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DESIGN OF ROLLER AND SENSOR MECHSANISMS FOR AN INNOVATION OF PAPER HANDLING MACHINE

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Abstract

Our civilized community is supported by paper: documents, books, postcards, and so on. Under the circumstances, many paper-handling machines are used. Rubber rollers are widely used for feeding of paper. Feeding without trouble i.e. reliable motion is required as a common technology. Therefore, the sensing of moving of paper is indispensable for the design of innovative paper-handling machines. This study presents three types of roller and sensor mechanisms with novel characteristics. i) Image sensor can detect paper displacement with sufficient repeatability and linearity. Its measurement includes about 10% error against the nominal resolution of the device i.e., 200 counts per inch (cpi). ii) A novel tactile sensor integrated roller works well. In the case of Roller type I, the PZT output amplitude is almost flat when the roller feeds paper; but when the roller slips on the paper, the output fluctuates. On the other hand, Roller type II can distinguish slipping/feeding by the amplitude level. iii) The roller has a relative rotation sensor including a rotary encoder that outputs many pulses when the roller slips on the paper; no pulse is counted when the roller feeds the paper. This roller correctly detects the paper feeding length. These methods can be selected according to the aims and specifications of paper-handling machines.

Keywords: Paper handling, Roller, Sensor, Innovation design, Paper feed

1. Introduction

Our civilized community is supported by paper in the form of documents, books, bills, postcards, and so on. Under the circumstances, many paper-handling machines - printers, facsimile machines, automatic teller machines, and ticket gate systems are useful equipment that satisfies our convenient, fast-paced, and labor-free lifestyles.

Rubber rollers are widely used for paper feeding in those paper-handling machines. Feeding paper sheets one at a time without defacing or mutilating the paper is a common and reliable technology for these machines. The contact force between the roller and paper must be very slight in order to avoid misfeeds, multiple feeds, crumpling or mutilation. However, an insufficient contact force engenders roller slipping on the paper and feeding failure. For that reason, sensing the moving condition of fed paper is indispensable for the design of innovational paper-handling machines.

From that perspective, this paper presents roller and sensor mechanisms. Several mechanisms were produced for trial; their functions were evaluated through experiments.

2. Method of paper feed sensing

A human can sense paper motion using a combination of vision and tactile senses to evaluate the displacement or acceleration of paper. Each sense is effective even if used by itself. Based on that observation, we designed three types of roller and sensor devices: (i) an image sensor, (ii) a tactile sensor-integrated roller, and (iii) a roller with a relative rotation sensor.

3. Image sensor

3.1 Outline of the image sensor

In recent years, in accordance with the widespread use of personal computers, optical mouse pointing devices have been become popular. Their quality has improved greatly. Figure 1 shows the internal structure of an optical mouse. The central part is an image sensor IC that detects the mouse movement. This device can easily identify a relative movement vector between the device and the surface by simply combining the lens and the LED. Figure 2 shows the light path. The light from the LED goes into the special lens and repeatedly reflects from internal components and then irradiates the paper surface. The light reflected on the paper surface incidences to the lens and enters the camera part through a receptor window. That image is translated into a 6-bit gray scale and is stored in memory. At that time, a comparison is made between the pre-movement image and the post-movement image. Thereby, the movement rates for the X direction and Y direction are calculated. The movement rate is output with XA, XB, and YA, YB, as pulses - similarly to linear encoder.

Figure 1 Optical mouse and its components

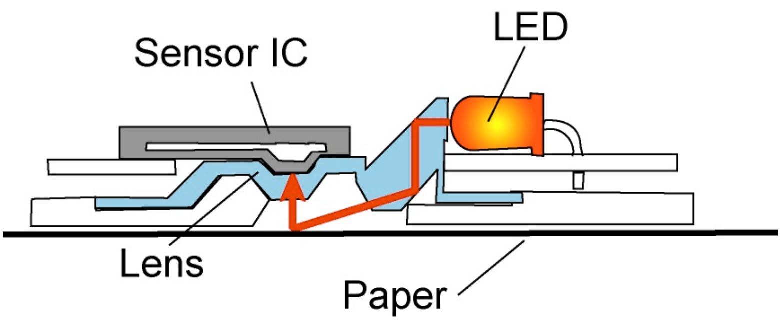

Figure 2 Light path from the LED to the image sensor

3.2 Paper-feed sensing using the image sensor

A commercially available mouse was dismantled. From it, the image sensor IC, lens, and LED were removed and wired onto a new universal circuit board to miniaturize the assembly. Figure 3 portrays these parts and Figure 4 illustrates the circuit diagram.

We did not feed the paper with a roller in this study because we seek to clarify the paper feeding length using the image sensor. Figure 5 shows that the paper was fixed on a precision X-axis stage with a micrometer. Above that, a paper-feed detecting sensor was placed with a magnet stand. The distance between the lens and the paper should be set correctly to focus the image. By moving the stage, the paper was moved 25 mm. During that motion, the number of sensor output pulses was counted for every 5 mm of movement. Nominal mouse sensitivity is a quad-edge evaluation, therefore implying a pulse rate of 400 cpi. However, because only the XA output pulses were each up-counted and down-counted, the pulse rate here was 200 cpi.

