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Appearance Quality Inspection System for Paper Making Industry†

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Abstract:

JFE Electrical & Control Systems has developed an appearance quality inspection monitoring device with optical image sensors of the flat sheet for the finishing line of a paper mill. The monitoring device detects defects on the edge of laminated paper, such as adhered paper particle, paper folding and abnormal alignment. Quantification of adhesion amount of paper dust by texture analysis method has been introduced. By the appropriate position of placement of cameras and lighting, detection of paper folding with high accuracy has been achieved. Detecting the abnormal alignment of paper of 0.5 mm was developed by optical cutting method. By introducing these technologies, automation of visual inspection has become possible to replace the conventional visual inspection. Two monitors have already been installed and are in operation in a paper mill company for folio sheeting line; in addition another four monitoring devices with the same technology are being used for plain paper copier.

1. Introduction

Since its establishment, JFE Electrical & Control Systems has developed a solution business for quality-related sensors as one of engineering businesses. The objects of these sensors include dimensions, shape and defect detection for the steel manufacturing plants of JFE Steel and for non-steel manufacturing industries. As one example, JFE Electrical & Control Systems and Oji Paper Co., Ltd. jointly developed an appearance quality inspection system for paper mill finishing lines. This system detects adhering paper particles, folded paper defects, and misalignment (protruding sheets, small misalignment) of stacks of paper such as printing paper and paper for plain paper copiers. Although these defects are important items for quality control, inspections of 100% of the product had been performed by visual checks by operators because a highly accurate automatic detection technology did not exist. JFE Electrical & Control Systems developed and commercialized a technology which enables detection of these abnormalities by utilizing image processing technology. This paper presents an outline of the appearance quality inspection system[1)] for stacked paper which was developed in this work.

2. Background of Development

2.1 Paper Mill Finishing Line

This section presents a simple outline of the paper mill finishing line. Paper in coil form is cut to the specified size by a slitter and rotary knife, normally in units of 5 sheets, after which the paper is stacked. Following visual inspection for fluffing, adhering paper particles, and folding of the cut edge, which occur in this process, and protruding sheets/small misalignment, which may occur during stacking, the paper stacks are wrapped and shipped. **Figure 1** shows the layout of a finishing line for communication paper.

2.2 Objects of Inspection

Paper mills produce paper with various properties.

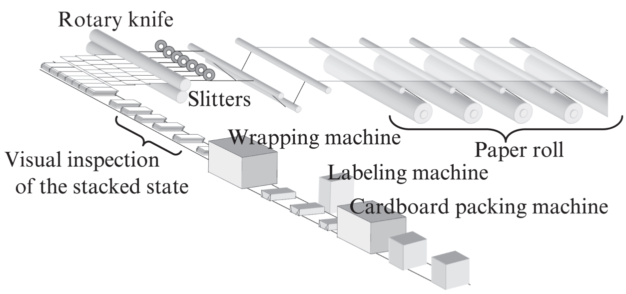

Fig. 1 Layout of finishing line for communication paper

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These products can be classified as "Communications paper," "Printing and writing paper," "Duplex board, packaging materials, and container board," "Newsprint," "Household paper (tissue, toilet rolls)," and "Functional materials." As discussed in the following, the objects of inspection by the developed system are "Communications paper," "Printing and writing paper," and "duplex board, packaging materials, and container board." These various products are not produced in a mixed manner on the same line. Basis weight is expressed by the weight of paper per 1 m^2, which is the general unit that is used in business transactions for paper. The approximate thickness of paper (mm) can be obtained by dividing the numerical basis weight by 850. A stack of communications paper is called a ream, and stacks of printing paper and writing paper and duplex board, etc. are called skids.

(1) Communications Paper

Cmmunication paper is the paper used in plain paper copier. The sizes of the paper are B5, A4, B4, A3, etc. in packages of 250, 500, and 1 000 sheets. The basis weight is approximately 64–68 g/m^2. Communications paper finishing lines produce 140 reams/min at maximum speed.

