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System Identification of Decision-Making Process in Gold Trading Game

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***Abstract*—The decision-making process of human are being researched in association with making psychological models and experiment technique. However, there is no mathematical models using transfer functions for representing such process as far as the authors know. In this research, a model of the decision-making process was constructed, which was consisting of proportional, integrator, and derivative elements. And, the coefficients of the each element, *Kp*, *Ki,* and *Kd*, were individually identified by the least-square method, using the input-output data obtained in the computer simulation game of gold trading, which was created especially for this research.**

In the result, *Ki/Kp*, the coefficient ratio between the integrator element and the proportional element, and *Kd*/*Kp*, that between the derivative element and the proportional element, were different for each individual. As these differences can be regarded as individual differences, the constructed model is considered to achieve the representation of individual properties, which is the aim of this research.

However, in this created game, the recall ratio of *Ki/Kp* and *Kd/Kp* was not high respectively, the average of them was only 15%. This low recall ratio can be due to the inadequacy of the game used for the identification, or the unsuitability of the structure of the constructed model. Thus, the improvement of the gold trading game and model's structure are the next challenges. Especially, the addition of learning function to the model of the decision-making process is one of the desirable challenges, because it could work even in short and repeated process like gold trading.

I. Background and Purpose

Nowadays, the decision-making process of human are being researched with making psychological models and psychological experiment technique. These model and experiment technique were used mainly in market research and more [1][2]. In particular, the magnitude estimation method is well-known as one of the process tracing method in psychological experiment techniques by which the decision-making process more clearly and qualitatively.

However, the research using the psychological experiment technique highly costs, because the researchers have to monitor experimental volunteers and the experiment conditions were limited such as the situations of the laboratory and the number of the researchers. Therefore, for solving these problems, the psychological models were required to develop and apply to various fields. In fact, such model has been also developed for a clinical decision support system [3].

In Japan, an action deciding model using fuzzy algorithm has been developed by Yamashita [4]. This model can represent the decision-making process in career formation as the analog to our thought patterns, because fuzzy algorithm can cope with the fuzziness of the decision-making process. However, fuzzy algorithm has a difficult problem that its membership functions and fuzzy rules cannot be designed uniquely.

Models using transfer functions are significant for representing the decision-making process in various situation more simply, however there is no such models as far as the authors know. In our laboratory, the simpler models of the decision-making process have been developed since around three years ago [5][6]. However, these models cannot represent individual differences of the decision-making process completely.

Therefore, in this research, a simpler model of the decision-making process in gold trading is constructed with the transfer functions of the proportional, the integrator, and the derivative elements, for helping in future team management and more. And, for the validation of this model, its parameters are individually identified by the least-square method, using input-output data obtained in the computer simulation game of gold trading, which was created especially for this research.

II. Construction of Model

In this research, the decision-making process of human brain is limited to the feedforward process from input information to output decisions. The process is hypothesized that it consists of each response to the present, the accumulated, and the trend information. And, its mathematical model was constructed based on this hypothesis, whose block diagram is shown in Figure1.

In the constructed model, the proportional, the integrator, and the derivative elements are included in parallel. The transfer functions of these elements are corresponding to each response to the present information, the accumulated

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information, and the trend information, respectively. The input variable $u(t)$ is the present gold price shown to a trader, and the output variable $y(t)$ is the decided trading amount of gold by the trader. The input-output relation of the model is shown by the equation (1).

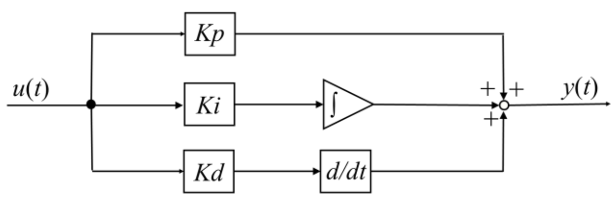

Figure 1. Structure of the model of the decision-making process consisting of the proportional, the integrator, and the derivative elements.

$$y(t) = Kd\frac{du(t)}{dt} + Kp \cdot u(t) + Ki\int_0^t u(\tau)\,d\tau \qquad (1)$$

The constants Kp, Ki, and Kd are the coefficients of the proportional, the integrator, and the derivative elements, respectively, which are regarded to reflect the magnitude of each response to the present, the accumulated, and the trend information. Also, the differences of these coefficient can be regarded as the individual differences in the decision-making process.