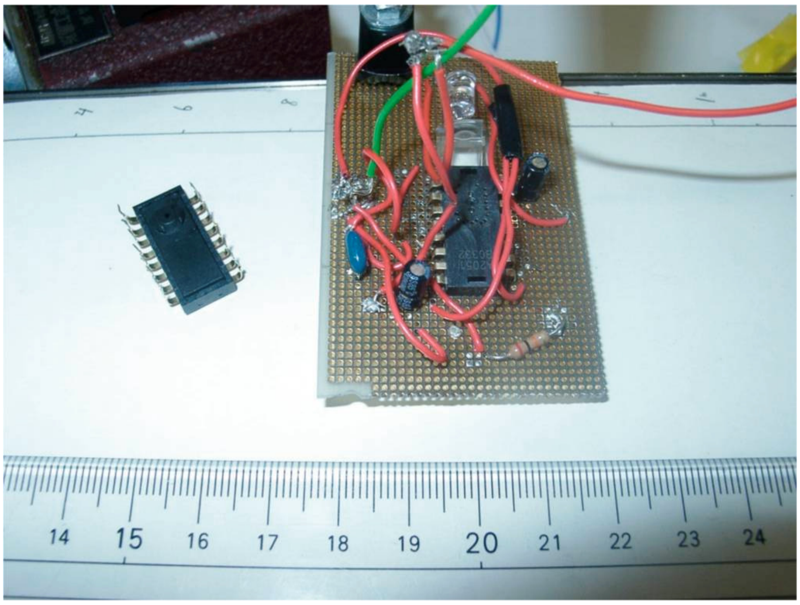

Figure 3　Photograph of image sensor unit

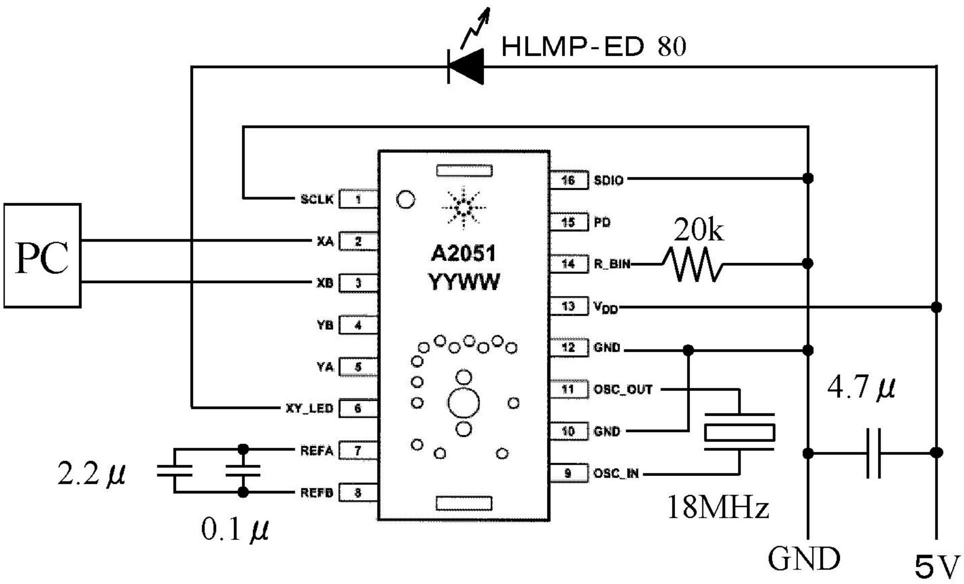

Figure 4　Circuit diagram of image sensor IC

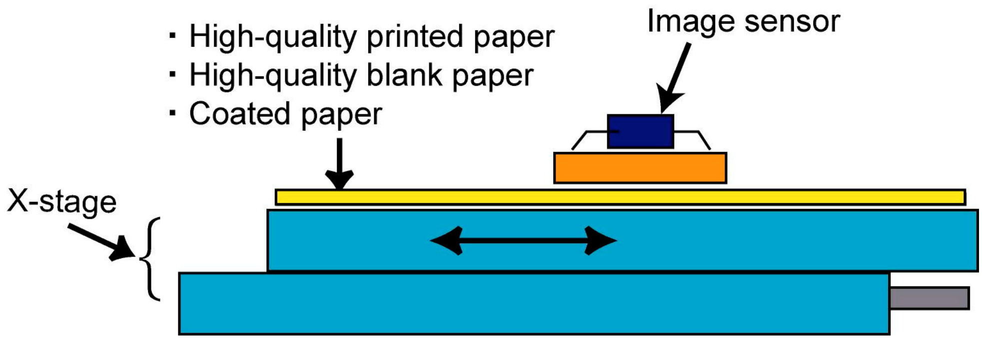

Figure 5 Layout image of the X-stage for feeding paper and image sensor

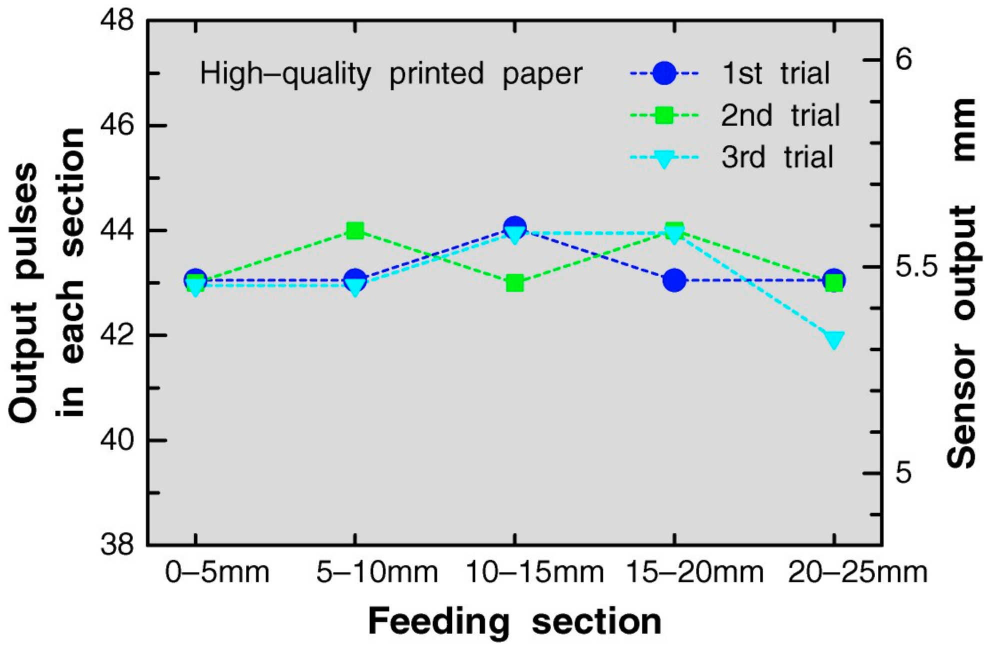

Figure 6 Relation between movement and output pulses for each section (high-quality printed paper)

The following three types of paper were used: high-quality printed paper, high-quality blank paper, and coated paper. Figures 6-8 show sensor outputs for actual movement distance of 5 mm. The pulses were 42-44 for high-quality printed paper, 42-45 for high-quality blank paper, and 44-47 for coated paper. Table 1 shows calculation results by summation of sensor output pulses for the actual 20 mm movement. The sensor measurement distance is longer than the actual movement distance with a 2-3 mm of error. Namely, compared with nominal mouse sensitivity, an approximately 10% margin of error of feeding rate exists. Because ADNS-2051 datasheets[1] shows that the sensitivity is higher for a white paper than a black paper. Results of this study also reflect that phenomenon. However, because of the fine repeatability for each paper, it can be used for actual measurement of a feeding rate if it is adjusted beforehand.

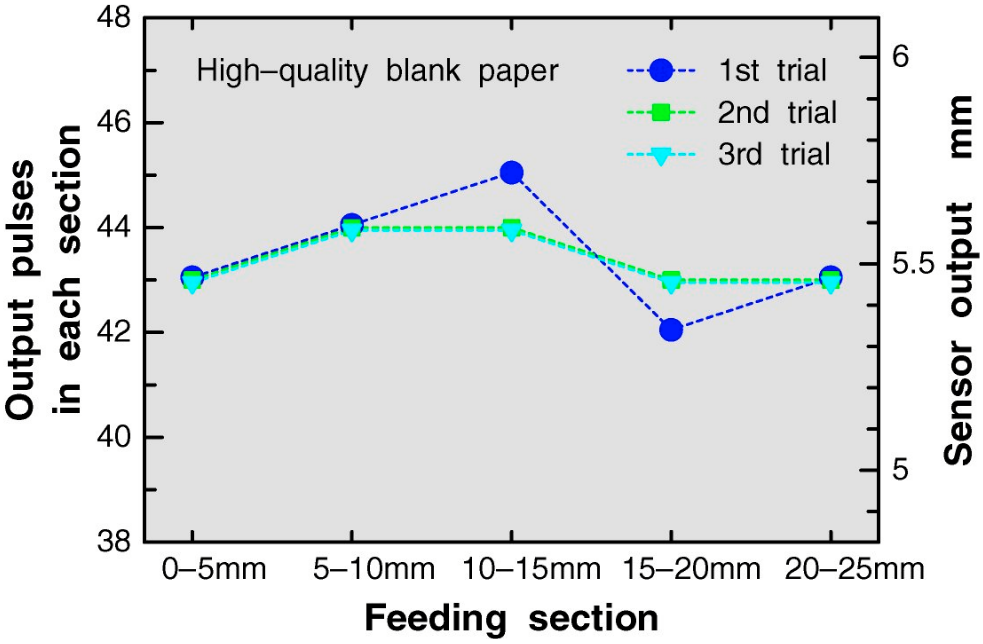

Figure 7 Relation between movement and output pulses for each section (high-quality blank paper)