(2) Printing and Writing Paper

Printing and writing paper is paper used in gravure printing, books and the like. Various types are produced, depending on the paper thickness, surface finish and coating and other specifications. Sizes include the standard sizes of series A (625 mm × 880 mm), duodecimo (788 mm × 1 091 mm), kraft paper (900 mm × 1 200 mm), and others. The basis weight ranges from 64 g/m^2 to 465 g/m^2. The maximum stack height and weight are approximately 1 700 mm and 1 800 kg, respectively. The production rate is approximately 30 skids/hour per line.

(3) Duplex Board, Packaging Materials, and Container Board

This type is mainly stock paper for cardboard boxes, paper for paper containers and building paper boards. The basis weight is 210 g/m^2 or more, and the maximum stack height is approximately 1 200 mm. Hourly production by one finishing line is roughly the same as that for printing and writing paper.

3. Detection Methods

3.1 Paper Particles

Paper particles occur depending on the condition of the slitter and rotary knife blades. If paper particles fall off in a printing press and adhere to the plate cylinder or other parts, missing spots will occur in the ink, resulting in a mass printing defect. For this reason, paper particles are an important quality control item for paper finishing lines. Conventionally, the operator made a sensory evaluation of the amount of adhering particles by visual inspection.

Photo 1 Normal lamination plane

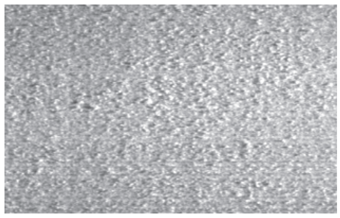

Photo 2 Fluffing

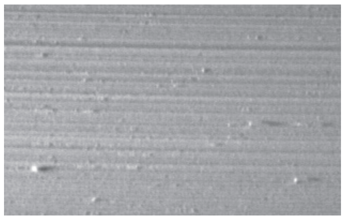

Photo 3 Adhesion of paper particles

In the developed inspection system, the lighting used to accentuate paper particles adhering to the stacked edge surface and the paper being inspected are arranged so that the optical axis of the lighting and the surface of the paper form an angle of 30° or less. A camera is arranged directly facing the inspection surface and photographs a field of view of 65 mm × 45 mm with a resolution of 0.1 mm. **Photo 1** shows a normal surface with no adhering paper particles, **Photo 2** shows a surface with fine filiform fluffing, and **Photo 3** shows adhesion of large spherical particles. Fluffing and particle adhesion are evaluated by separate algorithms, and a total evaluation value is obtained by weighting fluffing and adhesion.

3.1.1 Evaluation of fluffing

Accurate extraction of individual fluffing particles is difficult due to the small, fine, long shape of the particles. Therefore, the pattern caused by widespread distribution of fluffing is evaluated by texture analysis. A co-occurrence matrix is formed from the brightness values B_i and B_j of point i of the inspection range set in the