Thus, the individual differences in the decision-making process can be grasped when the coefficients are individually identified using the input-output data of the model.

III. System Identification

A computer game of trading gold was created in C language to obtain the input and output data of the model, which are used for its system identification. In this game, players decide and input the trading amount of gold for 12 weeks, while considering the gold price every week shown on the display. The players of the game were 30 volunteers aged 21 to 25 (male; 18, female; 12), who were ethically approved as the experimental subjects in Tokai University. The game was played 4 times for each player on the condition that the trading number of times of the game was not informed beforehand and the trading amount of gold was not limited.

Before playing game and after playing game, volunteers answered some questions, and the answers were used for validating of the reasonability of the obtained input-output data. Those questions were shown in Table 1.

The model shown by Figure 1 as a continuous time system was transformed into a discrete time system using backward difference, because the game is set to progress by the week. Also, the coefficients Kp, Ki, and Kd were calculated by the least-square method, using the obtained data of $u(t)$ and $y(t)$. The input-output relation transformed into discrete time system is shown by the equation (2).

Table 1. Questions asked to the volunteers.

Questions before the game	Questions after the game
Gender	Whether it is possible to predict the week when the game will end
Age	Way to decide the trading amount of gold in the game
Experience of financial trading such as gold, Fx, stocks, and more	Requests for game operability and reality
Interested in financial trading or not	

$$\begin{aligned} y(i) = y(i-1) + (Kp + Ki + Kd)\cdot u(i) \\ -(Kp + 2Kd)\cdot u(i-1) + Kd\cdot u(i-2) \end{aligned} \qquad (2)$$

IV. Results

The most volunteers could almost explain the way to decide the trading amount of gold as the answers to the questions after the game, except some volunteers. Also, a few problems on operating the game were pointed out, such as the input data could not be corrected even if the inputs were incorrect.

The coefficients Kp, Ki, and Kd were calculated four times for one volunteer, using the data sets every twelve weeks. And, the distribution of Ki/Kp and Kd/Kp of each volunteer were not matched normal distributions, because their kurtosis and skewness were 20.2 & -4.121, and 14.16 & -3.505. The main descriptive statistics values of these distributions were shown in Table 2. Where, Ki/Kp and Kd/Kp were respectively calculated by dividing the median of Ki and Kd of each volunteer by the absolute value of Kp's median of each volunteer.

Table 2. Descriptive statistics values of the distribution of Ki/Kp and Kd/Kp

	Ki/Kp*, the standardized parameter of *Ki	***Kd/Kp*, the standardized parameter of *Kd***
Maximum Value	0.0116	0.0003
75 percentile	-0.0034	0.000001
median	-0.035	-0.000002
25 percentile	0.0013	0.000005
Minimum Value	-0.0709	-0.0014

Because integration and differentiation are completely opposite mathematical operations, it is reasonable to illustrate individual's characteristics in the decision-making process as vectors on Cartesian coordinates, where the horizontal and vertical axes represent the ratio of Kp to the absolute value of Kp and the difference between Ki/Kp and Kd/Kp, respectively. The characteristics of the volunteers numbered 1, 10, and 21 identified using the data obtained only in the first game are shown in Figures 2, 3, and 4, respectively. The vector extending to the lower left in Figure.2 shows that the integration element worked more strongly than the derivative element, in the decision-making process of the volunteers numbered 1. And inversely, both vectors in Figure.3 anf 4 indicate that the derivative elements worked more strongly than the integration elements, in the volunteer numbered 21 and 30.

