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FAVORABLE CHARACTERISTICS OF INTELLIGENT MACHINE COOPERATING WITH INSTRUCTIONS BY FINGER MOVEMENTS IN THE CASE OF ONE-DIMENSIONAL MOVEMENT

Satoru SHIBATA*, Kouichi KANKUBO**, Mitsuru JINDAI*,
Tomonori YAMAMOTO* and Akira SHIMIZU*

**Ehime University, 3 Bunkyo-cho, Matsuyama, Ehime, 790-8577, Japan*

***Yuge National College of Maritime Technology, 1000, Shimoyuge, yuge-cho, Ochi-gun, Ehime, 794-2593, Japan*

Abstract: When intelligent machines coexist with humans, it is important that the intelligent machine's movement in response to human instruction is acceptable by the human state of mind. When a human instructs an intelligent machine with his or her finger, we focus on a simple and easy interface via which conversion of the finger indication to intelligent machine motion is realized by a transfer function. In this paper, we evaluate relations between the transfer functions and human feelings using Semantic Differential method. The results of the SD method show that there are typical forms of transfer functions and parameters to generate comfortable motion for humans. Desirable transfer functions are the first-order or the second-order delay elements in which the parameters must be chosen so that the maximum velocity of generated intelligent machine motion exists in the range of 71-77% of the maximum velocity of instruction movement. In addition, human feelings to the intelligent machine motion generated by human instructions are represented by the factors of "lively", "mild", and "interest".

Keywords: *Human-Intelligent machine interface, Instruction by finger movements, Transfer Functions, SD method, The factor of "mild"*

1. INTRODUCTION

Human-friendly and human-supportive intelligent machines have been desirable in recent years in the fields of welfare and medicine. These intelligent machines will serve as functional substitutes for the physically disabled, perform nursing care for the elderly, share daily space with humans for job assistance, and recognize individuals as their users. For example, if there is an intelligent machine in a room that can bring, carry and put things away for humans, the command method to the intelligent machine should not be too complicated. It is also necessary for the intelligent machine, in response to such commands, to show response characteristics that are human-friendly.

Various studies on the motions of robots, in which the robots move in accordance with human commands, have been conducted mainly to assist in daily life. The commands include voice commands[1] for carrying food, commands using a laser pointer[2] which is installed in the head part for assistance in eating, and direction control using face[3] or face and gaze[4] for an electric wheelchair. These studies, however, mainly focused on certain fixed motions by commands, rather than focusing on the motion characteristics from the start to the end.

Those motion characteristics of robots when assisting humans in everyday life are highly influential in terms of human state of mind. Thus, a certain command method is desired to mold those motion characteristics.

In this study, we independently conducted a survey by interviewing 80 healthy individuals (40 for each gender) aged 18 to 40 asking them to come up with as many methods as possible of giving a command to another person. As a result, all of the 80 subjects cited "command by voice," followed by "command by hand motion" (77 subjects) and "command by gesture" (58 subjects). In most cases of "voice command," the purpose of the motion is easily achieved when it is spoken by a human subject; motion characteristics that can implement that purpose displays human characteristic smoothness. In the case of an intelligent machine subject, the motion trajectory generated to accomplish the purpose is very important so that the intelligent machine motion will be acceptable by the human state of mind. However, it is difficult to direct the intelligent machine accurately by voice commands. By comparison, in the case of "hand-motion command," if the intelligent machine is controlled to cooperate with the hand movements, the "commander" can directly command the intelligent

machine on motor characteristics. Not only that, the intelligent machine's motion characteristics will reflect the smooth motion characteristics of the human hand motion as well, making them an effective interface. Therefore, in this research, we focused on the interface of intelligent machines that are operated by hand motion.

There have been a number of studies on manual control using an operation system on control subjects. Yet, the main purpose of those studies was to evaluate the adoptability, the degree of proficiency and learning property of human operators. In contrast, the interface focused on in this research is a command given by moving the fingertips, which is less burdensome physically and psychologically. Thus, there will be little adaptability or learning efficiency involved.