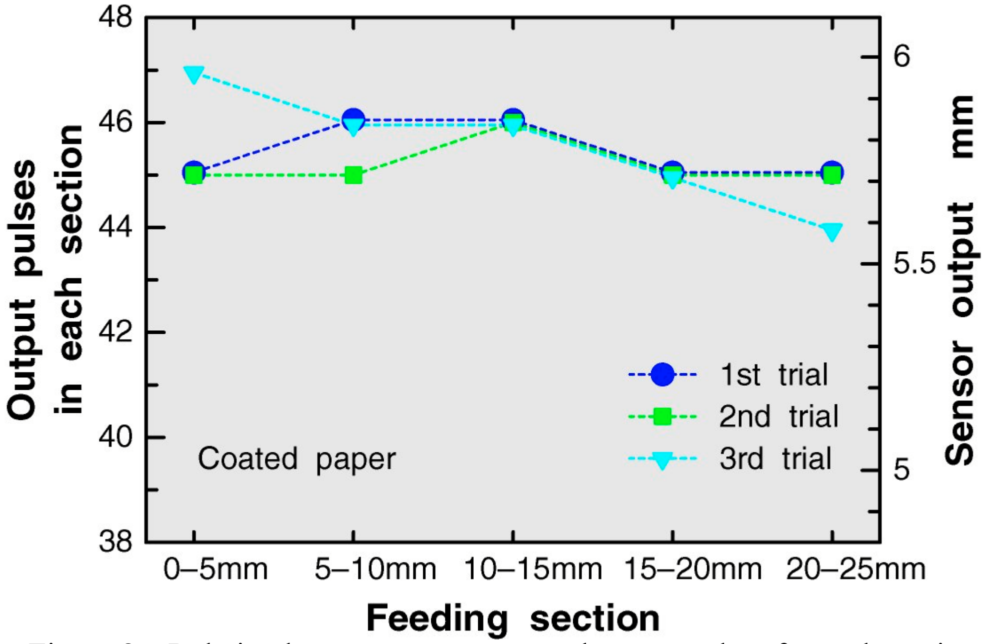

Figure 8 Relation between movement and output pulses for each section (coated paper)

Table 1 Summation of moving distance obtained by the image sensor against 20 mm of feeding

Kind of paper	Sensor output
High-quality printed paper	22.06mm
High-quality blank paper	22.09mm
Coated paper	23.16mm

4. Tactile sensor-integrated roller

4.1 Tactile sensor-integrated roller and a paper feeding test rig

This type of roller[2] has coaxial rings inside. The inner ring is linked to the outer ring by a beam on which a piezoelectric element is adhered. The roller's rotational acceleration is detected during its rotation. Two types of tactile sensing rubber rollers were made with different outer shapes and piezoelectric element supporting methods. The rollers were designated as Roller type I and Roller type II. Figure 9 shows that Roller type I supports the inner and outer rings with a ball bearing; it connects both rings with a torque beam and piezoceramic. It is attached around the outer part with a 1 mm thick nitrile rubber sheet. Roller type I was damaged from significant deformation of the piezoceramic element. Consequently, the method to support the piezoelectric element was improved. In addition, we produced Roller type II, with its superior miniaturization. Figure 10 depicts the Roller type II structure: the piezoceramic element sustained by three points bending by the spring pre-pressure. The rubber used for the outer part is polyurethane rubber.

The experiments were undertaken to elucidate basic roller characteristics by operating the roller in the system shown in Figure 11. The linear slider with uniform motion pulled a string wound around a countershaft pulley: thereby, it rotated the countershaft. In addition, the spinning of the countershaft was conveyed with a belt into the inner ring of the tactile sensor-integrated roller. Thereby, the inner ring revolved with this system in a constant velocity. An aluminum board was situated under the roller; the test paper was placed between the roller

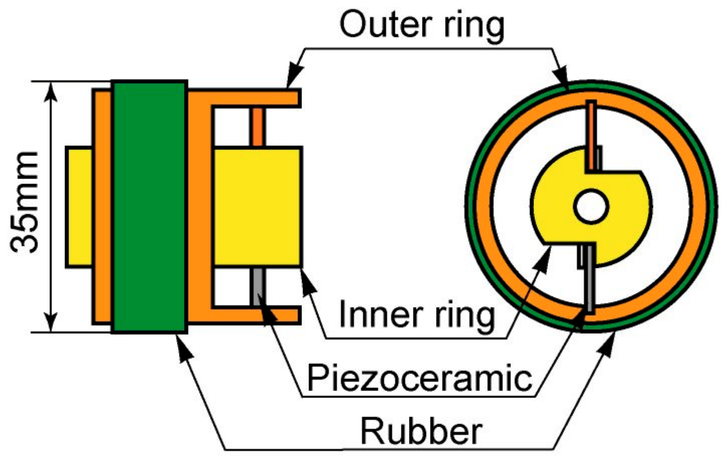

Figure 9 Schematic of the tactile sensor integrated roller (Roller type I)

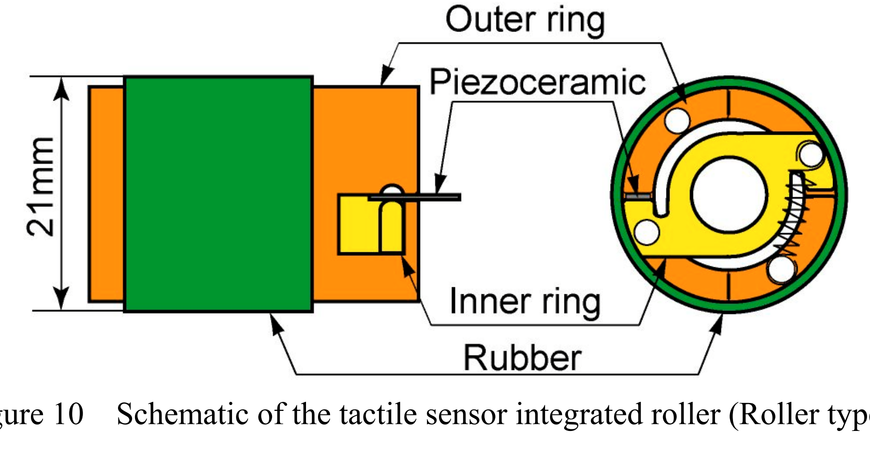

Figure 10 Schematic of the tactile sensor integrated roller (Roller type II)

