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Interactive Neural Network – Differential Evolution Framework for Haptic Feedback Retrieval System

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Abstract We propose a haptic database retrieval system based on user's perception and media converter that translates it into a physical haptic feedback. We have developed a three-dimensional psychological space that expresses human perception haptic stimuli by using semantic differential pairs. Differential Evolution (DE) algorithm searches and retrieves haptic stimuli within a haptic physical feature space. Moreover, Neural Networks (NN) maps the searched physical feature vectors into the psychological space. The distance between the mapped positions and target position in the psychological space is used for the GA search, and when the distance becomes less than the threshold value, the retrieval search ends. In this study, we have conducted a preliminary experiment to construct psychological space and the NN part of the proposed system. The result of the preliminary experiment and the configuration of the NN will be discussed in detail.

Keywords computational intelligence, evolutionary computation, neural network, differential evolution, haptic feedback

1. INTRODUCTION

Haptic feedback plays an important role in multimodal communication. In comparison with visual or audio feedback, haptic feedback has its own unique characteristics, such as the capability of delivering private information in a non-intrusive way.

There are special scenarios where haptic feedback is the only available feedback for user, e.g. in a meeting room where all devices have to be set to silent mode. Furthermore, for visually impaired person haptic feedback plays a significant role to support their daily life.

However, the design of haptic feedback in general still remains to be problematic. The problem revolves around the ways of displaying haptic feedback in consumer electronics and devices, which is still quite limited. The most commonly used haptic feedback is the combination of simple force patterns, akin to tactile stimulus generated by a simple tactile actuator, which can be characteristically found in mobile phones.

Therefore, we attempt to explore the possibility of expanding haptic feedback by enriching the amount of information it contains. To be precise, we developed various kinds of haptic stimuli by the superposition of three different ranges of frequency and render them by a pair of vibrotactile actuators.

However, the enrichment of haptic information may lead to another problem in designing haptic feedback. Too many haptic variables potentially increase the level of cognitive load of the haptic feedback designer, which in turn leads to the fatigue. In order to reduce that cognitive load, we propose an interactive NN-DE framework that utilizes both of designer perception and the computation capabilities of a computer.

The objective of this research is to propose an interactive NN-DE framework for haptic retrieval system. However, at the early stage of this research, we focus on analyzing the NN part and the correlation between physical and psychological spaces.

This paper consists of five sections in total. The second section discusses preceding researches and related works. The framework of our proposed NN-DE haptic retrieval system is discussed in section 3 and the result of our preliminary experiment is discussed in section 4. Finally, we conclude our research and discuss possible future works in section 5.

2. RELATED WORKS

2.1 Selective Stimulation Method

The concept of selective stimulation method is based on the fact that tactile receptors in human skin cannot directly sense physical factors. They can only detect inner skin deformation caused by contacting objects [1].

Therefore, the same reproduction of physical factors of any material can be replaced by artificial tactile stimulation to emulate identical reproduction of tactile receptors' nervous activities.

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Selective stimulation method is based on the direct manipulation of three tactile receptors, i.e. FA I (Fast Adapting Afferents Type I), FA II (Fast Adapting Afferents Type II), and SA I (Slow Adapting Afferents Type III).

In this research, we focuses on stimulating three tactile receptors based on detection thresholds as described by Konyo et al. [1]. Fig. 1 illustrates the detection threshold for each tactile receptor, i.e.:

- FA I: most sensitive within 25 – 40 Hz;
- FA II: most sensitive within 200 – 250 Hz;
- SA I: most sensitive at approximately less than 5 Hz;

In this study, we compose the haptic feedback by combining three amplitude variables and three frequency variables as described in table 1 and table 2.