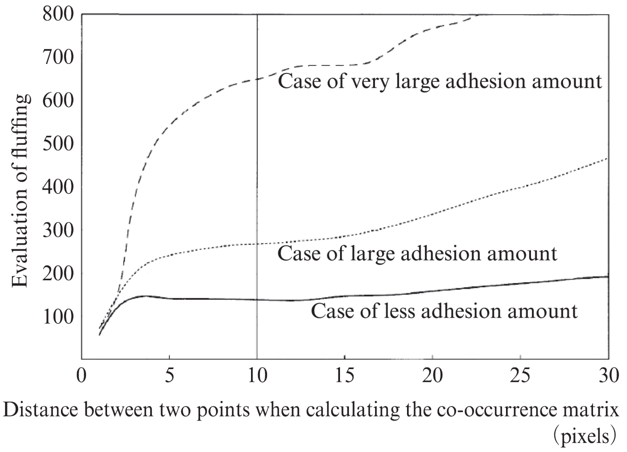

Fig. 2 Evaluation of fluffing

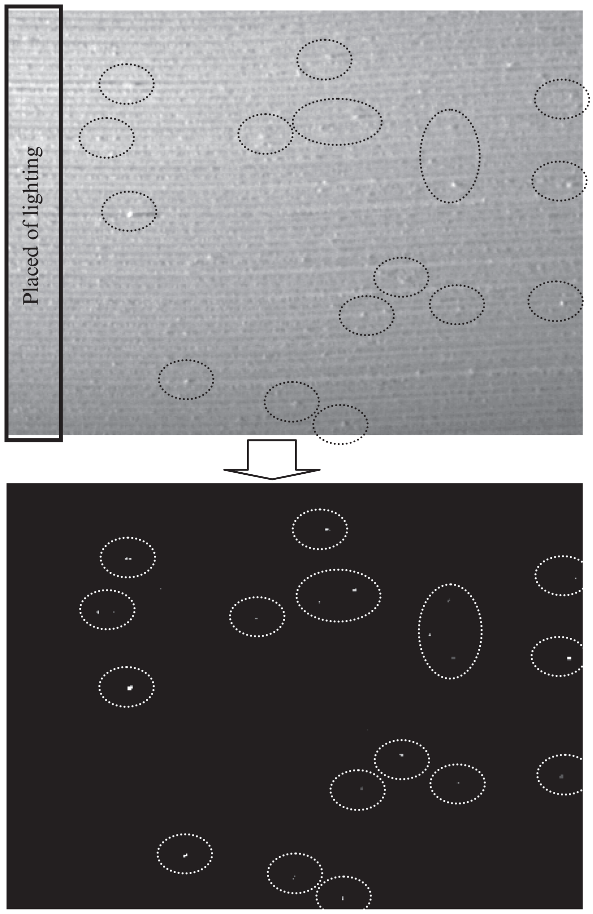

Photo 4 Extraction results of paper particles

image and point j, which is separated from point i by just a certain displacement $\delta = (r, \theta)$, and an evaluation is performed by using the following equation[2]. In this equation, $P\delta$ (B_i, B_j) expresses the probability that the brightness of 2 points separated by just δ within the inspection range will be (B_i, B_j).

$$\text{Evaluation of fluffing} = \sum_i \sum_j (B_i - B_j)^2 \bullet P_\delta(B_i, B_j)$$

Variations and undulations in the mean brightness of individual papers will occur in a stacked surface. Therefore, all the brightness values of pixels of $\theta = 0° \pm 25°$ and distance r are obtained, and in case 2 points exist on the same paper, point j is estimated based on the assumption that the brightness difference is small. **Figure 2** shows the calculated value and operator's evaluation of a sample. If the distance$r$is increased, it becomes difficult to follow undulations, and the evaluation value also increases due to the effect of nonuniformity of the lighting. At present, calculations are performed at $r = 10$ pixels.

3.1.2 Evaluation of particles

Spots where the brightness value in an image increases suddenly are extracted, and when a bright spot exists as a pair with a dark area due to the shadow on the opposite side from the direction where the lighting is installed, that bright spot is recognized as a particle. The area of bright spots is used in the evaluation. **Photo 4** shows an example of particle extraction. The brightness of the extracted spots in the extraction result image differs depending on the particle; this shows the probability of a particle judged from the brightness value of its pixels, etc.

3.2 Detection of Paper Folding

Paper folding occurs when there was an abnormality in the mechanical operation of the finishing line. The folded paper defect is the most important quality item, as it is a cause of printing machine damage. Since no technology which enabled automatic detection of paper folding had been established until now, detection depended on visual inspection by the operator.

3.2.1 Folding detection method

A laminated paper surface reflects illuminated light by diffuse reflection. However, in a folded part, the flat surface of the paper appears on the laminated surface and causes a strong reflection of the illuminated light. This means the fold is photographed as brighter than the surrounding area. Moreover, because the paper is higher at a fold, the right and left sides of the fold appear dark in the photograph. In image processing, folds are detected by searching for pairs of areas which are "darker than the surrounding area-brighter than the surrounding area." Because this method detects folds by the difference in the reflection of light, stable detection is possible even when folds have been crushed by self-weight in the downward direction of printing paper. **Figure 3** shows the arrangement of the camera and illuminator, and **Photo 5** shows an example of detection of a fold in communications paper.

