Fast-Response Pen-Type Interface for Reproduce a Realism Pen-on-Paper Experience

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Abstract. In this study, we propose a pen-type interface that uses a vibration motor to reproduces the feeling of writing on paper when writing using a stylus pen on a tablet device. Conventional pen-type interfaces have two problems. First, a delay occurs between the start of writing and the start of vibration. Second, because the frequency and amplitude of the vibration are fixed, the writing feel is not reproducible. Hence, we quantify the degree of time delay that humans can tolerate by conducting sensitivity evaluation experiments. To maintain the time delay within an acceptable range, we utilize an acceleration sensor to acquire the start of a writing action and the writing speed at the interface. This approach can reduce the system delay and ensure a fast response. Based on a subjective evaluation experiment, we confirm that the proposed method does not cause any time delays. To solve the second problem, the vibration generated in the pen when writing on paper at various speeds is measured, and the linear prediction coefficient of the autoregressive model is derived. The vibrations reproduced based on the model are transmitted to a vibrator at the interface in real time to improve the reproducibility of the writing feel. Spectrogram analysis results of the generated vibration confirm that the difference in vibration characteristics based on the writing speed can be reproduced.

Keywords: Writing feel · Auto regressive model · Vibration

1 Introduction

In recent years, the use of tablet devices has increased in various fields and industries. The adoption of information and communication technology (ICT) is accelerating in the education industry; consequently, the number of classes using tablet devices will increase. For example, the United Nations Educational, Scientific and Cultural Organization recommends ICT, because it promotes universal access to education and bridges the learning gap [1]. It has been confirmed that tablet-based applications can significantly reduce the disadvantages experienced when using curriculum-based measurements in schools [2]. In addition, drawing

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using tablets has become mainstream not only in the education industry, but also in the animation and manga industries.

The most typical input methods for tablets are tracing with a finger or writing using a stylus pen as if it were an actual writing instrument. For people who typically write on paper, such as notebooks, using a stylus pen allows an intuitive operation. However, writing on a tablet device using a stylus pen does not transmit sufficient haptic feedback to a finger touching the stylus pen because of the slight vibration caused by friction between the pen's tip and the writing surface. This causes discomfort among users owing to the difference felt compared with the sensation of writing on paper using a writing tool.

The purpose of this study is to achieve a vibration sensation equivalent to writing on paper by reproducing the vibration of writing on paper using a vibration actuator built into a pen-type interface.

2 Related Studies

Several interfaces have been developed to improve user experience by reproducing the vibration of writing on paper, and they can be classified into two types. The first type is an interface with an internal mechanical vibration actuator. Cho et al.'s RealPen [3] reproduces the feeling of writing on paper by acquiring vibrations that occur when writing on paper using an acceleration sensor, which generates the same vibration waveform from obtained data and drives a vibration actuator. Ii presents a vibration similar to the writing vibration that occurs on paper by determining the difference between the spectrum of writing vibration on paper and the frictional vibration that occurs between the tablet device and interface, as well as by considering the transfer function from the PC to the interface [4]. However, the interfaces developed in these studies detect the writing start timing from the change in the pointer coordinates on the tablet when the user moves the pen tip, which generates and outputs vibration subsequently; therefore a delay occurs between writing and the start of vibration, causing a sense of discomfort.

The second type is haptic feedback generated during writing, based on the principle of electric vibration. The EV-Pen [5] developed by Wang et al. provides tactile feedback to the user by generating electrostatic attraction between the pen tip and the electrode layer on the tablet surface, with the silica insulating layer on the tablet surface serving as a capacitor when the user writes while driving the interface with a vibration waveform with a preset amplitude and frequency. The EV-Pen provides accurate writing with a low error rate in the steering task of tracing a predetermined path. However, the haptic feedback obtained from the EV-Pen is only a periodic vibration signal comprising a preset amplitude and frequency. Typically, when writing on paper using a pen, the haptic feedback obtained differs depending on the writing speed. However, the EV-Pen lacks reproducibility because it cannot change the vibration presented by different writing speeds. In this study, the first type of method, where mechanical vibration actuators are used, is applied to reproduces the sensation of writing on paper.

3 Fast Response Implementation

When using a pen-type interface, The user feels discomfort owing to the delay between the time of writing and the start of vibration. In this section, we explain the effect of delays on users, as well as the implementation of a system to reduce delays.