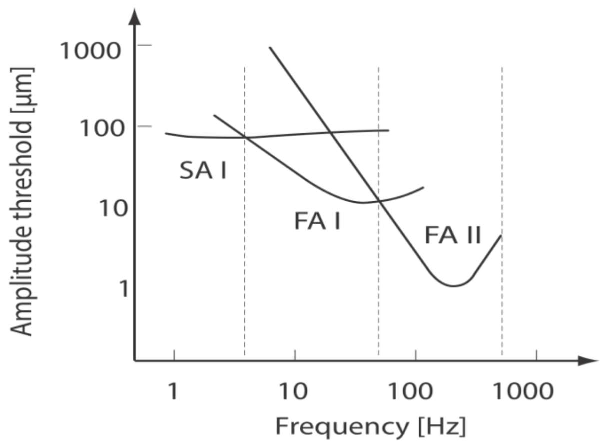

Fig.1 Detection thresholds of vibratory stimuli (based on Konyo [1] that is originally based on Bolanowski Jr. et al. [2])

Table 1: Three amplitude variables for a given haptic stimulus

Force Pattern	Receptor Target	Amplitude Range (micron)
Amplitude_FA1	FA1 (Meissner)	0 – 450
Amplitude_FA2	FA2 (Pacinian)	0 – 120
Amplitude_SA1	SA1 (Merkel)	0 – 600

Table 2: Three frequency variables for a given haptic stimulus

Force Pattern	Receptor Target	Frequency Range (Hz)
Frequency_FA1	FA1 (Meissner)	25 – 40
Frequency_FA2	FA2 (Pacinian)	200 – 250
Frequency_SA1	SA1 (Merkel)	0.4 – 7

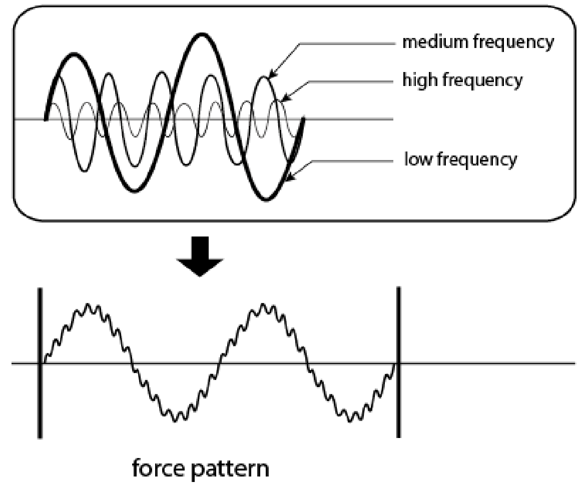

Fig.2 Haptic stimulus design by superposition in this research

The reasoning behind choosing these relatively narrow ranges is to exclusively stimulate a target receptor without simultaneously stimulate any other tactile receptors. For example, we are not expanding the stimuli to include 100 Hz as this frequency can stimulate both FA I and FA II.

Furthermore, amplitude ranges are determined by the amplitude threshold of each tactile receptor. For example, when stimulating both FA I and FA II at the shared range of frequency, FA II is more sensitive to the stimulation than FA I. Therefore, amplitude adjustment is necessary to prevent a stimulus from being too dominant compared to the others.

2.2 Haptic Feedback Design

There are various definitions in regard to haptic feedback design. However, in general haptic feedback can be referred to as hapticon, i.e. a programmed force pattern applied to a user through haptic interface that can be used to communicate a basic notion [3, 4].

In this study, our proposed haptic feedback design concept is illustrated in Fig. 2. The haptic feedback was created by the superposition of three haptic vibrations of different frequency ranges.

2.3 Media Database Retrieval System with Interactive Evolutionary Computation

Media retrieval by the combination of NN and GA has been proposed in several preceding researches. For example, Noda et al. propose a music database retrieval system based on *kansei* and a media converter that translates the same impression into different media [5]. Takagi et al. discuss artificial computation based *kansei* and its application in a media database retrieval system [6]. Furthermore, the media converter framework that takes various kinds of media as