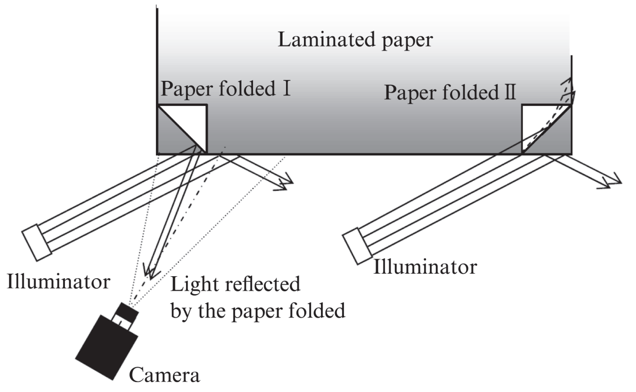

Fig. 3 Detection method of paper folded

Photo 5 Captured image of paper folded

3.2.2 Fold detection operation

With the camera/illuminator arrangement in Fig. 3, it is possible to detect fold I, but fold II cannot be detected because the strong reflected light does not return to the camera side. Therefore, in printing paper, which has a wide inspection surface, the entire surface is first detected by setting the camera and illuminator in the direction shown in Fig. 3, after which the angles of the camera and illuminator are changed for use in detection of fold II, and the entire surface is then inspected again. To solve this problem in the inspection system for communications paper, the camera is set directly facing the inspection surface, and photography is possible by high speed switching between the illumination for fold I and the illumination for fold II.

In the inspection system for printing and writing paper, assuming the camera resolution is 0.1 mm/pixel, in order to respond to the height of 1 700 mm of the skid, photography is performed with six 4 096 pixel line scan cameras arranged in a line on one side of the paper. In the inspection system for communications paper, one 1.4 M pixel area scan camera per side is used.

3.3 Detection of Misalignment

The condition in which 1 sheet to several sheets protrude 1 mm or more from the stacking plane is called abnormal alignment, and the condition in which several tens of sheets or more protrude together is called a lump. The condition in which irregularities with a size of 1 mm or less occur continuously over a wide range is called small abnormal alignment. Because abnormal alignment and lumps are caused by line trouble such as catching by the guides, etc. in the downstream process during transportation on the conveyor and similar problems, early discovery and action are necessary. Small abnormal alignment is an appearance problem, and action is also required. Although detection of abnormal alignment and lumps had been performed by definite reflective photoelectric sensors, performance was inadequate as the minimum detection size of abnormal alignment was 5.0 mm, and it was not possible to detect small abnormal alignment. Therefore, paper makers had responded by sensory inspection by the operator.

3.3.1 Abnormal alignment/ small abnormal alignment detection method

Detection of abnormal alignment and small abnormal alignment of stacked paper is performed by the optical cutting method (**Fig. 4**). Because images are acquired by using a laser projector installed with a 40° downward

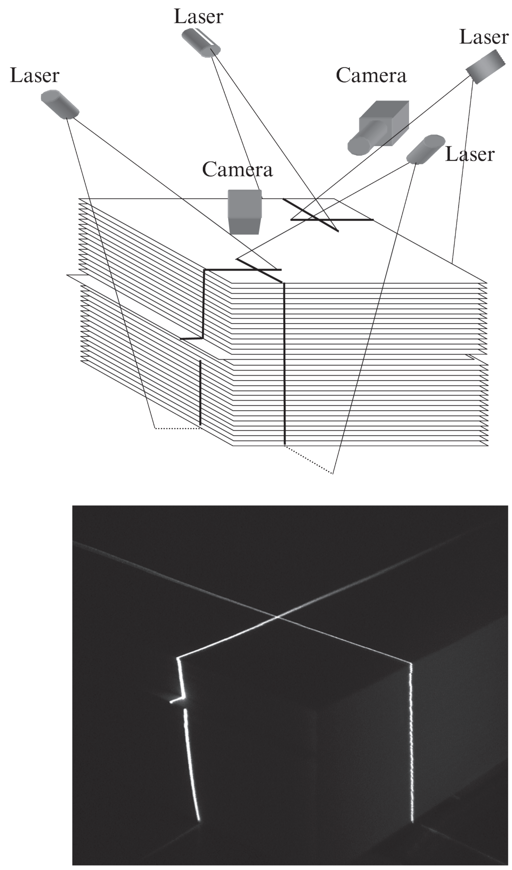

Fig. 4 Detection method abnormal aligned and captured image

and a camera with a 30° downward angle, a shadow is formed at the part where the paper protrudes, and the camera can capture the interruption in the laser trajectory. The part where the paper protrudes is judged to be immediately above the interruption of the laser trajectory.

