VIBRATION-BASED DATA COMMUNICATION BETWEEN SMARTPHONES

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ABSTRACT

Two-dimensional communication has been accepted as a new communication means which achieves a secure communication between devices. To realize this communication, a vibration-based communication method, which conveys data on a solid medium, has been proposed. This method, however, needs uncommon devices such as forcereactor and piezoelectric device to perform high data rate communications. Therefore, the current approach is not really practical in terms of the device specificity. This study focuses on a vibration-based communication system using smartphones, and thus it is practical because the required devices are only common smartphones. To achieve high data rate communications with this system, a multiple-step ASK as a digital modulation must be performed by smartphone, which has not, as yet, been realized. In this paper, a new method to perform a three-step ASK by smartphone will be proposed. In addition, the effectiveness of the proposed method through the evaluation experiments will be discussed.

1. INTRODUCTION

Two-dimensional communication has been proposed as a new communication means, which takes advantage of wired and wireless communications.

Makino et al. [1] proposed a two-dimensional communication system using Evanescent Waves to provide a Wi-Fi network only on the surface of a flat board. This system achieved an easy and secure two-dimensional communication between devices, but did not become popular due to the use of uncommon radio waves.

Takemura et al. [2][3] proposed a vibration-based two-dimensional communication method, in which the transmitted data is conveyed as vibrations on a solid medium. When the vibration is used as a transmission medium, the user can perceive the communication. It means that the user can know which device the data is sent to, and thus this method can be a secure communication means. This method utilized a forcereactor and a piezoelectric device to generate and detect vibration signals. The forcereactor is a flexible vibration generator since it can control the vibration strength and timing. Furthermore, the time constant to stop the vibration is shorter than flat motors. Hence, this method achieved to perform PSK (Phase Shift Keying) as a digital modulation for vibration signals. As a result, this system contributed to high data rate communications. However, this approach is not really practical because the forcereactor and the piezoelectric device are not commonly used, and thus the method would cause an implementation issue.

To overcome this difficulty, Yonezawa et al. [4] used a vibration motor and a three-axis accelerometer on a common smartphone to generate and detect vibration signals. Since these devices are fitted as standard equipment on smartphones, it solved the above issue. However, the vibration motor cannot freely control the vibration strength and timing. The device is unable to perform PSK, and thus it is difficult to achieve high data rate communications. As a matter of fact, they adopted a simple 1 bit ASK as a digital modulation. Hence, it achieved only 10 bps as the data rate. Note that this communication was performed in the condition of touching two smartphones directly without using any intermediate medium.

In this paper, a new method to perform a three-step ASK for vibration signals by smartphone will be proposed in order to achieve a higher data rate communication than the above work [4]. In addition, the effectiveness of the proposed method through the evaluation experiments will be discussed.

2. PROPOSED SYSTEM

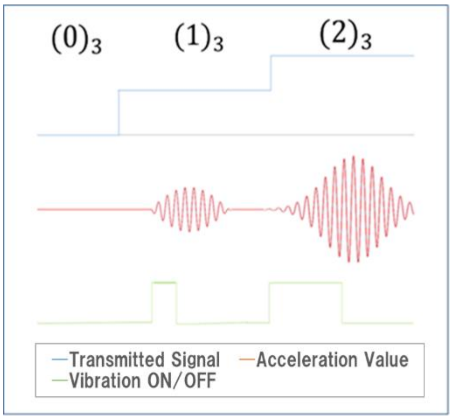

Fig. 1 Proposed multiple-step ASK for vibration signals

To perform a multiple-step ASK for vibration signals, the time duration of driving a vibration motor is focused. When the motor is switched off within a short time after it is switched on, the vibration is not fully generated and thus the vibration magnitude is smaller than the full capacity. If the vibration magnitude can be controlled by this operation, the multiple-step ASK can be realized. Hereafter, the time duration of driving a vibration motor is called "activating time" for the sake of simplicity. Figure 1 shows the proposed multiple-step ASK for vibration signals. Note that the number of steps is three in Fig. 1.

Figure 2 presents the observed acceleration values varying the activating time obtained by a preliminary experiment. Here, the observed acceleration values means the values detected by the three-axis accelerometer on a smartphone (NEXUS6 made by Motorola with Android ver.5.1) when the vibration motor is being driven during the designated activating time. Therefore, the acceleration value indicates the vibration magnitude. In Fig.2, each value indicates the average value of 20 times measurements and the error bar represents the standard deviation.

