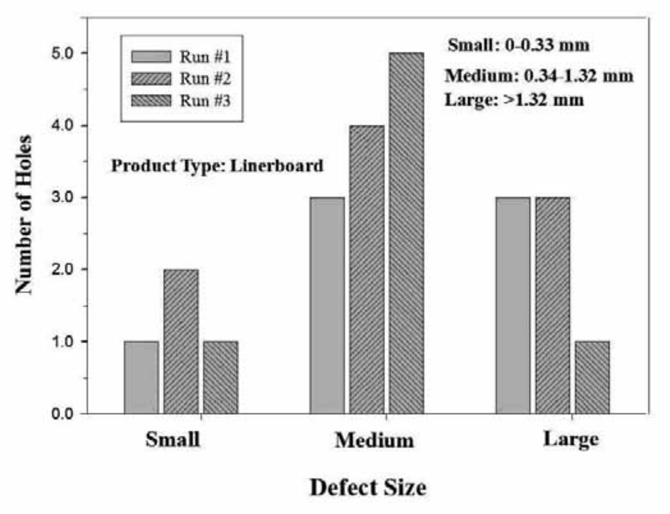


***Figure 8.*** Comparison among the number of holes detected in Linerboard for the runs 1-3.

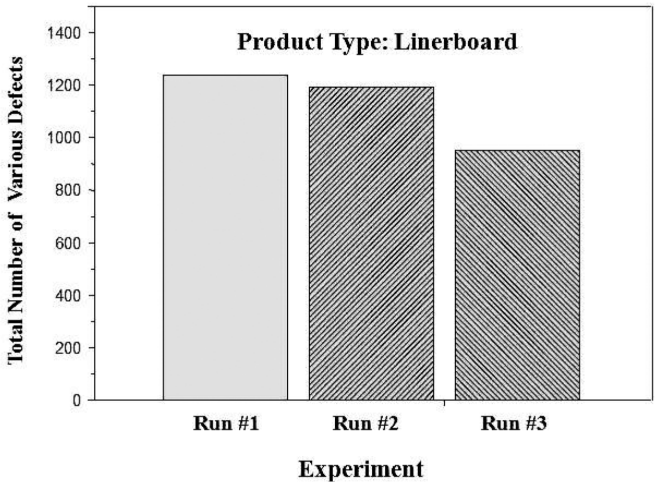


***Figure 9.*** Comparison among the total number of defects detected in Linerboard for the runs 1-3.

Shown in Fig. 10 is a comparison among the number of spots in each of three size category of small (0-1.00 mm), medium (1.01-2.0 mm) and large (> 2.0 mm) for a roll of Newsprint (identified as Run #F6).

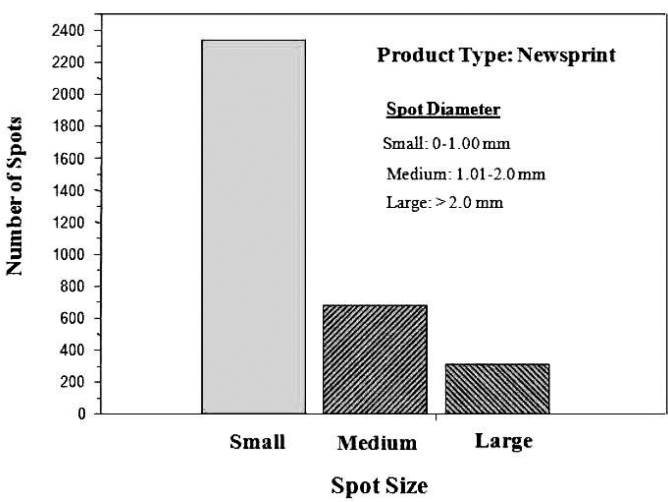


***Figure 10.*** Number of spots detected in Newsprint

Shown in Fig. 11 is a comparison between the number of spots detected for the offset Bond type of paper for the three size categories.