In the detection program, abnormal alignment, lumps, small abnormal alignment and waviness are identified and quantified based on the condition of the laser trajectory, and thresholds for output of these respective abnormalities are set. The minimum detection size of irregularities in the stacked paper edge surface is 0.5 mm.

3.3.2 Abnormal alignment/ small abnormal alignment detection operation

In inspections of communication paper, lasers are irradiated on two surfaces, i. e., the slit surface, which is cut by the slitter, and the knife surface, which is cut by the rotary knife. Laser irradiation is performed at the two diagonally-opposed corners, and photography is done with a resolution of 0.1 mm/pixel by a 2.0 M pixel area scan camera. With printing and writing paper, it is not possible to acquire all the information for the height direction in a single operation. Therefore, photography is performed continuously while simultaneously raising/lowering a laser projector and a 2 048 pixel line scan camera. The camera resolution is approximately 0.09 mm/pixel in both the width and vertical directions, and the minimum detection size is 0.5 mm. **Photo 6** shows an example of small abnormal alignment and lumps of printing and writing paper.

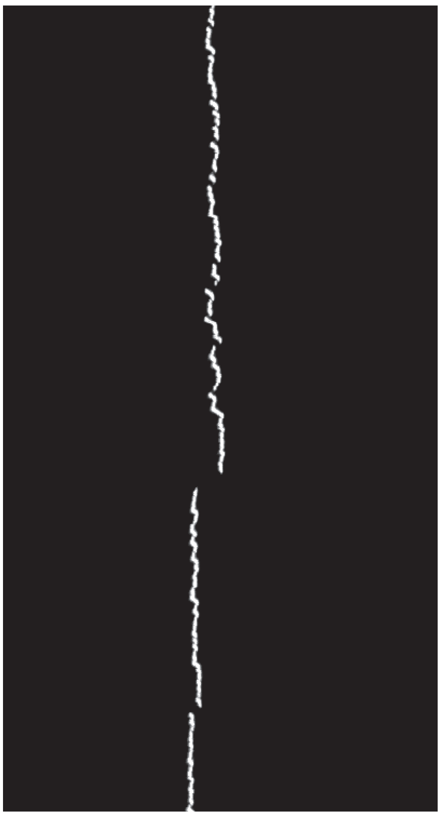

Photo 6 Captured image of small abnormal aligned and lumps

4. Inspection System

4.1 Appearance Quality Inspection System for Communications Paper

Figure 5 shows the inspection points of the inspection system for communications paper. **Photo 7** shows the appearance of the inspection system. In order to perform these inspections, the following equipment is housed in a space of 800 mm in the conveyor moving direction.