Concerning the interface, which was the focus in this research, a person was assumed to give commands to an intelligent machine situated far from him or her. The master-slave system is a well-known remote operating method to conduct a task in an environment where the humans do not have direct access. In contrast, in this study, we assumed an intelligent machine that can operate in the same task space as that of a human with the goal of coexistence. For this reason, the commander focused on the less burdensome command motions by hands, not advanced command methods such as the master arm operation.

Previous studies on robot motions and human psychology include those on the emotional evaluation for mechanical motions[5], the influence of motion characteristics of the horizontal two-joint robot on human psychology[6], psychological impact on the horizontal motions of a scalar-type robot arm[7], robot motion evaluation using biological signals[8], and the psychological evaluation of robot avoidance motions[9]. The results of those studies all revealed that the maximum velocity and velocity patterns of a robot when in motion could greatly influence human psychology. Thus, it is necessary to consider the maximum velocity and velocity patterns to achieve human-friendly intelligent machine motions.

In this research, as a fundamental study of a human-friendly and human-supportive intelligent machine system, we proposed an intelligent machine system less burdensome for humans, by which the intelligent machine can perform cooperative motions in response to human hand command motions and one in

which intelligent machine motion characteristics could be taken into consideration. This system converts human hand command motions to intelligent machine motions by shaping their waveforms with a transfer function. More specifically, the system generates intelligent machine motions by means of a transfer function that assumes the location of a human hand to be "input" and the intelligent machine location "output." Multiple motion characteristics are created by changing the shape of the transfer function and the parameter values, thus making it possible to change the maximum velocity and velocity patterns of intelligent machine motions. Next, using the semantic differential method (SD), we clarified how those values should be configured to create motion characteristics more appealing to human state of mind. Then by analyzing the results, we discussed the representative factors in human state of mind regarding hand-command-obedient intelligent machine motions.

2. GENERATION OF INTELLIGENT MACHINE MOTIONS

In this section, we examine what motion characteristics an intelligent machine, which is capable of following human hand command motions, needs to generate in order to be human-friendly or acceptable to humans. To do so, we adopted the following patterns of motion characteristics:

Table 1: Transfer functions

$G1 = 1$	$G2 = e^{-0.3s}$	$G21 = \frac{e^{-0.15s}}{0.1s+1}$
$G3 = \frac{1}{0.1s+1}$	$G31 = \frac{1}{0.2s+1}$	$G32 = \frac{1}{0.4s+1}$
$G4 = \frac{e^{-0.3s}}{0.1s+1}$	$G41 = \frac{e^{-0.3s}}{0.2s+1}$	$G42 = \frac{e^{-0.3s}}{0.4s+1}$
$G5 = \frac{1}{(0.1s+1)^2}$	$G51 = \frac{1}{(0.2s+1)^2}$	$G52 = \frac{1}{(0.4s+1)^2}$
$G6 = \frac{e^{-0.3s}}{(0.1s+1)^2}$	$G61 = \frac{e^{-0.3s}}{(0.2s+1)^2}$	$G62 = \frac{e^{-0.3s}}{(0.4s+1)^2}$

Pattern 1: Meticulous reconstruction of human hand command motions

This is the reconstruction by the intelligent machine of human motions. "Cybernetic motion" was named by Ogawa et al.[5] after quantitatively analyzing the motions of living creatures. Based on the conclusion that humans feel comfortable with cybernetic motions and the notion of Shibata et al.[6] that velocity patterns similar to the

motions of human upper limbs make human-like impressions on humans, human smooth motion characteristics are candidates for those that are appealing to human state of mind. Those motion characteristics become possible by directly reconstructing in an intelligent machine the motions in response to human command motions (G1 in Table 1).

Pattern 2: Reconstruction of motions by which a human moves things in response to human hand command motions.

