カオス振動が人体に与える影響解析とその応用

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1 Introduction

In our daily life, we often observe various kinds of complex phenomena. These complex phenomena could be generated from deterministic nonlinear dynamical systems or stochastic systems. In our research, we investigate how such complicated vibrations affect to human bodies. In particular, we focused on the chaotic vibrations generated from chaotic dynamical systems. We also introduce chaotic vibrations with $1/f$ structure that have already been acknowledged to have positive effects on human bodies indirectly.

Low-frequency electrical therapy devices and EMS (Electronic neuro-Muscular Stimulation) devices are typical examples of applications of electrostimulations for medical treatments such as mitigation of throbbing pains and therapy of muscles. It has been reported that muscle contraction by electrostimulation encourages rehabilitation of paraplegics moves[1, 2]. These results of positive effects by electrostimulation indicate that it is important to develop an effective electrostimulation method.

In this project, we investigated how electrical complicated vibrations, such as chaotic dynamics, affect human bodies. We produced a new device with chaotic electrical vibrations and analyzed its effects by experiments. To realize this issue, firstly, we analyzed output characteristics of a low-frequency electrical therapy device which is commercially available. Then, we confirmed that its outputs are not complex but periodic. Next, we investigated electrical components of the low-frequency electrical therapy device. By modifying this commercial device, we made a new device that generates chaotic electrical vibrations and estimated its effects on human bodies. To estimate the effectiveness, we used subjective evaluation as an estimation method. We used Thurstone's paired-comparison method[3]. In the experiments, we adopted three kinds of stimuli, namely, chaotic, intermittent chaotic and periodic vibrations. The experiments and statistical analysis show that effectiveness of the chaotic vibration and the intermittent chaotic vibration is almost the same, and the periodic vibration is the least effective.

2 How to make the chaotic vibration generator

The low-frequency electrical therapy device "Elepuls HV-F127" manufactured by Omron Corp. is a device used for electrical therapy (Fig.1). It uses pads attached to the surface of the human body. Elepuls causes contraction and flaccid of muscles by stimulating with electronic pulses. Example of an output waveform is shown in Fig. 1(b). By the electrostimulation, it reduces the stiffness out of a neck, relieves pains of muscles or recovers from its fatigues.

The Elepuls realizes various types of electrostimulation called "modes" by repeatedly generating rectangular pulses (Fig.1(b)) and combining these pulses in several ways. Among several modes, we used the patting mode. In the patting mode, T_{off} varies while $T_{\mathrm{on}}(= T_{\mathrm{up}} + T_{\mathrm{down}} + T_{\mathrm{int}})$ is constant. When the pulse arises (T_{on}), one can feel electrostimulation. Then, T_{off} corresponds to an interval of a single patting. Namely, T_{off} is a control parameter of patting frequency. In this paper, by modulating T_{off} by a chaotic map, we realized a chaotic patting mode in which intervals of the patting are chaotic.

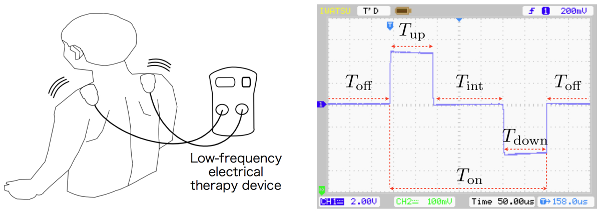

Figure 1: (a) How to use the Elepuls and (b) an output waveform of the Elepuls.

On the basal plate of the Elepuls, micro control units (MCU) controls timings of flipping switches by sending signals to four switching elements of the inverter. Then, the pulses are transmitted to the human body through the pads. In the MCU, switching timings are programmed as the modes. Thus, to change a periodic output to a chaotic output, we controlled the switching timings of the inverter.

Firstly, using a personal computer (PC) as a controller, we implemented a device which converts serial signals sent by the PC to 4-bit parallel signals using a serial-parallel converter, USB-8-bit parallel converter IC manufactured by FTDI Corp.[6]. Next, to control the switching timings by the parallel signals, we cut off wires connecting MCU to four switching elements of the inverter and connected each signal wire of the converter to the switching elements.

Next, we controlled the switching timings by using two maps. The first map is the logistic map[4]:

$$x(t+1) = ax(t)(1 - x(t)). \tag{1}$$

In Eq.(1), we set $a = 4$ to produce a fully chaotic time series. The second map is a modified Bernoulli map[5]:

$$x(t+1) = \begin{cases} x(t) + 2^{B-1}(1-2\epsilon)x(t)^B + \epsilon \\ \qquad\qquad (0 \le x(t) < 1/2)\,, \\ x(t) - 2^{B-1}(1-2\epsilon)(1-x(t))^B - \epsilon \\ \qquad\qquad (1/2 \le x(t) \le 1)\,, \end{cases} \tag{2}$$

where we set $B = 2.0$ and $\epsilon = 1.0 \times 10^{-5}$ to produce intermittent chaotic response which shows a $1/f$ spectral structure. In the modified patting mode of the chaotic vibration generator, we transformed the outputs from these chaotic maps to T_{off} by the following equation:

$$T_{\mathrm{off}}(t) = \frac{\max(\mathrm{T_{off}}) - \min(\mathrm{T_{off}})}{\max(x) - \min(x)} \times x(t) + \min(\mathrm{T_{off}}) \tag{3}$$

where T_{off} indicates a temporal interval of electrostimulation, $\max(T_{\mathrm{off}})$ and $\min(T_{\mathrm{off}})$ indicate the maximum value and the minimum value of T_{off}, and $\max(x)$ and $\min(x)$ are the maximum and the minimum values of $x(t)$ obtained by Eqs.(1) or (2).