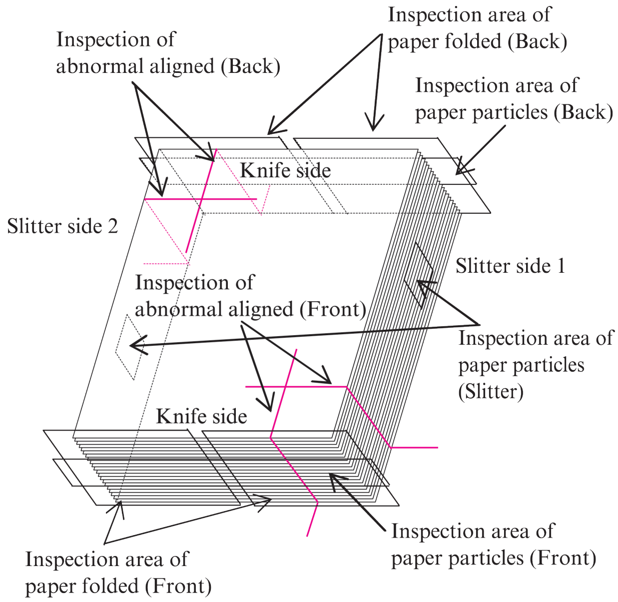

Fig. 5 Inspection points for plain paper copier

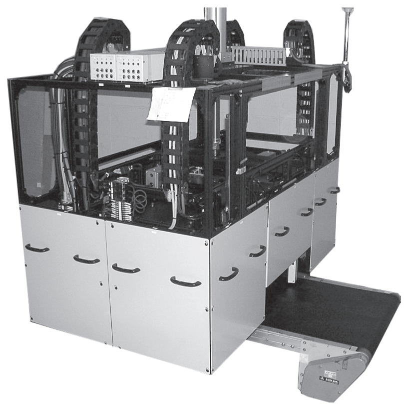

Photo 7 Appearance quality inspection system for plain paper copier

(1) Paper Particle Inspection
- Front side knife: 300 K pixel area scan camera + LED illuminator, 1 unit
- Back side knife: 300 K pixel area scan camera + LED illuminator, 1 unit
- Slitter 1: 300 K pixel area scan camera + LED illuminator, 1 unit
- Slitter 2: 300 K pixel area scan camera + LED illuminator, 1 unit

(2) Folded Paper Inspection (Corresponding to Fold I and Fold II)
- Front side: 1.4 M pixel area scan camera + LED illuminator, 2 units
- Back side: 1.4 M pixel area scan camera + LED illuminator, 2 units

(3) Abnormal Alignment Inspection
- Front side: 2.0 M pixel area scan camera + Laser projector, 2 units
- Back side: 2.0 M pixel area scan camera + Laser projector, 2 units

Close tracking of the movement of reams is performed by an encoder attached to the conveyor motor, and the timing is adjusted at the timing of each inspection so that the illumination does not interfere with other inspections. This makes it possible to perform inspection without interference by illumination, even in treatment of 140 reams/minute, in which a maximum of 3 reams are present in the device at all times.

In order to support inspection of sizes from B5 to A3, a mechanism which moves this equipment as a single unit by means of an electric cylinder is provided in the inspection device.

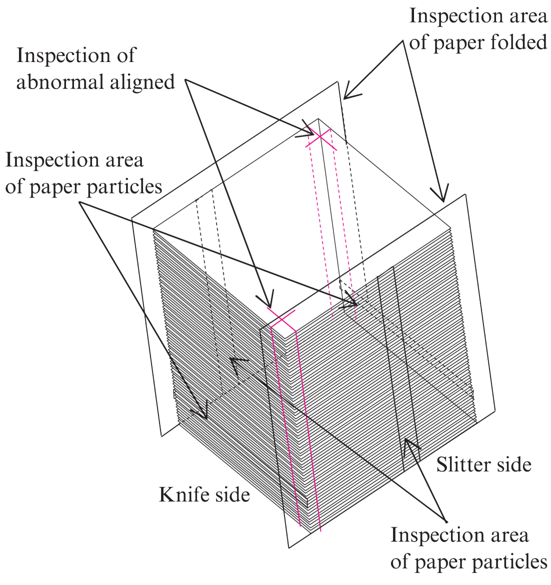

Fig. 6 Inspection points for folio sheeting line

4.2 Appearance Quality Inspection System for Printing and Writing Paper

Figure 6 shows the inspection points of the inspection system for printing and writing paper. **Photos 8** and **9** show views of the inspection system. The following equipment is installed in the inspection system.

(1) Paper Particle Inspection

Inspection areas: Knife side, 2 areas; Slitter side, 2 areas

Each area is equipped with a 300 K pixel area scan camera, 1 unit + LED illuminator, 1 unit

(2) Folded Paper Inspection (Corresponding to Fold I and Fold II)

Inspection areas: Slitter side, 2 areas

Each area is equipped with 4 096 pixel line scan cameras, 6 units + LED illuminator, 2 sets