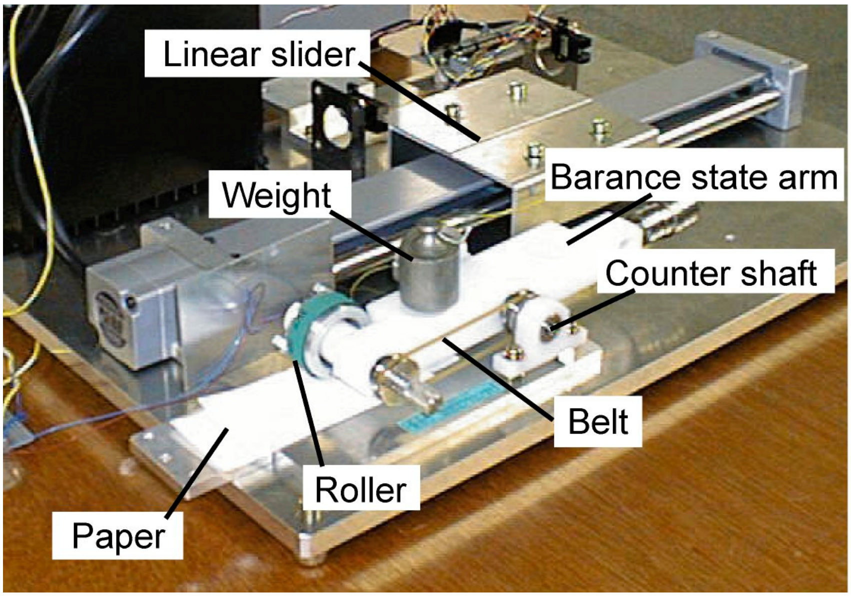

Figure 11 Photograph of the paper feeding test rig by rollers

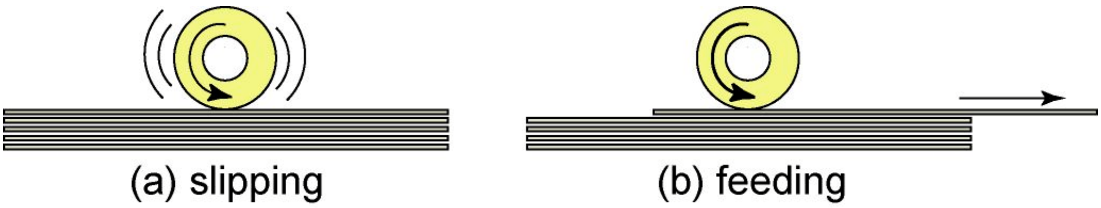

Figure 12 Slipping and feeding motion between roller and paper

and the board. The sensor output signal went through a 16-160 Hz band-pass filter. It was amplified 10 times and recorded in the computer after A/D translation.

4.2 Sensor output features according to motion

Sensor outputs were compared in two different states. Figure 12(a) depicts slipping that occurs between the paper and the rubber roller (slipping). Figure 12(b) shows the roller revolution, which causes sliding between the top paper and the next paper, and the consequent paper separation (feeding). Several pilot experiments revealed that slipping occurred when the roller contact force was small; feeding took place when the force was strong. In the case of slipping measurements, we decided to fix the paper on the board with sticky tape to facilitate slipping between the paper and the rubber.

Figures 13 and 14 illustrate the sensor outputs of Roller type I in the states of slipping and feeding. The peripheral velocity of the roller was 32 mm/s; the time when the linear slider began the motion is t=0. A slight amplitude increase lasted for about 0.15 s during the slipping because of the roller revolution; the amplitude increased soon thereafter. The amplitude repeats that increase and decrease with about 0.06 s frequency. It seems likely that this fluctuation occurs as a result of the stick slip between the paper and rubber: the roller leaps up on the paper. During feeding, the sensor output amplitude increased at the beginning of the movement. We infer that this results from the amplitude caused by movement between the fed paper and the stuck paper. In addition, irregular impulse-typed signals, like that shown at 0.1 s, were measured. Nevertheless, this did not happen at all in some trials. We were unable to find the reason for this inconsistent phenomenon.

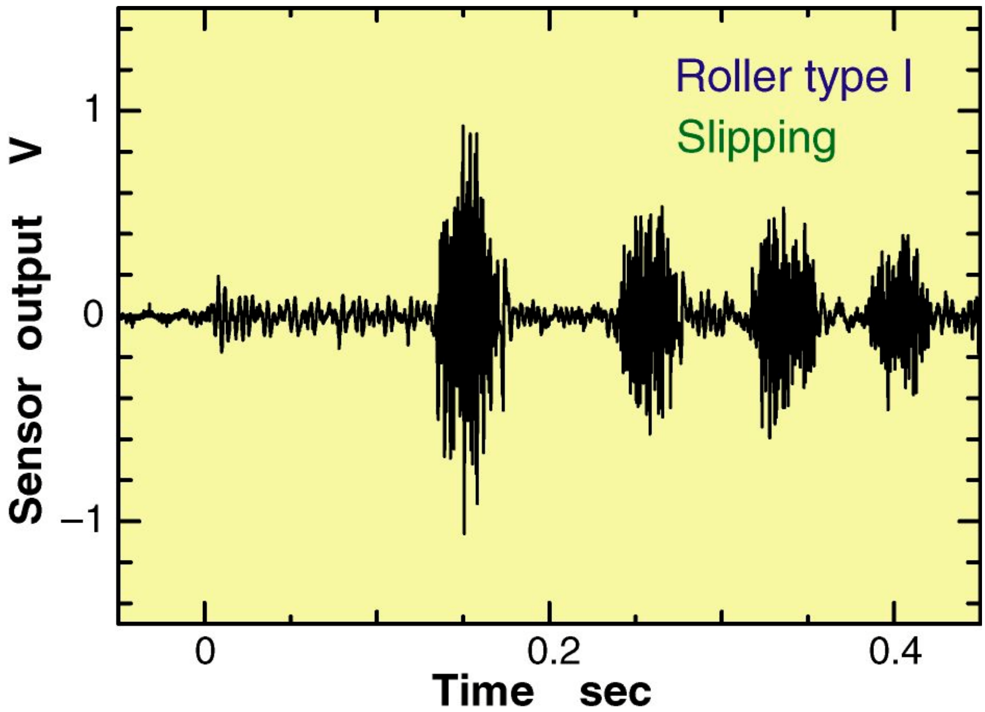

Figure 13 Sensor output when the roller is slipping on the paper (type I)