The characteristics of the volunteers numbered 21, 24 identifed every game are shown together in Figure.5, 6, respectively. When limited to only two volunteers shown in Figures 5, 6, the both of the recall ratio, that individual's characteristic vectors calculated in each game match up, were 75% . However, its mean value calculated for all volunteers, that is the total recall ratio, was lower as only around 15%.

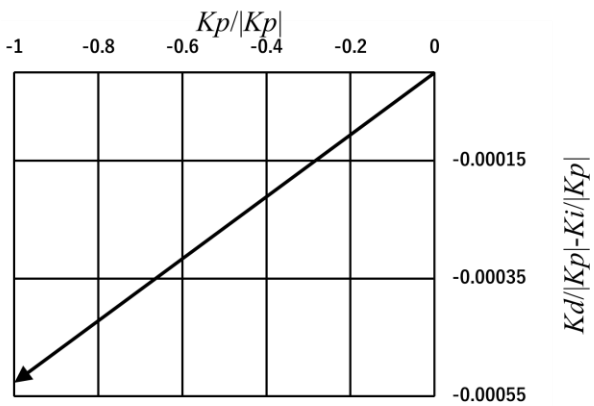

Figure 2. Characteristics of the decision-making process of the volunteer numbered 1, identified using the data obtained only in the first game.

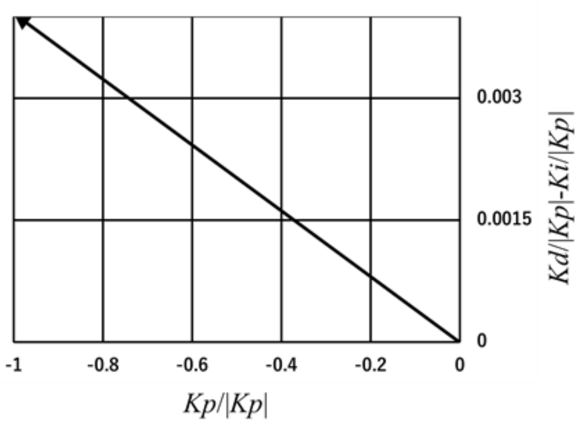

Figure 3. Characteristics of the decision-making process of the volunteer numbered 21, identified only in the first game.

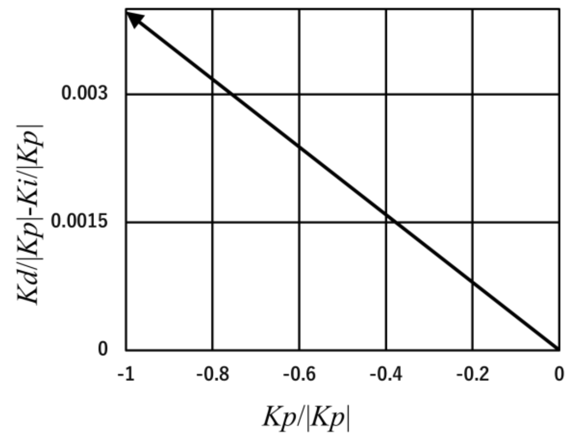

Figure 4. Characteristics of the decision-making process of the volunteer numbered 30, identified using the data obtained only in the first game.

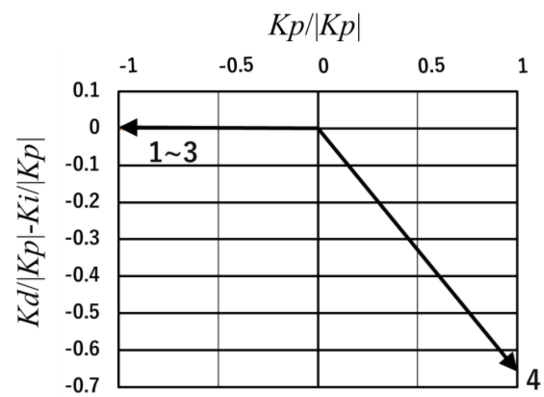

Figure 5. Characteristics of the decision-making process in the volunteer numbered 21, identified using the data obtained every game. The numbers of 1 to4 indicate how many times the game was played.