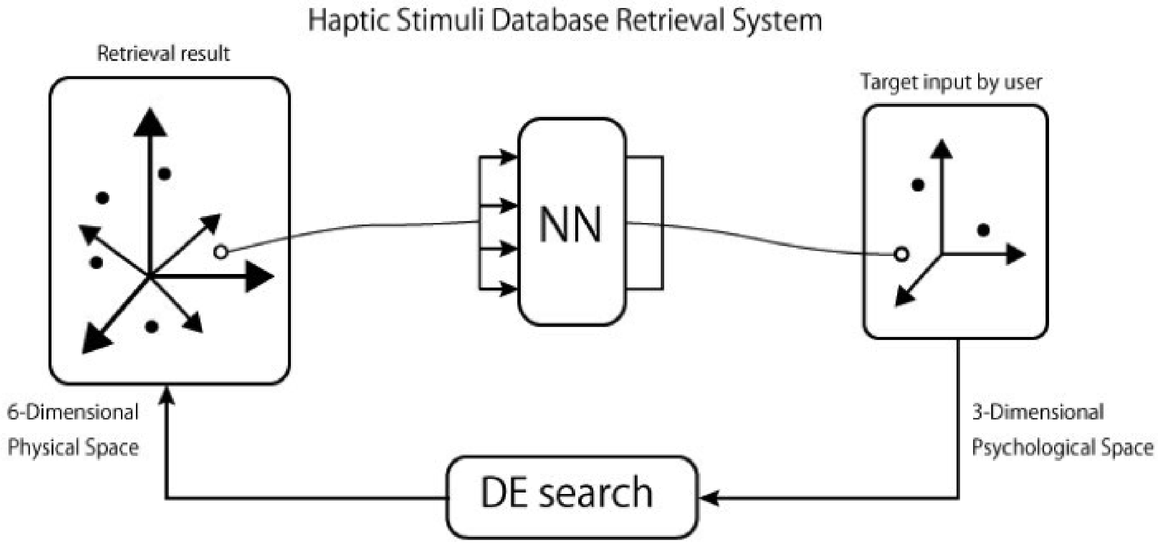

Fig.3 Our proposed haptic database retrieval system that is based on impression. A user points a target impression in the psychological space and GA searches media data whose impression is similar to the target impression. GA searches the media data in a physical feature space and NN maps the coordinates into psychological space. A fitness value for the GA is the distance between the searched coordinate and target coordinate in the psychological space.

inputs and generates different media as the outputs while preserving the same impressions has been described by Takagi et al. [7]. These researches share a point in common, that psychological space and physical space can be integrated and retrieved by the assistance of a neuro-genetic framework.

3. THE FRAMEWORK OF NN-DE RETRIEVAL SYSTEM

Fig. 3 shows the scheme of our proposed haptic database retrieval system. First, user inputs a subjective psychological impression that he/she wants to retrieve into the system as the coordinate in the psychological space. DE conducts a search within the physical space to find the appropriate values of physical features that can represent the desired impression.

The physical features are mapped back into psychological features by the neural network (NN). In the psychological space, the similarity score of the physical variables and the user's input is calculated as the distance between two coordinates. After the distance has been measured, the value is fed to the DE for conducting the search in the next generation.

Our system retrieves haptic feedback based on the mapping relationship between the impression of the texture in the psychological space and its physical features in the physical space by using the combination of NN and DE.

3.1 Construction of the Psychological Space

The haptic database consists of six haptic variables as described in section 2.1, i.e. FA I frequency, FA II frequency, SA I frequency, FA I amplitude, FA II amplitude, and SA II amplitude. We construct a psychological space to express the impression of a retrieval target by using the Semantic Differential (SD) method.

The SD method reduces the redundancy among the adjective pairs and obtains fewer factors describing the original adjective pairs by using Principle Component Analysis (PCA).

The psychological space used in our proposed system has three dimensions as shown in table 3. These factors are obtained from PCA that has been conducted by Hayakawa et al. [8]. This psychological space is the core of our haptic database retrieval system. The installment of the psychological space enables computer to *feel* the impressions of haptic feedback.