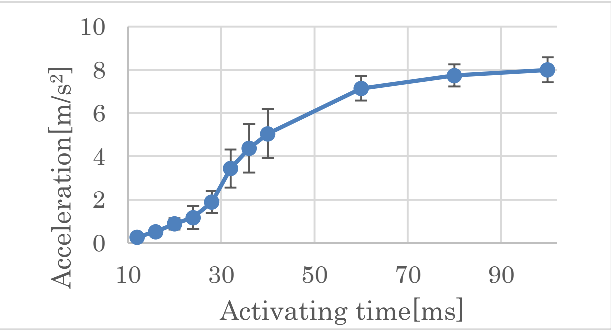

Fig. 2 Relationship between observed acceleration value and activating time

As seen in Fig. 2, when the activating time is between 30 ms and 40 ms, the fluctuations of magnitudes are quite large, and thus the generated vibration magnitudes are not stable. On the other hand, when the activating time is more than 50 ms, the generated vibration magnitudes are large and stable with small fluctuations. The most important thing for deciding the number of steps of ASK is to differentiate each vibration magnitude. However, if the activating time is large, it influences the maximum transmission data rate. As a result from the thorough investigation, a three-step ASK with the activating time of less than 50 ms has been selected. Figure 3 illustrates the determined 3 steps of signals, namely, no amplitude, small amplitude and large amplitude which correspond to $(0)_3$, $(1)_3$ and $(2)_3$ in ternary, respectively.

The activating times x_1 and x_2 for the signals of $(1)_3$ and $(2)_3$ have also been selected as 20 ms and 40 ms, respectively. This is because these activating times do not make overlapped vibration magnitudes as seen in Fig. 2.

In Fig. 3, y indicates the duration time for 1 signal. Hereafter, y is called "signal duration time" for the sake of simplicity. The smaller the signal duration time is selected, the higher the transmission data rate is achieved. However, if the signal duration time is too small, the next vibration is generated before the previous vibration evaporates, resulting in the vibration interference. Therefore, the signal duration time influences the maximum transmission data rate as well as the activating time.

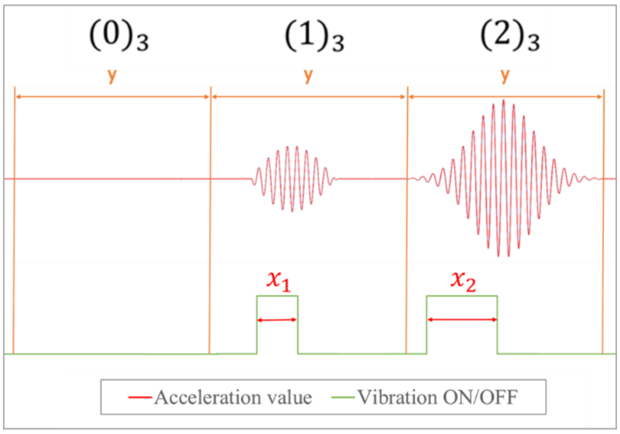

Fig. 3 Proposed three-step ASK

3. PERFORMANCE EVALUATION

An evaluation experiment was conducted to validate the proposed three-step ASK in terms of the bit error rate (BER). Two threshold values for amplitude were determined to differentiate $(2)_3$ from $(1)_3$ and $(1)_3$ from $(0)_3$, respectively. The signal duration time was varied from 80 ms to 300 ms to change the transmission data rate. Two smartphones (NEXUS6) were prepared as the sender (vibration generator) and the receiver (vibration detector) and they were placed touching each other directly during the communication. The successive signals $(012)_3$ were sent from the sender to the receiver 15 times to measure the bit error rate.

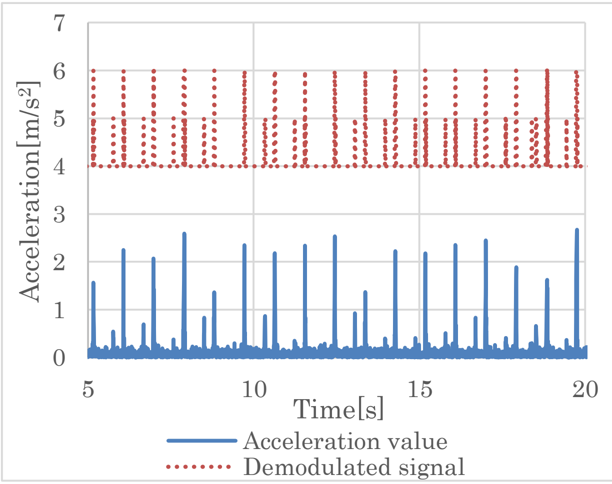

Fig. 4 Observed acceleration values and demodulated signals in ternary

Figure 4 shows the observed acceleration values and the demodulated signals in ternary. When get result of Fig. 4, signal duration time has been selected as 300 ms. From the upper graph in Fig. 4, it is obvious that the observed acceleration values were demodulated imperfectly. This influences the BER of the communication. Table 1 shows the comparison between ternary and binary for the used signals. The BER of the experimental result was calculated based on this table.

Table 1 Comparison table between ternary and binary

Demodulated signals in ternary	Data in binary to calculate BER
$(00)_3$	$(000)_2$
$(01)_3$	$(001)_2$
$(02)_3$	$(010)_2$
$(10)_3$	$(011)_2$
$(11)_3$	$(100)_2$
$(12)_3$	$(101)_2$
$(20)_3$	$(110)_2$
$(21)_3$	$(111)_2$
$(22)_3$	——

Figure 5 shows the result of calculated bit error rate varying the transmitted data rate. The value of horizontal axis was calculated from the value of activating time. This graph reveals that the BER becomes higher when the transmission data rate increases.