As a preliminary experiment, we obtained the human control characteristics when a human moves things following the command of another human's motions. As a result, the transfer function between the two is expressed as a first-order delay element (time constant: 0.1 sec.) with dead time (0.15 sec.). Thus, we reconstructed the human motion using this transfer function (G21 in Table 1).

Pattern 3: Modification of the obtained parameters and shapes of human transfer functions

Since the evaluation subjects are not humans but intelligent machines, parameters different from the human transfer function may be desirable. Yet, it is a well-known fact that human characteristics are smooth. Therefore, it is difficult to imagine that the optimum solution was very different from the human transfer function. Based on the parameter value of human transfer function, we first selected a parameter value that energizes different emotions. The dead time is determined in the following manner: we prepared the dead time of 0.1 ~ 0.4 sec. with 0.1 sec. intervals for all the subjects. The pilot test result on all transfer functions showed that 0.3 sec. is the most appropriate value for subjects regardless of the form of transfer function. We also confirmed that whether the value has increased or decreased, the sense of inappropriateness increases. For this reason, we adopted 0.3 sec. for the dead time. There were fifteen kinds of as shown in Table 1.

The input of transfer function was the location of the fingertip while the person was giving a command and the output was the location of the intelligent machine. We analyzed the relationship between human state of mind and the motion characteristics generated by the transfer function. We also examined the efficacy of the transfer function proposed from those findings and the parameter value of transfer function to achieve the objective of this study.

3. EXPERIMENTS

When we consider an intelligent machine which carries an object instead of human or hands over an object to human in a daily environment in the near future, the intelligent machine should have a simple structure and conduct tasks with simple trajectory so that the intelligent machine can be used easily as the extension of a tool or a machine and be acceptable to human state of mind. In addition, when we consider a motion of the intelligent machine cooperating with instructions by human finger movement, the motion should be generated by the end effector of the intelligent machine. In this research, a person is assumed to give commands to an intelligent machine situated far from him or her to move an object from one point to another.

We conducted a subjective evaluation test using a one degree-of-freedom intelligent machine on the above three patterns to clarify the influence of intelligent machine motions following the human command motions upon human state of mind. As the one-dimensional motion, the horizontal motion or the approaching and departing motions can be considered. However, because the subjective evaluation on approaching and departing can be different, we will analyze that case separately as a future research. In this research, we studied right-and-left horizontal motions, which have little influence of the difference of the motion direction on human state of mind.

3.1. Experimental setup

Figure 1 shows the outline of the experimental setup in this research. The subject sat in a chair directly in front of the intelligent machine and gave commands to the intelligent machine by operating a lever of the indicator on the desk. For the indicator, we used a linear displacement meter that outputs voltage in correspondence to the movement zone (MIDORI PRECISIONS; effective range of movement 300 mm, coefficient of friction 0.98N; "the indicator" hereafter). As a pilot test, we measured the moving distance of the lever when the indicator lever was moved to the right or to the left from an arbitrary origin in the same manner as in the actual test. The results showed that the maximum moving distance was 261mm and the mean moving distance was 198mm (standard deviation 49mm). Thus, we determined the effective range of movement to be 300mm.

Figure 1: Experimental setup

For an intelligent machine that moves in coordination with human command motions, we used a Mega Thrust Motor (NSK; maximum velocity 1,800mm/sec., effective range of movement 1,390mm; “the intelligent machine” hereafter). As the result of the pilot test, we confirmed that the tracking error on human command motions was 0.84% on average, meaning that the intelligent machine was sufficiently able to track human command motions.

The voltage corresponding to the moving location of the indicator lever was output from the indicator and was input into a PC (NEC; clock frequency 400MHz) through an A/D converter. The location signal became the input to the transfer function mentioned in the previous section and calculated the operation volume to the intelligent machine. The operation volume was input into the intelligent machine through the D/A converter and the driver. The intelligent machine tracked the command motions given with fifteen kinds of motion characteristics by the human. The sampling time of the system was 8msec.