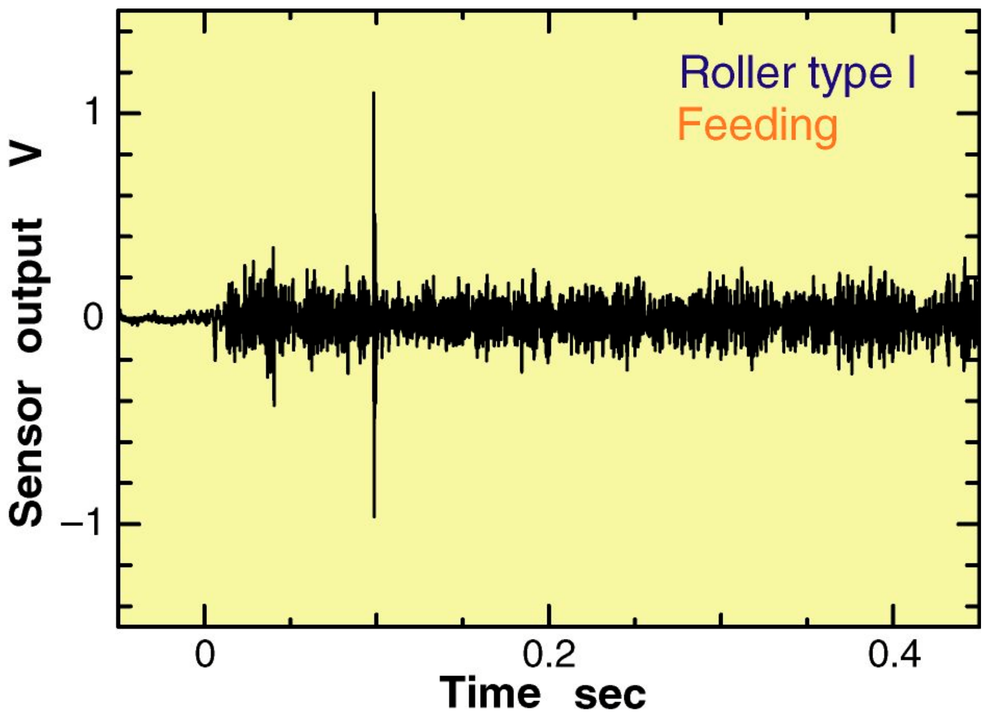

Figure 14 Sensor output when the roller is feeding the paper (Roller type I)

Figures 15 and 16 show sensor outputs in the states of slipping and feeding for Roller type II. That roller's peripheral velocity was 20 mm/s. The slipping state showed no clear change in the signal when the roller began revolving at $t = 0$. Moreover, the fluctuating amplitude, which was found for Roller type I, did not occur at all. Approximately 1.5 times higher amplitude was found in the feeding state than in the slipping state.

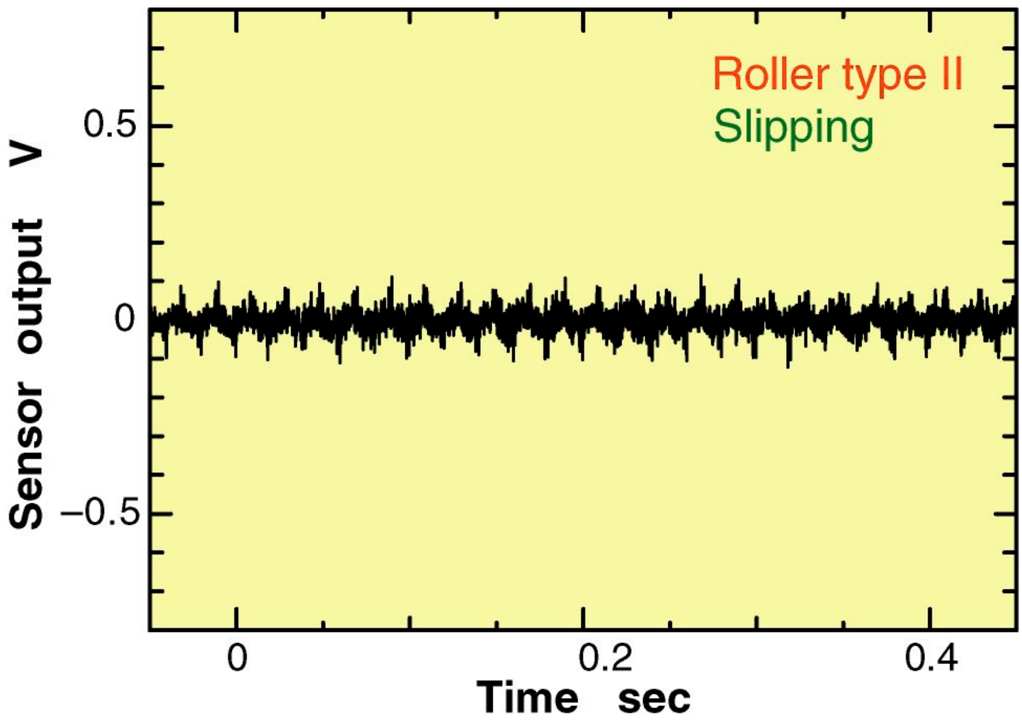

Figure 15 Sensor output when the roller is slipping on the paper (Roller type II)

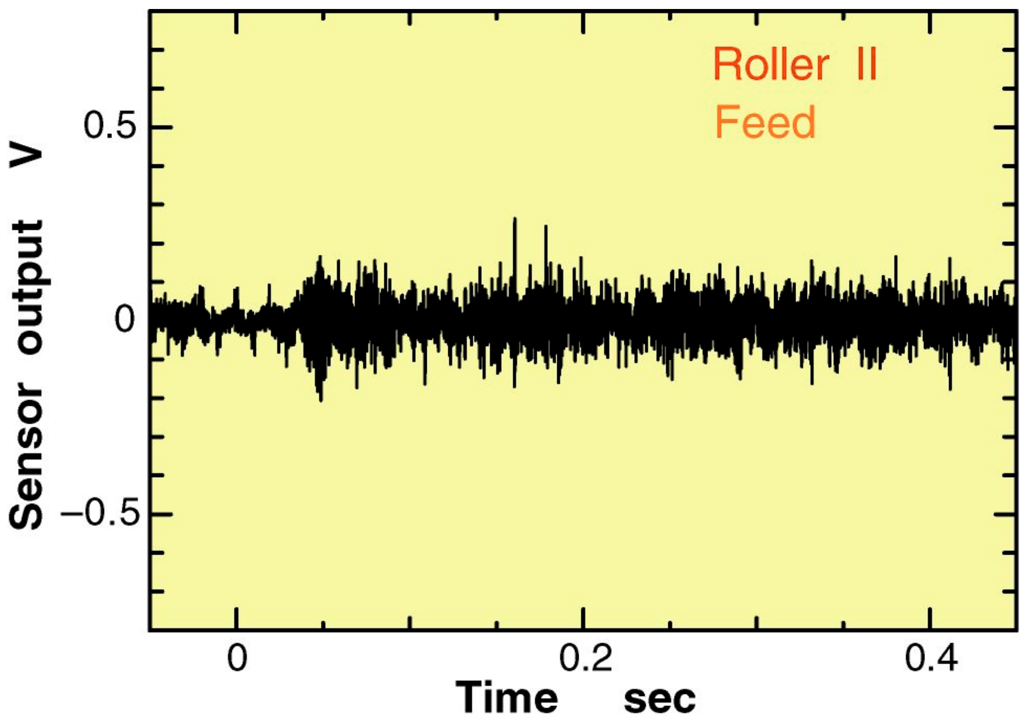

Figure 16 Sensor output when the roller is feeding the paper (Roller type II)

Another measurement for slipping by Roller type II was implemented at the revolving speed of the roller 36 mm/s using high-quality paper, coated paper, and lower-quality printing paper. Using FFT analysis, the amplitude spectrum was calculated. The sums of the amplitudes of the respective frequency components for paper roughness are shown in Figure 17: the amplitude attributable to the paper roughness increased concomitant with increased speed.