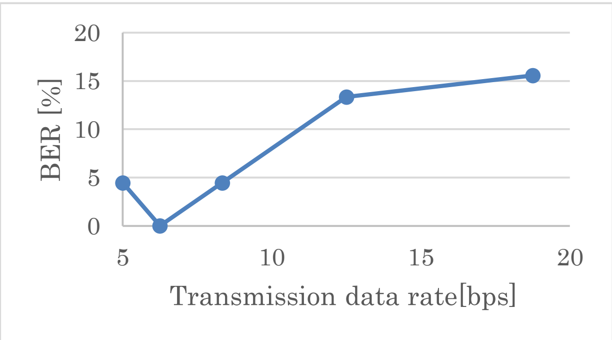

Fig. 5 BER vs. transmission data rate

4. IMPROVEMENT OF BER

The reason why the BER increased for high data rate communications has been investigated. Figure 6 shows how the signals are demodulated. The demodulation is performed every signal duration time. The largest amplitude within a signal duration time is detected and the value is compared with the two threshold values stated in the previous section, then the signal value is determined. However, sometimes, the amplitude of the previous signal does not evaporate enough in the next signal duration time. Look at the 4th signal of $(1)_3$ described in red in Fig. 6. The largest amplitude is detected in the range of the two threshold values and the signal is determined as $(1)_3$ but the transmitted signal is $(0)_3$. Even though the algorithm works correctly, the demodulated signal value is wrong. However, this can be solved to extend the signal duration time so that the previous signal can evaporate within the signal duration time. As a result, the BER can be improved although it makes the transmission data rate decrease as mentioned in Section 2.

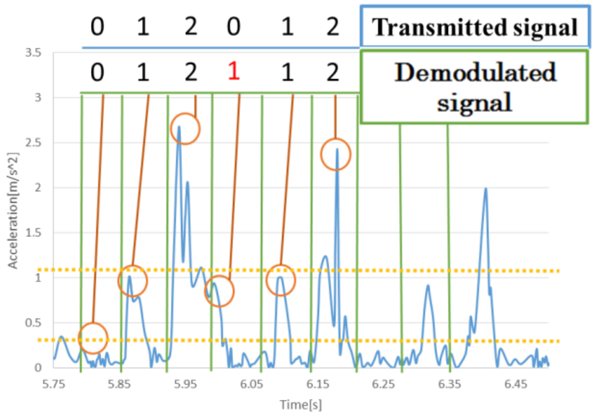

Fig. 6 Wrong decision of demodulated signal

Apart from the above reason, there is another issue that increases the BER. When the vibration for $(1)_3$ is generated, the detected amplitude is not stable. Sometimes, the amplitude does not reach the threshold which determines the signal as $(1)_3$, and thus the signal is regarded as $(0)_3$. To resolve this issue, a new vibration generation method for $(1)_3$ was discussed in this study. The amplitude does not reach the threshold sometimes, but not always. Hence, if the vibration is generated more than once, the probability that the amplitude does not reach the threshold would decrease. Fortunately, the signal duration time for $(1)_3$ is just one-half of the one for $(2)_3$. Therefore, the vibration for $(1)_3$ can be generated at least twice without any serious modification of the proposed method.

Figure 7 shows the observed acceleration values and the demodulated signals in ternary obtained by the new vibration generation method for $(1)_3$. From the upper graph in Fig. 7, it is clear that the signal $(1)_3$ is correctly detected, therefore, it is concluded that the new vibration generation method for $(1)_3$ has been validated. Finally, the BER for the transmission can be reduced drastically.

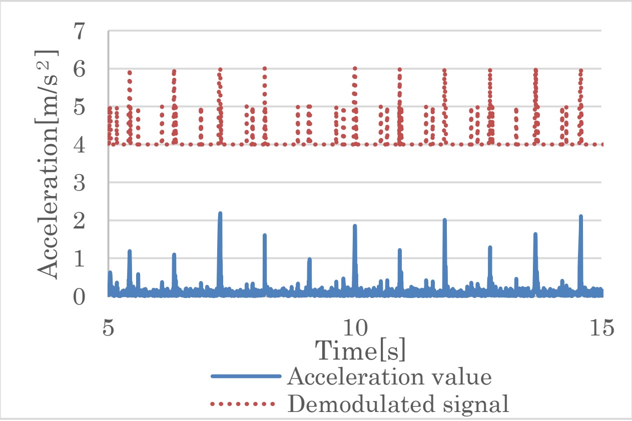

Fig. 7 Observed acceleration values and demodulated signals in ternary obtained by new vibration generation method

5. CONCLUSION

In this paper, a method to perform a new three-step ASK was proposed and the feasibility was shown. The transmission data rate of 6.3 bps with the BER of 0% was achieved. When the transmission data rate increased, the BER also increased. For example, when the transmission data rate was 18.8 bps, the BER was 15%. To solve the BER issue, an approach to generate $(1)_3$ signal twice was proposed and the effectiveness was shown. As future work, the modification of the proposed method will be performed and another modulation method will also be investigated.

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