3.2. Subjective evaluation

For the subjective evaluation of motions, Ogawa et al.[5] evaluated mechanical motions with a variety of velocity patterns using the SD method. The SD method is one of the subjective evaluation methods for a wide range of stimulations such as music, merchandise, environment and movement. The subjects evaluated several adjective pairs (SD scale) on a scale of seven. A factor analysis was conducted on the obtained results to draw common factors that exist behind the scale.

Yamamoto et al.[9] conducted a subjective analysis on

the intelligent machine’s human avoidance motions using the SD method. This study matches those by Ogawa et al. and Yamamoto et al. in terms of subjective evaluation of motions using the SD method. Here, following the general procedure of the SD method, the subjects evaluated intelligent machine motions on a scale of 1 to 7, which had been generated by each transfer function regarding as many adjective pairs on stimulations as possible. Factor analysis was conducted on the obtained results to draw common factors that exist behind the scale. In addition, the obtained results were analyzed in more detail from the standpoint of the coexistence with intelligent machines, and the parameters of desirable transfer functions were examined.

Twenty adjective pairs that had been selected from reports by Ogawa et al. and Yamamoto et al. were selected in terms of citing the adjective pairs related to motions. Kanda et al.[10] extracted intimacy factors concerning the impression of an intelligent machine on humans. For this reason, we added two more pairs of adjectives, “reassuring -surprising” and “nice-dreadful” to the above adjective pairs to generate motion characteristics that are appealing to human state of mind. The subjects evaluated those 22 adjective pairs.

3.3. Experimental procedure

Before beginning the evaluations, the evaluation forms of 22 adjective pairs divided equally in half (11 each) were distributed to the subjects. The entry method, how to sit in the chair, and the operating method of the indicator were explained as follows..

(1) For every transfer function, the subject repeats a 12-sec. command motion, repeating this motion twice. After each motion, the subject evaluates the adjective pair. If the subject requests, a motion can be repeated as many times as he or she wishes.

(2) As shown in Fig. 2, the subject sits in a chair directly in front of the intelligent machine. The subject adjusts the height of the chair to find a comfortable height of the hand while lightly holding the indicator lever, which is installed at the starting point, with the right hand. The initial distance between the intelligent machine and the subject is set at 1,200mm, but, the subject can change it as needed during the test.

(3) No restrictions were placed on the stationary position, precision and motion time of the intelligent machine. Thus, freer command motions were employed.

(4) Instead of operating the intelligent machine while

looking at the indicator lever, the subject moves the lever to lead the intelligent machine to an arbitrary location while looking at it from the front.

Figure 2: Experimental method

Methods (1) and (2) are designed to lessen the mental and physical burden on the subject. In our daily life in general, locations for positioning things are determined in advance. However, since this study is a very fundamental one, we decided not to require accuracy in positioning things. That will be a future assignment. Therefore, the subject employs free command motions without the need to consider the influence of the stop location and precision (Method (3)). As for (4), since the objective is to evaluate the motion characteristics of the intelligent machine, the subject is required to focus on the intelligent machine motion not the command motion.

In this research, the size of the object to be moved by the intelligent machine was assumed to be about the size a healthy person can pick up and move by hand without much burden. Thus, a 150mm-side cube was adopted. The color of the object was lime green, which is believed to be sufficiently conspicuous yet causes least fatigue to the eye. The maximum range of intelligent machine movement was assumed to be 900mm for the reason that the intelligent machine would put things away in place of a human in a daily environment. The intelligent machine location was set at maximum (900mm) when the moving location of the indicator lever is at its maximum (300mm).