3.1 Effects of Delays

The time between writing and the onset of vibration was measured using a pen-type interface developed by Ii's [4]. The delay varied based on the writing speed; at a writing speed of 3 cm/s, the delay exceeded 0.3 s. Therefore, users felt discomfort when using the interface developed by Ii. Based on an evaluation experiment conducted by Miyazato et al. pertaining to delay [6], we investigated the amount of delay tolerable by users. Experimental collaborators were instructed to write with various lengths of delay and rate the degree of discomfort on a five-point scale. The results showed that writing with a delay exceeding approximately 0.1 s was uncomfortable to the users.

3.2 System to Reduce Delays

The authors developed a new system [7] to reduce delay. A prototype (Fig. 1) that can detect the movement of the pen nib by itself, equipped with a pressure sensor to detect the ground state of the interface pen nib and writing surface, and a gesture sensor to detect the timing of writing was built; subsequently, the delay values were measured, as shown in Table 1. It was confirmed that the writing speed was below 0.1 s, whict was the criterion for feeling discomfort, at all writing speeds. An analysis of variance at the 5-% significance level showed no significant difference in term of the increase or decrease in latency values at different writing speeds. In conclusion, the new system using the gesture sensor reduces delay, which is important for improving reproducibility.

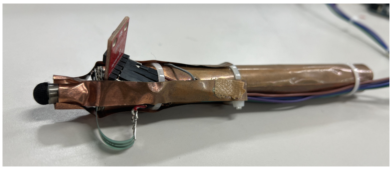


Fig. 1. Prototype

Table 1. Average of reduced delays

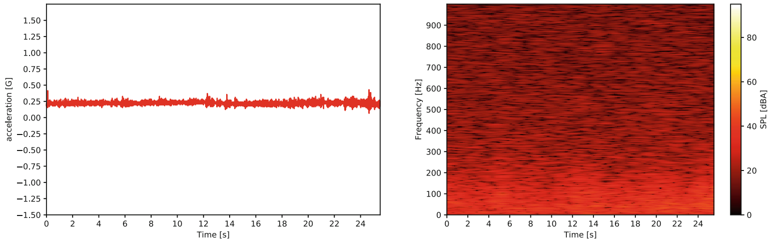
Writing speed (cm/s)	Average delay (s)
1	0.064
2	0.059
3	0.061

4 Reproduction of Writing Vibration at Different Writing Speeds

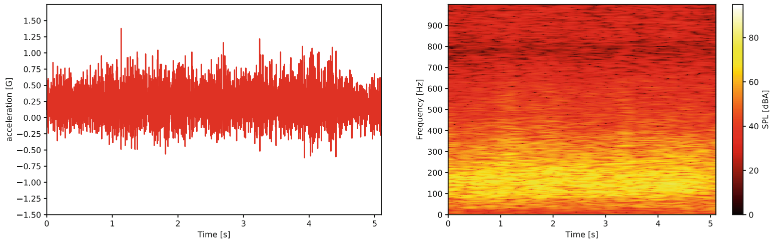
When writing on paper using a pen, the vibration transmitted from the grasp to the fingers differs based on the writing speed. In general, when paper is manufactured, after the surface is smoothed via coating, it is heated by metal and elastic rolls to render it smoother and shinier. However, in terms of paper, which is typically used for drawing letters and pictures, the number of rolls used is reduced to process the paper, which results in microscopic irregularities on the surface of the paper. When the nib moves at different writing speeds while in contact with the paper, the vibration level transmitted to the finger differs, owing to the difference in the number of irregularities in contact per unit of time. Therefore, it is expected that the frequency characteristics of the vibrations produced by each increase in the writing speed will differ. In this section, we describe the construction of a system that changes the presented vibration based on the writing speed when an interface is used.