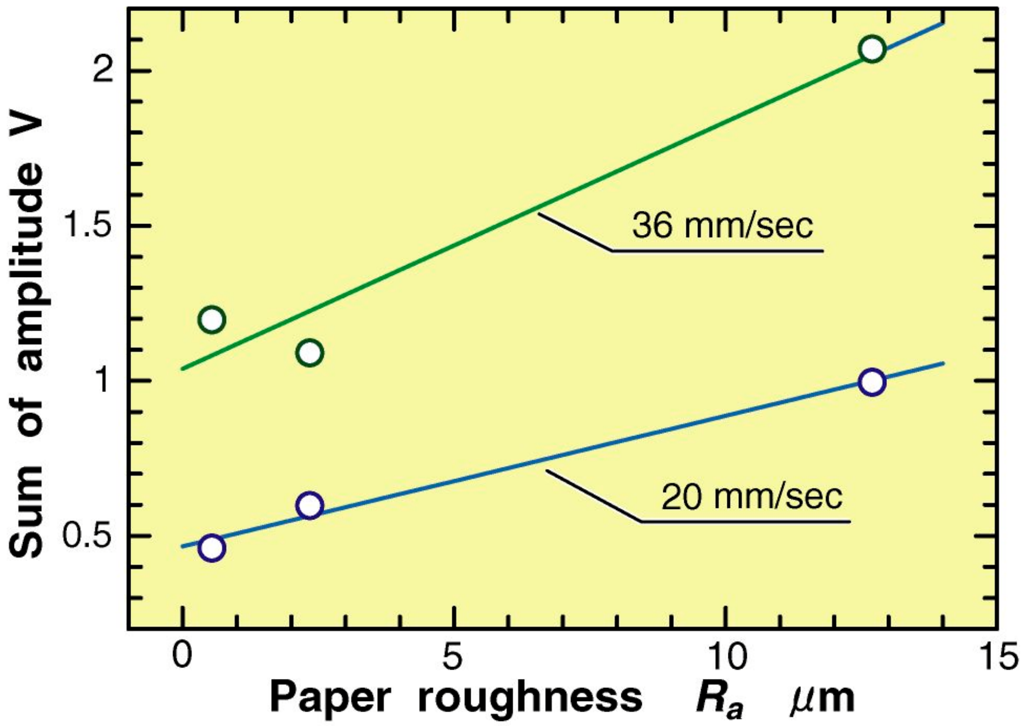

Figure 17 Sensor amplitude against the paper roughness and feeding speed (Roller type II)

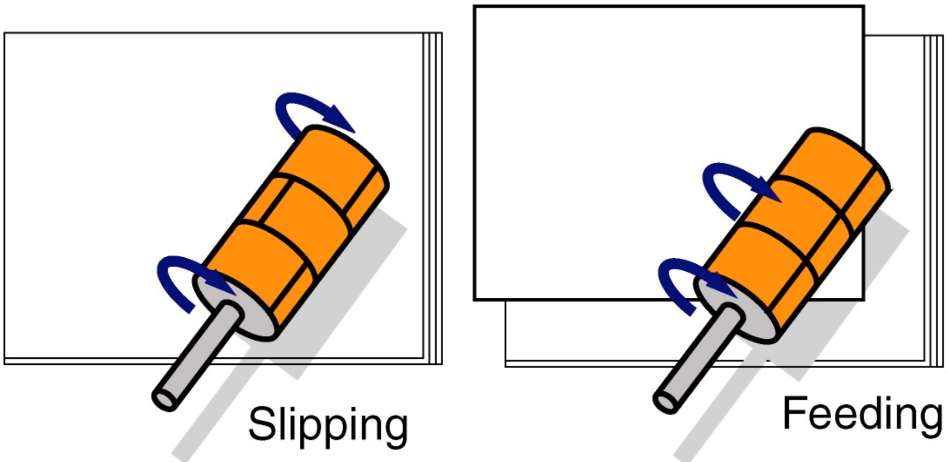

Figure 18 Motion of the roller with relative rotation sensor when slipping/feeding paper

5. Roller with relative rotation sensor

5.1 Design of the roller with relative rotation sensor

This type of roller[3] consists of two driving rollers and one sensing roller in the same axis. The sensing roller is sandwiched between two driving rollers and rotates freely. Figure 18 shows a pattern diagram of this roller with relative rotation sensor. An LED is mounted in a driving roller and an encoder IC is on another driving roller. The sensing roller wheel acts as the slit of the encoder to detect the relative rotational angle. In the case of the driving rollers slip on the paper, because of insufficient load, the sensing roller touches the paper and does not rotate by the frictional force between the sensing roller and the paper. As a result, output pulses are counted.

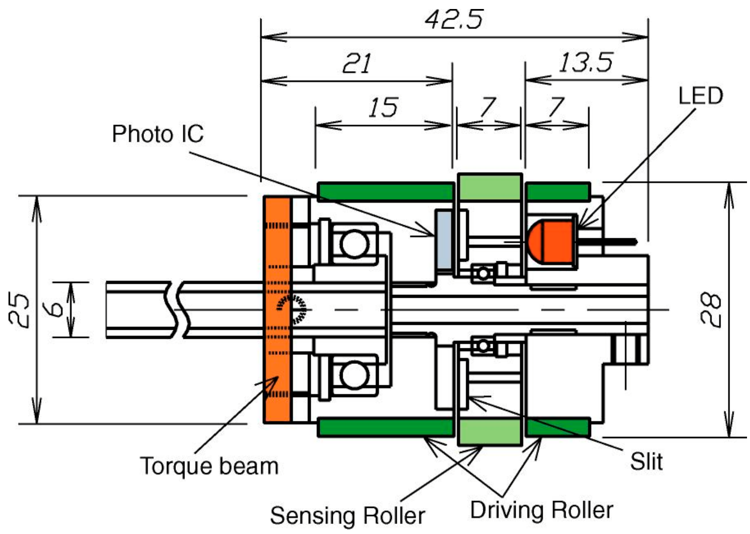

Figure 19 Design of the roller with relative rotation sensor

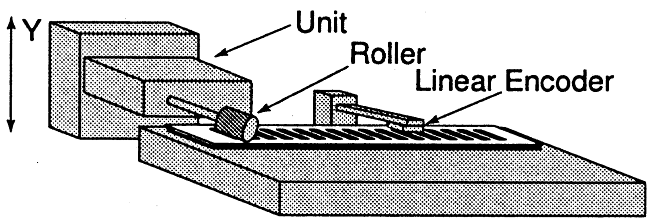

Figure 20 Schematic illustration of paper feeding test using the roller with relative rotation sensor

On the other hand, under circumstances in which sufficient load is given and the paper is fed, the differential between the driving rollers and the sensing roller is lost, because the sensing roller rotates along with the fed paper. So, no pulse is detected when the roller feed the paper. Therefore, the relative rotation between the driving rollers and sensing roller indicates the motion of paper.