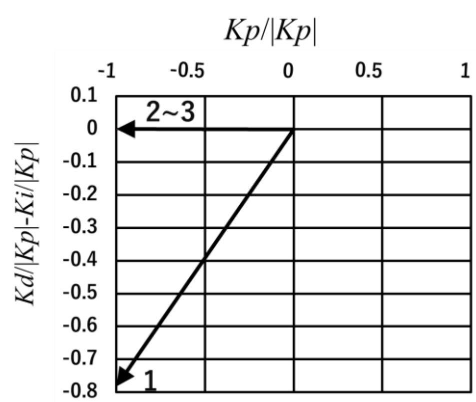

Figure 6. Characteristics of the decision-making process in the volunteer numbered 24, identified using the data obtained every game. The numbers of 1 to4 indicate how many times the game was played.

V. DISCUSSION

The model constructed in this research has only feedforward structure without feedback loop. The reason is that the feedback function which the gold price changes depending on the trading amount of gold, is not in the decision-making process in brain but in the economical process in society. However, the learning loop which works to maximize the gain in gold trading is in the decision-making process in brain. Thus, the research around the learning loop described below is necessary as a next challenge.

The individual differences of the decision-making process in the game of gold trading were analyzed reasonably by identifying the constructed model. However, the game was played only four times per a volunteer and the total recall ratio of the vectors of the characteristics was not high. Thus, it may be necessary to repeat system identification more while improving the structure of the model.

The characteristics in the decision making process identified using the input-output data were almost not different to that estimated from the answers to the questions after playing games except some volunteers, who could not explain their characteristics of the decision-making process in trading gold. Thus, the construted model might be help to understand own characteristics in the decision-making proces, especially for person who does not understand themselves clearly.

The improvement of the model could be required such as considering the learning function in the decision-making process, because human can learn even in short process such as the game of trading gold. A block diagram of the model with the learning function is illustrated by an example of Figure.7. *F* in the Figure.7 represents a transfer function of the learning function, by which the coefficients *Kp*, *Ki*, and *Kd* are adjusted.

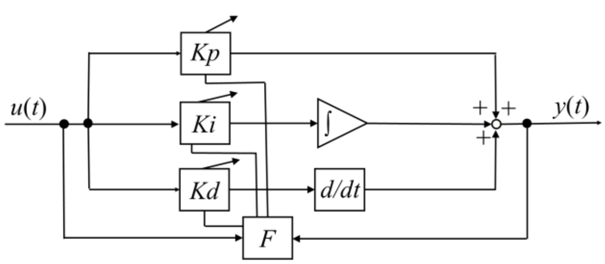

Figure 7. Example of a block diagram of the model with a learning function.

Also, the decision-making process of human is not known clearly, especially in the case that the input variables are chaotic. Therefore, the model of the decision-making process based on the chaotic information is required to construct for representing the decision-making process more essentially, regardless of trading gold.

In this research, although its experimental volunteers did not need to speak and to be close to the researcher, the experiments were done reasonably. And, the experiments using a computer game can be useful for taking data of more volunteers at the same time. These merits are not common in traditional psychological experiments. Thus, such experiment using a computer game could become a breakthrough for investigating the decision-making process, in particular in the case such as under the circumstances of COVID19.

VI. CONCLUSION

The individual differences of the psychological characteristics were analyzed reasonably by constructing and identifying the mathematical model of the decision-making process, using the game of gold trading as an example. However, a few improvements remain in the constructed model. Therefore, a model in the consideration of learning and/or chaos is necessary to construct for advancing higher-precision analysis of the decision-making process. And, the experiment using a computer game, such as one in this research, could be useful in the case such as under the circumstances of COVID19.

APPENDIX

This research was done under the approval by the ethical committee for human experimental subjects at Tokai University, especially in accordance with Japanese guidelines on Novel Coronavirus (COVID19).

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