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Basic investigation on development of ultrasonic sensor for tape detection on banknotes
紙幣内のテープ検知に向けた超音波センサの開発に関する基礎的研究

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1. Introduction

In addition to the double feed detection function to prevent miscounting of banknotes, the demand for state detection function of banknote is increasing in recent years. The state detection sensor is expected to detect conditions including fatigued and broken banknotes, and etc. Especially, the detection of tape on banknote is considered one of the key points in the conditions. To deal with this demand, we firstly focused on the tape detection function and started the development of new sensor module. This paper describes the present development status and the envisioned future development.

2. Observation of vibration velocity on paper with tape

Clarification of the vibration behavior of paper with tape, caused by the ultrasonic irradiation, is important for proposing an effective tape detection technique. In this section, the vibration behavior of both paper and paper with tape are measured by a laser Doppler vibrometer (LDV). The difference is investigated and then the optimum parameter for the tape detection is determined.

2.1 Experimental conditions

The paper used was the copy paper on which the tape with a length of 7.5 cm, a wide of 3 mm, and a thickness of 30 um was sticked. The measurement was performed by changing the distance between centers of ultrasonic irradiation position and tape from 0 to 7.5 mm (**Fig. 3**).

The measurement system used is shown in **Fig. 1**. The ultrasonic sensor (Murata MA300D1) was used as a transmitter. The distance between the sensor and the paper was 1 cm. A sinusoidal signal with a center frequency of 300 kHz and amplitude of 30 Vpp was applied to the transmitter. Vibration velocity of paper was measured using a LDV. Then, the signals were transmitted from a signal processing apparatus and visualized in a PC.

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2.2 Results and discussion

Fig. 2 shows the distribution of vibration velocity of paper generated by the ultrasonic irradiation. To assess the influence of tape, the vibration velocities obtained on the dashed line in **Fig. 2** (or **Fig. 3**) was compared. The vibration velocity waveforms are shown in **Fig. 3**. The arrows in upper figure show the ultrasonic irradiation points, and the peak positions of velocity waveforms in lower figure are fit to the points. When irradiating ultrasonic to the center of tape, the amplitude ratio of vibration velocity was 70% compared with the result obtained from the position without tape. Then, the attenuation of the velocity decreased as the distance between centers of the

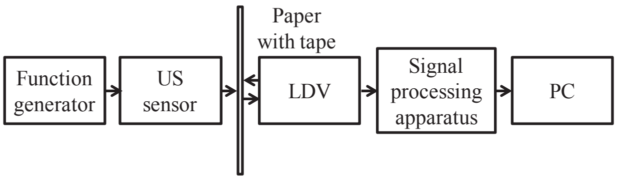

Fig. 1 Measurement system used.

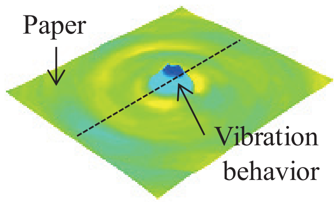

Fig. 2 Vibration behavior of paper.

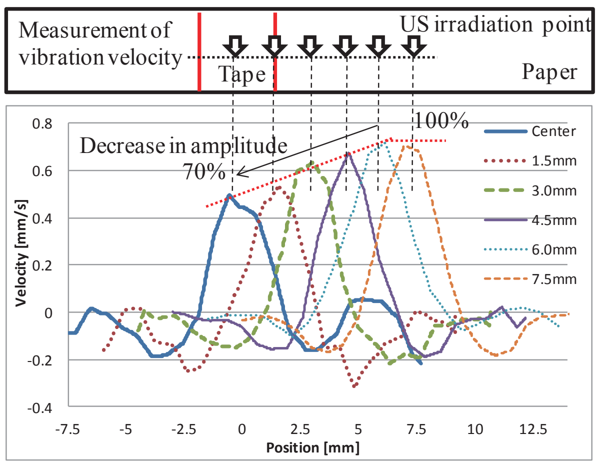

Fig. 3 Comparison of vibration velocity waveforms.

tape and the irradiation point increased. This relates to the mass of paper and tape; as expressed in the motion equation, total mass in the ultrasonic irradiation area affects the amplitude of vibration velocity. Thus, the tape detection may be possible using the amplitude of transmitted wave because the vibration velocity measured at the position of tape clearly decreased.

3. Observation of transmitted wave through paper with tape

In this section, the possibility of tape detection on banknotes using the amplitude of a transmitted wave is investigated.