Figure 19 shows the detailed design of the roller. The interval of the slit embedded in the sensing roller is 12 degrees. The rubber hardness of the sensing roller is JIS (Japan Industrial Standard) A40/S; its outer diameter is 28.5 mm. Therefore, it can detect a 1.5 mm feeding rate. A bearing is used to sustain the radial adjustment. Both driving rollers - the tip one (with the LED) and the bottom one (with the Photo IC) - are connected with a screw. The driving force from the motor is transmitted to the bottom-side driving roller through the shaft and torque beam. The driving rollers have 28.0 mm outer diameter with rubber hardness of JIS A60/S.

5.2 Evaluation of the roller with relative rotation sensor

To evaluate the performance of the roller with a relative rotation sensor, paper-feeding experiments were done using several types of paper. The Figure 20 shows the outline of the experimental equipment. Test paper strips of 60 mm by 300 mm are placed under the roller. The strip has a printed 3 mm black/white interval pattern to measure the feeding length.

First, the roller is rotated at a constant speed; later, the roller shaft is gradually descended. Meanwhile, the roller contacts with the paper and feeds the strip.

It is anticipated that if the roller presents the ideal performance as intended, the relative rotation of driving roller and sensing roller, and paper feeding length will be shown as Figure

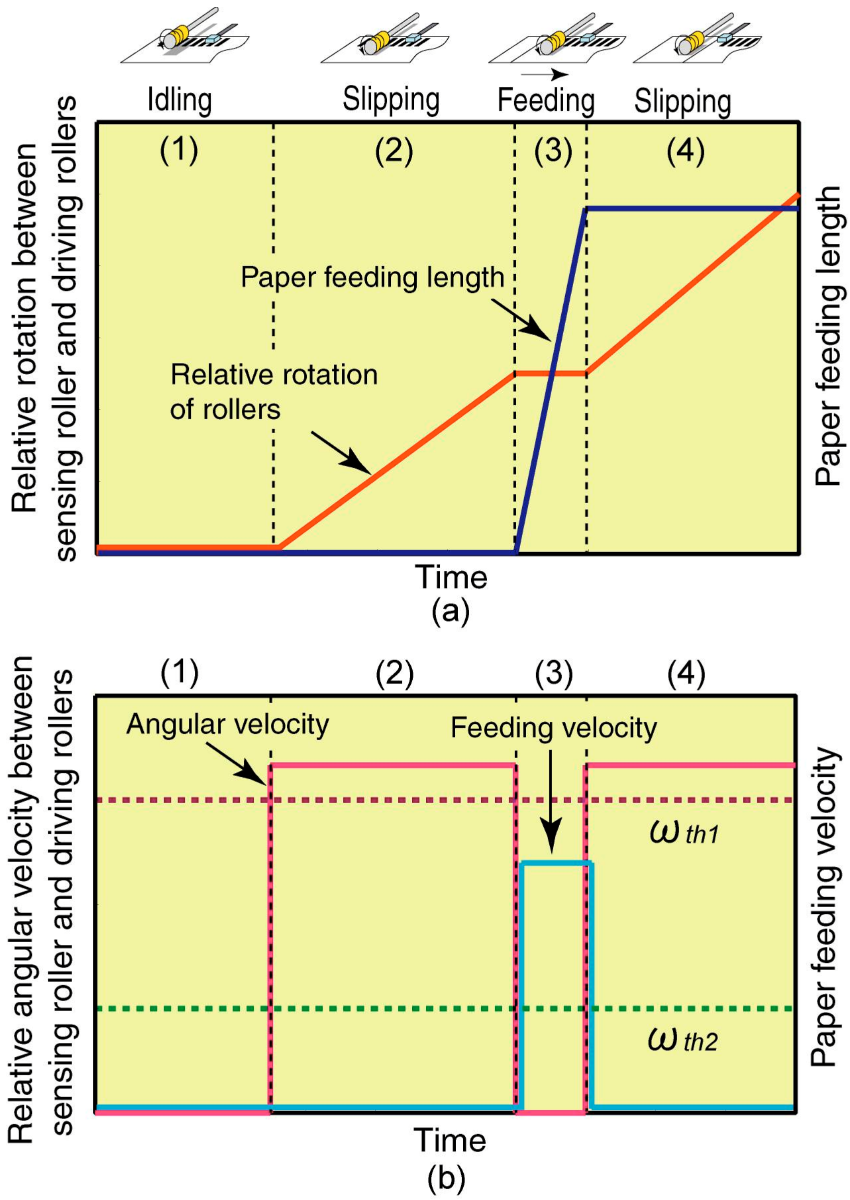

Figure 21 The ideal motion of roller with relative rotation sensor

21(a). In addition, the pulse rate of the rotary encoder, i.e. the relative angular velocity between sensing roller and driving rollers and paper feeding velocity are shown as (b).

These data are divisible into four states.

(1) Idling : In this state where the roller is revolving, it is not touching the paper. Under this state, the sensing roller rotates together with the driving rollers because of the friction of the bearing.

(2) Slipping : In this state where the roller is touching the paper, it is slipping. Thus, the driving roller is rotating, but the sensing roller is at a standstill because of the friction with the paper. At this point, a differential occurs between the driving roller and sensing roller.

(3) Feeding : At this point, the paper is fed with the friction of the driving roller. The sensing roller rotates along because of the friction with the paper. Consequently, the differential between the driving roller and sensing roller disappears.

(4) Slipping : In this state, the roller slips again after the first paper is fed. It reverts to stage (2).