4.1 Vibration Characteristics at Different Writing Speeds

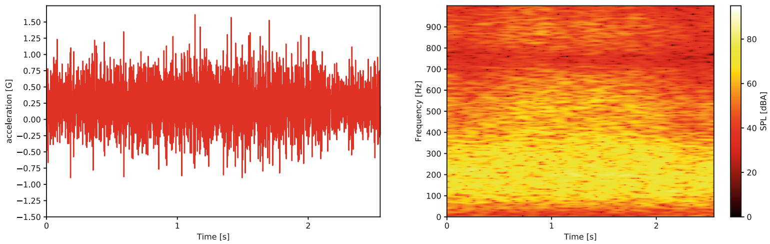
To confirm that the vibration transmitted to the fingertip varies with the writing speed, we measured the vibration produced when writing on paper at each writing speed. An acceleration sensor (ADXL337, Analog Devices) was attached to the grip of a twist-type ballpoint pen (Parker), and a straight line was written from left to right on a copy paper. The writing distance was fixed at 25.5 cm, and 10 measurements were performed for each writing speed from 1 to 10 cm/s (1 cm/s increments). A tablet device was placed under the copy paper and the writing surface, and a black dot was displayed on the screen; the black dot moved in a straight line at a specified speed. This allows users to write at a constant speed. Because the high-frequency vibration felt at the fingertip is primarily independent of directionality [8], only the acceleration component perpendicular to the pen axis was considered in this study. The sampling frequency was 5890 Hz. Figure 2 shows the results for writing speeds of 1, 5, and 10 cm/s. Figure 2 shows the waveforms and spectrograms of the writing vibrations that occur while writing on paper. As shown by the spectrograms for each writing speed, vibrations with more high-frequency components were generated as the writing speed increased. Therefore, it is more meaningful to present vibrations that match the user's writing speed.



(a) writing speed 1 cm/s



(b) writing speed 5 cm/s



(c) writing speed 10 cm/s

Fig. 2. Vibration waveform and spectrogram on paper

4.2 Vibration Reproduction Method for Each Writing Speed

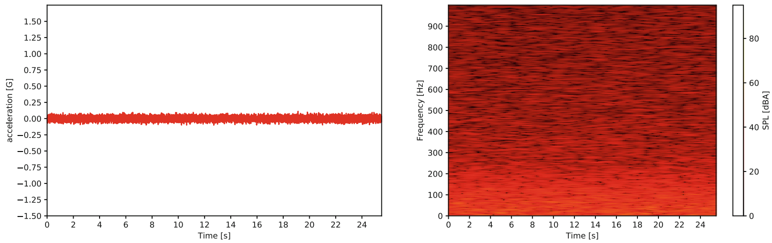
As indicate in Sect. 4.1, it is confirmed that the writing vibration caused by the writing speed exhibits different vibration characteristics. When writing on paper or on a tablet device, users do not maintain the same writing speed, but change their writing speed depending on the writing direction and type. Therefore, instead of periodically presenting a single vibration prepared in advance to the user, it is necessary to acquire the user's writing speed in real time, as well as generate and present a new writing vibration for each writing speed. In this study, we propose a method to model the writing vibration measured on paper at each writing speed and then present it to the user.

Writing Vibration Modeling. In particular, we propose a method to reconstruct writing vibration using linear predictive coding (LPC) based on the writing vibration on paper. The LPC can be used to estimate the current signal from previous signals. The reconstructed writing vibration reproduces the power spectrum of the original vibration waveform. Vibration can be generated for each presentation. Using white Gaussian noise as the signal source during vibration reconstruction, the waveform does not become a constant repetition of waveforms, and the user is presented with the sensation of writing without periodicity. The data $\hat{y_n}$ of the presented vibration are calculated using the following equation:

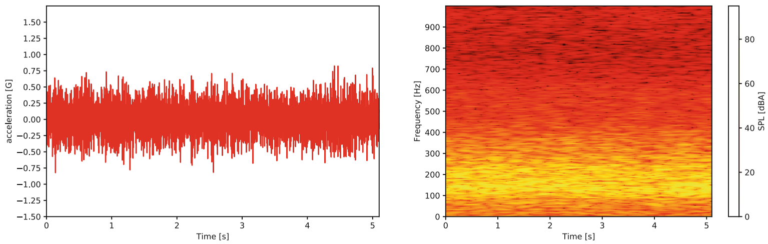
$$\hat{y_n} = e_n - \sum_{i=1}^{k} a_i y_{n-i} \tag{1}$$

where e_n is the white Gaussian noise, k the order that determines the range of previous data to be referenced, a_i the linear prediction coefficient, and y_{n-i} the i-sample past value of the reconstructed writing vibration. The value of e_n was calculated using the Box-Muller method, and k was determined using the Akaike information criterion. Using statistical model and, a Python statistical analysis library, we obtained the order from the data written data on paper, and the order $k = 27$ in this implementation. a_i is used to calculate the writing data measured on paper using the Levinson-Durbin method [9] at each writing speed.