3.1 Experimental conditions

The paper used was one-dollar bill (width 155 mm, depth 65 mm) on which 9 different sizes tapes were sticked (**Fig. 4**). **Fig. 5** explains the layout of sensors and the banknote in detail. To transmit and receive ultrasonic signals, customized transducers (depth/width 5 mm, resonance frequency 300 kHz) were used. In the experiment, the banknote was set on the xy stage and moved at every 1 s. Here, the step sizes in x- or y-directions were 1 mm.

10 cycles of rectangular wave with a center frequency of 300 kHz and amplitude of 10 Vpp were applied to the transmitter. The measured signal was amplified to 60 dB using a preamplifier and visualized in an oscilloscope.

3.2 Results and discussion

Fig. 6 shows the 2D image obtained from amplitudes of transmitted waves. The result tells us that the tape detection is possible using the amplitude of transmitted wave. Moreover, accurate tape detection is possible when the measurement is permitted in a narrow pitch.

When applying this technology to a sensor module, the tape detection for multiple banknotes is required to be done in a short time. To satisfy the demand, the sensor module is assumed to be the structure formed by arranging sensors in a row, which causes the limitation on the resolution in x-direction of 2D image. Therefore, the value of travel distance in the x-direction is changed to 5 mm as is the same with the sensor width, and the measurement was carried out. **Fig. 7** shows the result. The obtained image became obscure compared with **Fig. 6**, indicating that arranging sensors in a narrow pitch is important for the accurate tape detection.

4. Conclusion

All the results suggest that the tape detection is possible using the amplitude of transmitted wave, while increase in the number of sensors is effective in detection of tape on banknote. However, the increase in the number of sensors leads to high cost. Therefore, further investigation is required to clarify the relationships between the tape detection performance and the production cost.

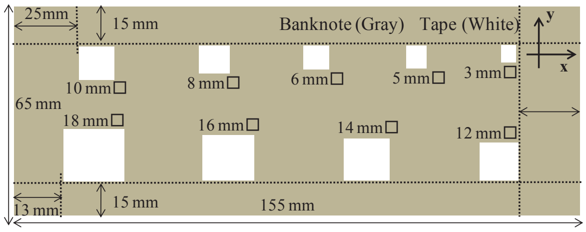

Fig. 4 Schematic illustration of banknote with tapes.

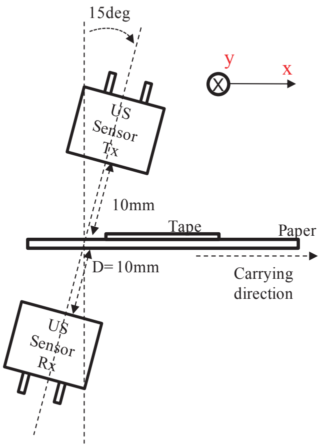

Fig. 5 Measurement system used.

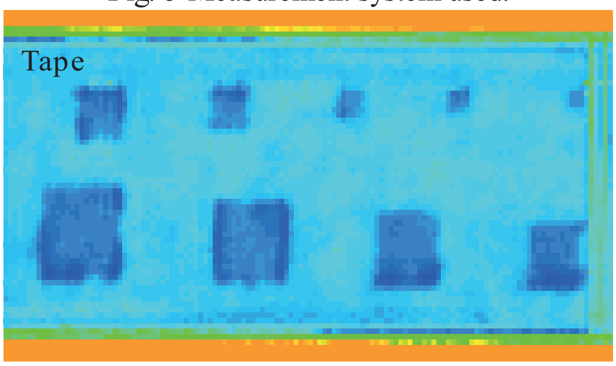

Fig. 6 2D image. Travel distance 1 mm.

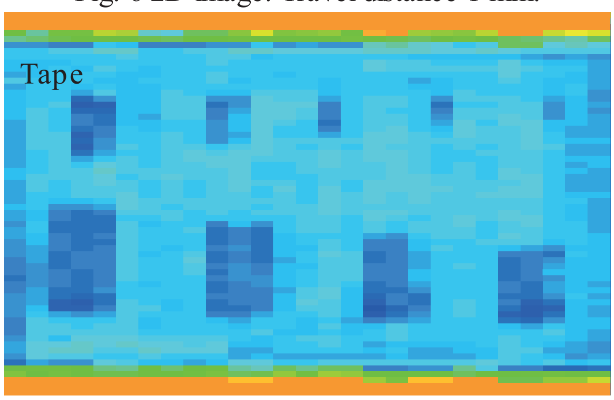

Fig. 7 2D image. Travel distance 5 mm.