Table 3: Three factors in tactile psychological spaces as described by Hayakawa et al. [8]

Factor	Semantic Differential Pair
Roughness	rough – smooth
Hardness	hard – soft
Dampness	dry – damp

3.2 Physical Features of Haptic Data

The haptic database consists of six haptic variables as described in section 2.1, i.e. FA I frequency, FA II frequency, SA I frequency, FA I amplitude, FA II amplitude, and SA I amplitude. This means that each haptic stimulus has a vector of 6-dimension physical features.

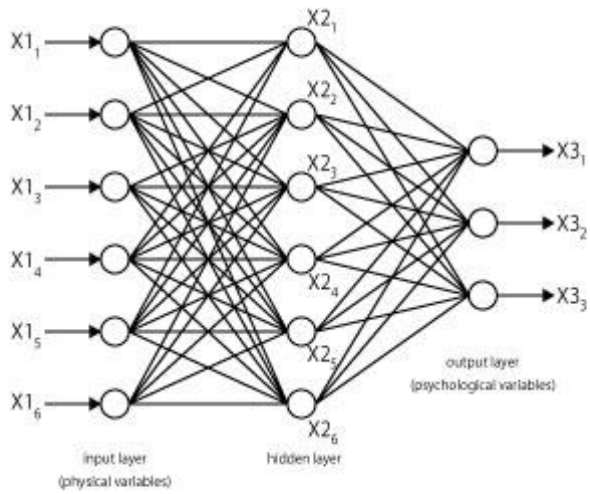

Fig.4 Artificial Neural Network configuration in this study

Table 4: Weight values (W_{ij}) for neurons between input layer $X1_j$ and hidden layer $X2_i$

	$X1_1$	$X1_2$	$X1_3$	$X1_4$	$X1_5$	$X1_6$
$X2_1$	0.104	0.029	0.026	0.001	-0.138	-0.092
$X2_2$	0.036	-0.097	0.187	0.021	-0.163	-0.099
$X2_3$	0.019	0.019	-0.017	0.091	-0.035	0.060
$X2_4$	0.033	-0.055	0.135	0.049	0.013	-0.050
$X2_5$	-0.131	0.046	0.174	-0.003	-0.065	-0.059
$X2_6$	-0.078	0.059	0.179	-0.020	0.069	0.054

Table 5: Weight values (W_{ij}) for neurons between hidden layer $X2_j$ and output layer $X3_i$

	$X2_1$	$X2_2$	$X2_3$	$X2_4$	$X2_5$	$X2_6$
$X3_1$	-0.180	-0.143	-0.038	-0.057	-0.084	-0.128
$X3^2$	0.018	0.057	0.002	0.006	0.132	-0.083
$X3_3$	-0.098	-0.075	-0.016	-0.189	0.093	0.045

4. PRELIMINARY EXPERIMENT: NEURAL NETWORK LEARNING BY BACKPROPAGATION

We have conducted preliminary experiment to construct a neural network model by using backpropagation learning. Five participants (four university students and one academic supervisor) participated in our study. In this experiment, each participant gives scores to a Semantic Differential (SD) Questionnaire within an hour. There were 100 stimuli to be evaluated. The stimuli were generated randomly and there are no identical stimuli within those 100. Therefore, we obtained 5 x 100 data that are used for backpropagation learning.

4.1 Neural Network Learning by Backpropagation Algorithm

Backpropagation is a supervised learning method that can be used to train artificial neural network by using a dataset that consists of inputs and outputs. Backpropagation algorithm compares the outputs from feed-forward neural network and the output from training data and calculates the errors. These errors are used for NN learning by updating weight values in output and hidden neurons.

In this study, our Artificial Neural Network (ANN) has the configuration of 6:6:3, i.e. the respective number of neurons in input, hidden, and output layer, as described in Fig. 4. Furthermore, the formulas of the calculation of each neuron in output and hidden layer are described in (1) and (2).

$$X2_i = \phi_i\left(\sum_{j=1}^{N} W_{ij} X1_j\right) \quad (1)$$

$$X3_i = \phi_i\left(\sum_{j=1}^{N} W_{ij} X2_j\right) \quad (2)$$

where φi is the activation function and N is the total number of neurons in a given layer. For the hidden layer formula (1), φi is between -0.5 and 0.5; and for the output layer formula (2) φi is between 0 and 1.