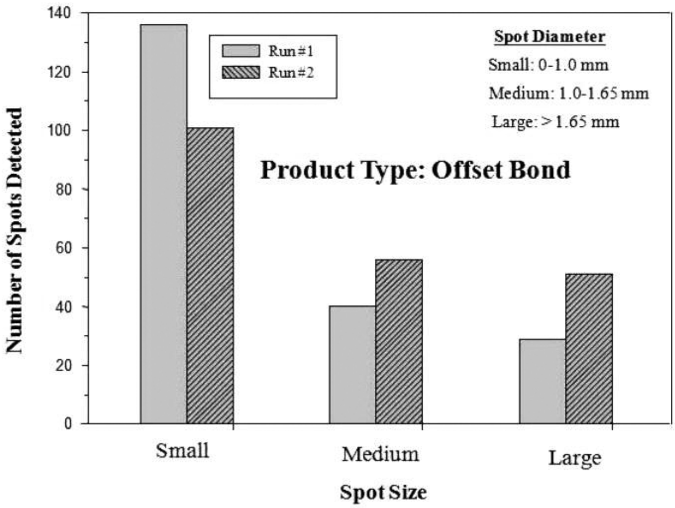


***Figure 11.*** Comparison between the number of spots detected in the Offset Bond paper.

## SUMMARY AND CONCLUSIONS

The RKB Opto-electronics, Inc., Model 3030 Video Web Inspection System using CCD camera-based technology, in particular the 1024 CCD Line Scanning Chip, could detect many holes and spots that were present in various types of papers. By using their CCD area-scan technology, RKB could also detect coating scratches and streaks in the coated samples. Many spots introduced in the calibration roll were much smaller than 1-mm diameter. Also, the spacing between each two spots for many spots were too close to detect them at a machine speed of 1006 m/min (3300 feet/min). Another limiting factor was that the calibrated defects were distributed along a 76.2 cm (30”) of CD width, while the field of view of the camera (length of the line scanned across the web) was only 34.3 cm (13.5”). Therefore, during the trails with the calibration sheets, only 45% of the calibrated defects were located in the field of view of the single camera system. Furthermore, during the trials in Appleton, there were some difficulties in maintaining a stable web in which there was no sheet fluttering. Because of these limiting factors, many small spots introduced on the calibration sheet (e.g., spots less than 1 mm in diameter, and closely packed spots) were not detected. For instance from a total of 1320 spots that were 1-mm in diameter and placed on the calibration sheet, only 638 spots were in the field of view of the camera; and from these spots, only 136 spots were detected. From a total of 1418 spots with less that 1-mm in diameter, about 638 spots were in the field of view of the camera, however, the camera setting was such that only spots that were greater than or equal to 1-mm in diameter could be detected. It should be noted that during the trails with the calibrated rolls, more emphasis was given to repeatability of the tests than detection of absolute number of defects. However, the problems mentioned also contributed to differences in number of defects in runs that were made for determination of system repeatability. It appeared that the web inspection system was sensitive to the splicing tapes used in the calibrated sheets and erroneously identified them as defects (*e.g.*, holes). Comparison between the number of spots detected using the calibrated roll indicates that the differences obtained between the two runs for medium and large spots were smaller than those obtained for the small spots. Therefore, it appears that the system exhibits better repeatability for spots greater than 1.0 mm in diameter. Although it was expected that the leader and trailer sections of the calibrated roll would be defect free, based on the data provided by the system, some spots were present in these sections. It was determined that among the mill environmental and operational variables, sheet fluttering and slacking of the web had a significant influence on detection capability of the system. It should be noted that the speed of the paper machine used in these experiments was higher than those normally used in the previous runs with the pilot machine. Therefore it was not possible to assess relative performance of the machine compared to previous runs under similar conditions. In general, methods used in the RKB system for displaying and presenting the results in which dark spots are represented by black disks and color band over each disk is introduced to show classification of the spots make it very easy for an operator to inspect the product quality.

## ACKNOWLEDGEMENTS

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