Figure 2 shows output waveforms. In Fig.2, one vertical bar represents one set of rectangular pulses shown in Fig.1 (the scale is minified). Then, intervals between the vertical bars correspond to T_{off}. Figure 2 (a) and (b) show chaotic waveforms, while Fig.2(c) shows a periodic waveform. These results show that we could control the timings to output rectangular pulses arbitrarily by our chaotic vibration generator.

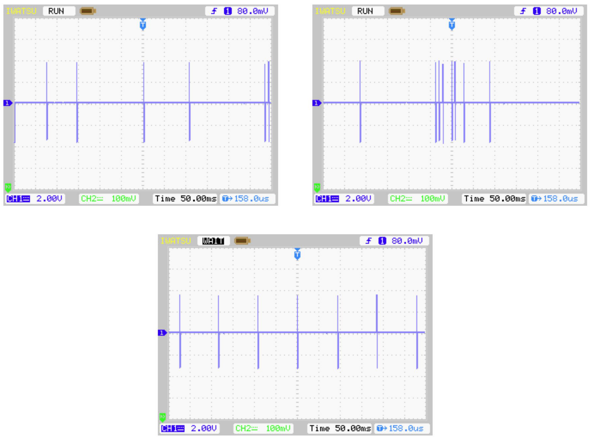

Figure 2: Examples of generated outputs by the chaotic vibration generator when $\max(\mathrm{T_{off}}) = 165.0$ [ms], $\min(\mathrm{T_{off}}) = 2.0$ [ms]. (a), (b) chaotic waveforms with the parameter $a = 4.0$ and (c) a periodic waveform with $a = 2.0$.

3 Experiments and Results

Thurstone's paired-comparison method[3] identifies a rank-order scale of several complicated stimuli.

We conducted experiments on 12 subjects who have stiffness. The process of the experiments is understood by these subjects. In this experiment, the subjects spent a time as usual. When they finished their daily works, we gave a stimulus for 10 minutes at the condition that subjects sat down on a chair. We attached the pads to a part where subjects claimed a stiffness. We used three kinds of stimuli described below.

1. The chaotic vibration produced by the logistic map[4] (Eq.(1)) with $\max(\mathrm{T_{off}}) = 1,000$ [ms] and $\min(\mathrm{T_{off}}) = 400$ [ms].
2. The intermittent chaotic vibration produced by the modified Bernoulli map[5] (Eq.(2)) with $\max(\mathrm{T_{off}}) = 1,000$ [ms] and $\min(\mathrm{T_{off}}) = 400$ [ms].
3. The periodic vibration with $T_{\mathrm{off}} = 720$ [ms].

We compared all possible pairs of two stimuli among these three stimuli. We randomly choose a pair from these three pairs (A, B and C). Then we conducted the pair-comparison. When we used the pair A, first we gave a stimulus randomly among the pairs to the subject. The next day, we gave another stimulus. Then we have a subject answer of which stimulus was better from a viewpoint of the feeling and body conditions after the experiment on the third day. We also repeated the same procedure to the pairs B and C, and the experiment is conducted during 3 days × 3 pairs = 9 days.

Table 1 shows data obtained by the paired-comparison. In Table 1, each element indicates the number of subjects who have judged that the stimulus corresponding to the row was better than that corresponding to the column. For example, the number "2" of the (3, 1)th entry in the table indicates that the number of subjects is two, who have judged that the periodic vibrations was better than the chaotic vibrations.

We obtained the rank-order scale shown in Fig.3 from the results of Table 1. The results indicate that the effectiveness of the chaotic vibration and the intermittent chaotic vibration is the same, and is better than the periodic vibration.

Table 1: Results of the paired-comparison.

	chaotic	intermittent chaotic	periodic
chaotic	–	6	10
intermittent chaotic	6	–	10
periodic	2	2	–

Next, we tested validity of the rank-order value (Fig.3) by χ^2 test, because the model has some assumptions. As a result, $\chi^2 = 0.14$ is smaller than the value of χ^2 with the 1 degree of freedom is 1 and confidence interval of 95% ($\chi^2 = 3.84$). This result indicates that the rank-order values obtained by applying the model) to the paired-comparison data (Table 1) are reliable, however we could not show the difference of the chaotic vibration and the intermittent chaotic vibration. In this sense, one of the important future work is to increase the number of subjects to show how the difference between the stimuli is significant. It is also an important issue to show the reproducibility of the paired-comparison data.

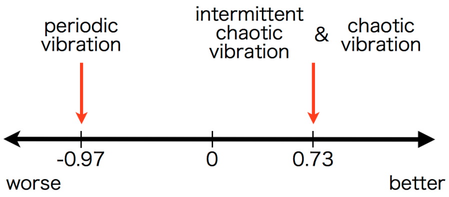

Figure 3: Results of the rank-order scale of three stimuli by the paired-comparison method.

4 Conclusion

We produced a chaotic vibration generator by modifying the low-frequency electrical therapy device which is commercially available. We analyzed how does it affect to human bodies. The data we obtained by the experiment indicate that the complex vibrations are better than the periodic vibration.

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