The complete weight values for neurons between the input layer and the hidden layer are shown in Table 4. Furthermore, those between the hidden layer and the output layer are shown in Table 5.

4.2 Analysis of the Correlation between Input and Output Variables

ANN can solve non-linearity problems by modifying the weight values in accordance to the NN learning, thus it can be utilized to explain non-linearity in our physical–psychological model. By exclusively select a combination of input variables, we use the ANN configuration to analyze relative importance of each input variables to the output variables.

For instance, we have investigated the correlation between two variables (amplitude_SA1 and amplitude_FA2) and dampness factor. As shown in Fig. 5, amplitude_FA1 negatively correlates to dampness (Fig. 5-a) while amplitude_FA2 has a positive correlation to dampness (Fig. 5-b).

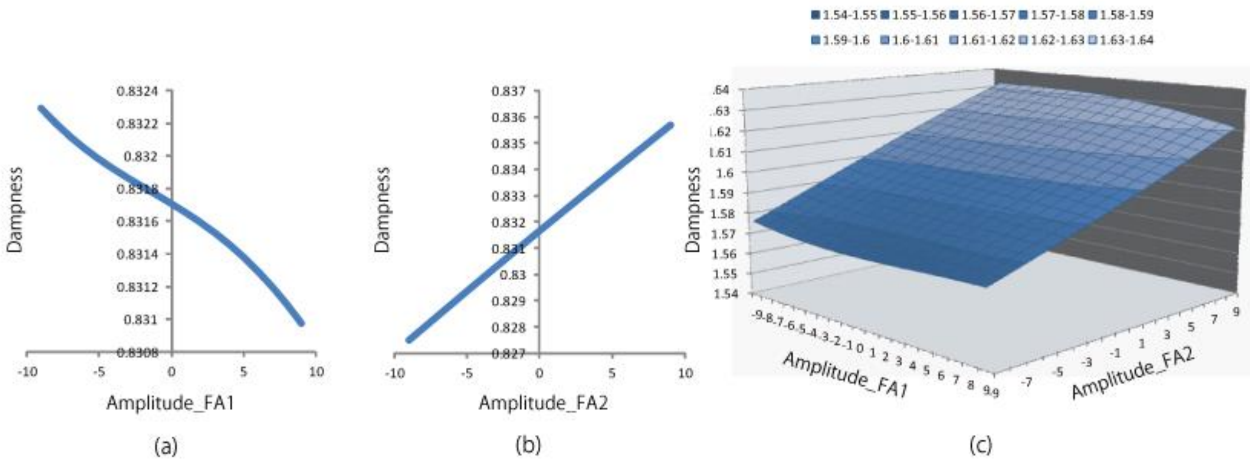

Fig.5 The correlation between amplitude_FA1 and dampness (a); amplitude_FA2 and dampness (b); and amplitude_FA1, amplitude_FA2, and dampness (c)

Furthermore, Fig. 5-c shows the complete correlation between amplitude_FA1, amplitude_FA2, and dampness (as the dependent variable). It is evident that there are non-linear correlations between those three variables and amplitude_FA2 has more influence in determining dampness sensation than amplitude_FA1. Based on the correlation between those three variables, the psychological sensation of dampness can be maximized by decreasing amplitude_FA1 and increasing amplitude_FA2.

5. Conclusion and Future Works

In this paper, we have described our proposed NN-DE haptic retrieval system. At the initial stage in this study, we have developed the neural network part that is responsible for mapping the physical features into psychological impression.

Furthermore, we have conducted preliminary experiment to investigate the correlation between psychological input variables and physical outputs. By utilizing this ANN configuration, we can determine the correlation properties between input and output variables. For instance, there are non-linear correlations between amplitude_FA1, amplitude_FA2, and dampness.

Future works will be focused on the finishing of NN-DE based haptic database retrieval system and further analysis of the correlation between each corresponding input and output variables.

Acknowledgement

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