(3) Abnormal Alignment Inspection

Inspection areas: 2 areas at diagonally-opposed corners

Each area is equipped with a 2 048 pixel line scan

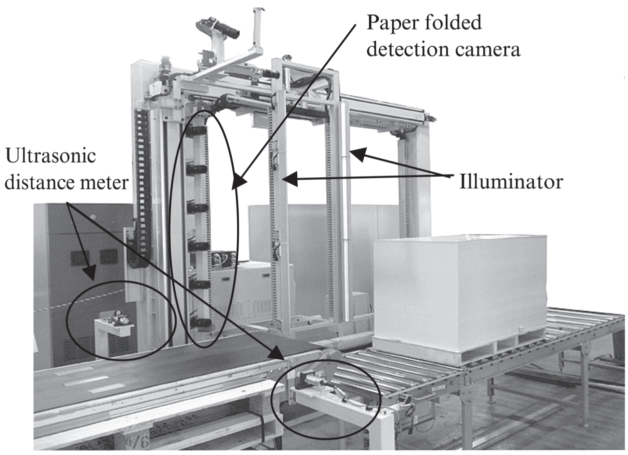

Photo 8 Appearance quality inspection system for folio sheeting line

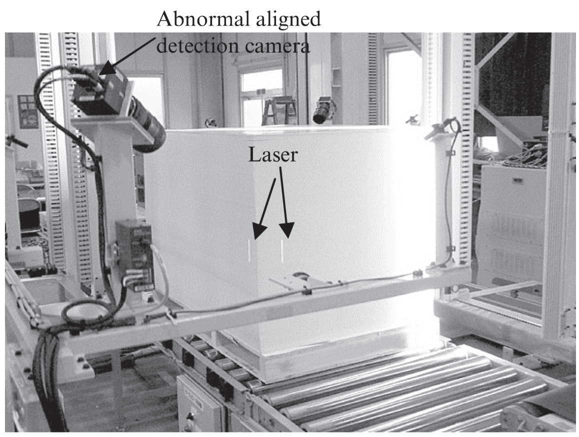

Photo 9 Appearance quality inspection system for folio sheeting line—Detection abnormal aligned

camera, 1 unit + Laser projector, 2 units

Due to the large inspection area, the system comprises a total of 18 cameras to enable inspection of all items and 8 PCs for processing of the results. Because printing and writing paper is produced in a wide variety of sizes, an ultrasonic distance meter is installed upstream from the inspection device to measure the edge position of the skids, and the cameras and illuminators are positioned by servo motors.

When an abnormality is detected in these inspections, the skid is stopped at a predetermined position in the following process and an alarm is output. At this time, a judgment card showing the position of the skid and the type of abnormality with an attached image is printed out so that the operator can confirm the condition of the abnormality while referring to the card. The processing time of the inspection system is (45–90 seconds from stop the conveyor until photograph) + (15–30 seconds from the photography to output of the results).

5. Conclusion

This paper introduced inspection methods and structure of appearance quality inspection systems for paper mill finishing lines. The main content is summarized below.

(1) A judgment method for paper particles on the cut edges of stacked paper was explained. The two conditions of fluffing and adhering paper particles exist at the edge. Fluffing is quantified by texture analysis, and particles are extracted from the background by utilizing illumination characteristics.

(2) A method for detecting folds in the stacked edge was explained. In the stacked surface and the plane of the paper, the reflection of illuminated light is different. By using this difference, a camera/lighting arrangement was presented to detect a fold appears in the stacked surface. This has made it possible to detect a fold of even 1 sheet under a condition in which a large load is applied, for example, in the case of printing paper.

(3) For detection of abnormal alignment (protruding sheets) and small abnormal alignment at the stacked edge, a method for detecting irregularities of the stacked edge with sensitivity of 0.5 mm by using the optical cutting method was presented.

(4) For stacked communications paper and printing and writing paper, an inspection system which performs inspections for paper particles, folds, abnormal alignment (protruding sheets), and small abnormal alignment was introduced.

JFE Electrical & Control Systems successively delivered four inspection systems for communications paper finishing lines since 2007 and two inspection systems for printing and writing paper finishing lines since February 2009. In all cases, this equipment is operating smoothly and has made important contributions to quality improvement and improvement of the operating efficiency of operators[3]. In 2014, JFE Electrical & Control Systems and Oji Paper Co., Ltd. jointly received the 42nd Sasaki Award from Japan Technical Association of the Paper and Pulp Industry (Japan TAPPI), whose main members are paper making companies. The award recognized the two companies as companies which have made remarkable achievements through technical development/research and development, thereby contributing to the paper and pulp industry.

In the future, JFE Electrical & Control Systems will continue to work to develop devices which contribute to operational improvement and improvement of product quality by solutions in which image processing, laser technology and other measurement technologies are core features.

The author wishes to take this opportunity to express his deep appreciation to Oji Paper Co., Ltd., Oji Engineering Co., Ltd., Nichinan Oji Shigyo Co., Ltd., and Yonago Oji Shigyo Co., Ltd. for their valuable advice in the development and introduction of this inspection system.

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