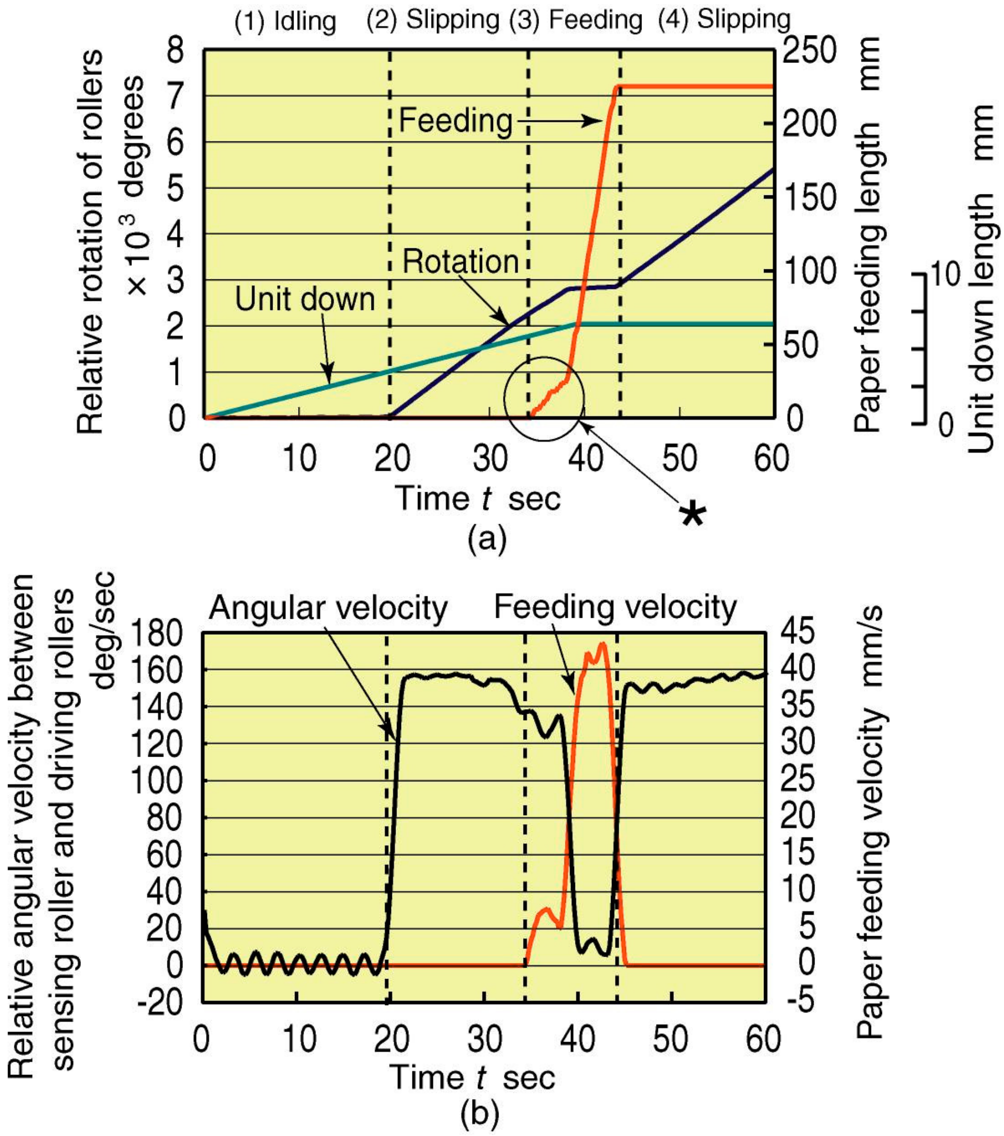

Figure 22 Result of paper feeding experiment using high-quality paper

When the relative rotation velocity is greater than ω_{thr1}, the beginning of slipping can be detected. Subsequently, when the relative rotation speed is less than ω_{thr2}, the beginning of paper feeding can be detected.

Figure 22 shows the result of an experiment using high-quality paper. Graph (a) shows abscissa axis of time and the ordinal axis of the relative rotation angle between the sensing roller and driving rollers and feeding length of the paper. Graph (b) shows data where the abscissa axis presents the relative rotating velocity between the rollers and velocity of the paper feeding. Consequently, the status closely resembles that shown in Figure 21. In state (1), no differential between the driving roller and sensing roller, but because the sensing roller shakes slightly, the rotating speed shows positive and negative values. Moreover, state (3) shows that two stages of change exist in the slope of the paper feeding rate and relative rotation velocity for the part with the * mark. The presence of these states means that, at the beginning stage of paper-feeding, slipping and feeding are repeatedly caused by the lack of contact load. From some point, the load becomes sufficiently strong and slipping occurs only slightly, i.e. the paper is fed certainly. Almost identical results have come from experiments using recycled paper and coated paper.

6. Features of rollers and design innovation

Three types of paper-feeding detecting devices and rollers are introduced in Chapters 3-5, along with design examples and evaluation of their performance. Their characteristics are summarized as follows.

i) Image sensor

- Capability of measuring the feeding length without touching the paper
- High resolution feeding length measurement
- Feeding length measurement values differ according to paper quality
- Difficult to integrate with the roller because of the large sizes of the IC and lens
- Very reasonable price
- Capability of detecting two-dimensional movement

ii) Tactile sensor-integrated roller

- Output depends on the paper quality or feeding speed, in other words, such conditions will be observed
- Inability to determine an absolute figure of the feeding length
- Vulnerability of PZT to breakage when excessive torque is loaded to the roller. Concern about its strength and ruggedness
- High cost because signaling requires a slip ring

iii) Roller with relative rotation sensor

- Ability to detect paper-feeding independent of the paper quality
- Ability to detect the sipping revolutionary angle with low resolution
- Depending on the sensing roller's outer size and hardness, it may damage the paper
- Difficult to miniaturize it because the rotary-encoder must be installed inside
- High cost because the signaling requires a slip ring

These methods will be selected according to the aims and specifications of paper handling machines. For example, the image sensor will detect the feeding rate in the feeding direction, but it might also measure swinging from the feeding direction using two-dimensional sensor functions for most paper-feeding machines.

For machines to achieve postal sorting, which requires handling of various types of paper, adoptive control can be achieved by knowing the type of target paper using the tactile sensor-integrated roller. Such a measure is expected to increase the reliability of paper conveyance and decrease the pressure against the paper.

The roller with the relative rotation sensor may be available for the purpose of innovation of a book page turning machine because this roller can detect the slipping/feeding independent of the paper quality. Moreover, regarding the tactile sensor-integrated roller, and roller with relative rotation sensor, paper feeding from a paper cassette would improve processing for copy machines or printers. However, cost reductions, such as eliminating the slip ring, will be required to achieve this. Thereby, these roller systems are beneficial for performance improvement of many paper-feeding machines. However, in all the methods presented in this study, it is impossible to detect situations of multiple feeding or two or more sheets of paper. It is our urgent task to resolve that difficulty.

7. Conclusions

Through this study, the authors designed and developed three types of roller and sensor mechanisms for a new paper-feeding device. The following summarize results taken from each device.

1. An approximately 10% of error exists for the paper-feeding length and image sensor output for high-quality paper or coated paper. The sensitivity depends on the paper quality. Reproducibility and linearity of measurement by the image sensor were fine; it is possible to detect the feeding rate with ± 0.2 mm precision if a correction coefficient is given.
2. For tactile sensor-integrated roller type I, it is possible to detect the state of slipping and feeding by the existence and absence of periodical change in the output amplitude because of the stick slip. For tactile sensor-integrated roller type II, it is possible to distinguish the paper motion from slipping to feeding by the amplitude level changing.
3. A Roller with relative rotation sensor can detect roller slippage on the paper by detecting the relative rotation between the sensing roller and the driving rollers.
4. These methods will be selected according to the aims and specifications of paper-handling machines.

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