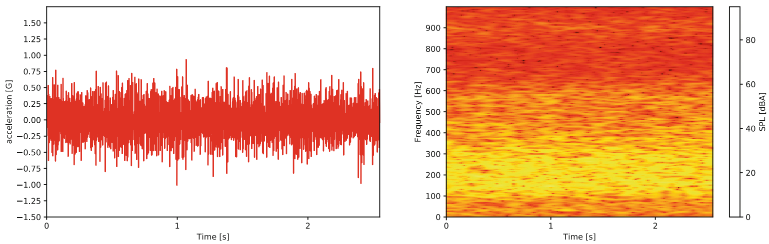
Vibration Characteristics of Reproduced Writing Vibration. The vibration waveform and spectrogram of the reconstructed writing vibration based on the writing vibration on paper, as shown in Figure 2, are shown in Fig. 3. The reconstructed writing vibration shows that it is can reproduce the vibration characteristics of different writing speeds on paper. The results indicate that if the linear prediction coefficients are appropriately selected using the user's writing speed as a parameter, then the vibration of writing on paper can be reproduced, and the randomness of the vibration can be obtained. Furthermore, vibration can be presented to the user in real time, and hence the result above was obtained.



(a) writing speed 1 cm/s



(b) writing speed 5 cm/s



(c) writing speed 10 cm/s

Fig. 3. Vibration waveform and spectrogram of reconstructed writing vibration

5 Conclusion

In this study, we propose a pen-type interface that can reproduce the feel of writing on paper when writing using a stylus pen on a tablet device. We developed a system that achieves two elements: the fast response required to improve the reproducibility of the writing sensation and the real-time modification of the presented vibration in response to the writing speed. It was confirmed that the delay from the time of writing to the start of vibration can be reduced by detecting the timing of writing at the interface using a gesture sensor and a pressure sensor as a method to guarantee a high-speed response. Additionally, it was confirmed that LPC based on written vibrations on paper.

can be used to reconstruct vibrations with vibration characteristics equivalent to those of written vibrations on paper. Future prospects include the development of a system that can acquire a user's writing speed in real time and select appropriate linear prediction coefficients based on the acquired writing speed. In addition, by producing a mechanism and exterior to present the reconstructed vibration to the user and conducting comparative evaluation experiments using existing interfaces, we show that the interface developed in this study can improve the reproducibility of the writing sensation on paper.

References

1. UNESCO: ICT in education (2021). https://en.unesco.org/themes/ict-education
2. Blumenthal, S., Blumenthal, Y.: Tablet or paper and pen? Examining mode effects on German elementary school students. Computation skills with curriculum-based measurements. Int. J. Educ. Methodol. **6**(4), 669–680 (2020)
3. Cho, Y., Bianchi, A., Marquardt, N., Bianchi-Berthouze, N.: RealPen: providing realism in handwriting tasks on touch surfaces using auditory-tactile feedback. In: Proceedings of the 29th Annual Symposium on User Interface Software and Technology, pp. 195–205 (2016)
4. Ii, C.: Generation of writing sensation on a tablet based on the vibration transmission characteristics of writing instruments. Kwansei Gakuin University Graduation thesis (2019)
5. Wang, Q., Ren, X., Sarcar, S., Sun, X.: EV-Pen: leveraging electrovibration haptic feedback in pen interaction. In: Proceedings of the 2016 ACM on Interaction, Surfaces and Spaces, pp. 57–66 (2016)
6. Miyazato, T., Kishino, F.: Subjective evaluation of delayed perception between visual and tactile information. J. Inst. Telev. Eng. Japan **49**(10), 1353–1356 (1995)
7. Watanabe, R., Yamazaki, Y., Imura, M.: Development of a fast-response pen interface for improved reproducibility of writing feel. In: Information Processing Society of Japan: Interaction 2021, 2A02 (2021)
8. Bell, J., Bolanowski, S., Holmes, M.H.: The structure and function of Pacinian corpuscles. A review. Progr. Neurobiol. **42**(1), 79–128 (1994)
9. Ljung, L.: System Identification: Theory for the User. Prentice Hall, Hoboken (1999)