4. EXPERIMENTAL RESULTS AND DISCUSSIONS

4.1. Results of subjective evaluation

Under the above conditions, we conducted a subjective evaluation for 50 healthy right-handed people (25 for each gender) of ages 19 to 20. The gender difference in evaluation of the subjects showed three kinds of significant differences in transfer functions G4, G41 and G6 (significance level 5% in a t test of the mean). We attribute the difference to the fact that male subjects reacted emotionally to the delay in motion due to dead time. Figure 3 shows the means of the evaluation points on 22 adjective pairs of five transfer functions, which are distinctive and considered to be representative of the 15 transfer functions.

In Fig. 3, in adjective pairs such as “fast” “agile” “light” and “active,” we observed significant differences (significance level 5% in a t-test of the mean) of G2 in comparison to other transfer functions. Although G3 showed a mean of 4 or greater, no major difference (standard deviation 0.2) was observed between the adjective pairs. G42 was lowly evaluated (the mean of adjective pairs 3.5) for many adjectives while G32 and G51 were highly evaluated. Particularly in “reassuring”, “nice”, “soft”, and “smooth”, a significant difference

Figure 3: Mean value of evaluation

(significance level 5% in a t test of the mean,) from other transfer functions was observed.

Next, a factor analysis was conducted based on the evaluation results. Since there were three factors greater than 1 in eigenvalues of the variance-covariance matrix, the number of factors was assumed to be 3. We then

applied a major factor method to obtain factor loading and performed an orthogonal rotation by the varimax method for easier interpretation of individual factors. Table 2 shows the results.

Table 2: Results of factor analysis

	Factor 1	Factor 2	Factor 3	Communality
Agile – Dull	-0.9	-0.07	0.16	0.834
Active – Inactive	-0.87	-0.04	0.2	0.808
Fast – Slow	-0.87	-0.09	0.19	0.803
Light – Heavy	-0.82	0.14	0.24	0.755
Strong – Weak	-0.73	-0.16	0.23	0.626
Comfortable – Uncomfortable	-0.68	0.29	0.36	0.693
Beautiful – Ugly	-0.62	0.35	0.38	0.671
Pleasant – Unpleasant	-0.56	0.35	0.45	0.646
Agreeable – Disagreeable	-0.5	0.37	0.47	0.626
Soft – Hard	0.12	0.77	-0.04	0.618
Nice – Dreadful	0.13	0.76	0.04	0.605
Calm – Restless	-0.06	0.71	0.14	0.531
Reassuring – Surprising	-0.03	0.63	0.11	0.413
Delicate – Rough	-0.26	0.61	0.23	0.502
Elegant – Coarse	-0.33	0.58	0.26	0.518
Smooth – Awkward	-0.35	0.55	0.22	0.482
Human-like – Mechanical	0.04	0.51	0.18	0.301
Exciting – Unexciting	-0.38	0.16	0.77	0.783
Favorite – Disgusting	-0.35	0.29	0.74	0.76
Interesting – Boring	-0.38	0.18	0.65	0.611
Animal – Vegetable	-0.46	0.1	0.19	0.261
Fresh – Old	-0.41	0.35	0.43	0.483
Percent of communality (%)	27.89	47.014	60.64	

Judging from the adjective pairs of the first factor in Table 2, it is assumed these motions are cheerful, energetic and strong yet neat and rhythmical. Thus, we can regard the first factor as the “lively” factor.

From the adjective pairs of the second factor, it is assumed these motions are mild, carefree warm and soothing to the heart. Thus, we can regard the second factor as the “mild” factor.

From the adjective pairs of the third factor, it is assumed these motions are related to “interest.” This is also a proof that the commander is observing with some interest the intelligent machine he or she is moving.

To generate motion characteristics in line with the goal of this research, it is of primary importance that the intelligent machine motions give a “mild” impression to the commander. With that in mind, it is also necessary to have motions that generate “lively” feelings.

The factor score distribution of individual factors was investigated based on the factor analysis findings in order to determine the parameters for a desirable transfer function. Figure 4 shows the factor score distribution of the first and second factors. It shows factor scores of the subjects plotted with the first (“lively”) factor on the x-axis and the second (“mild”) factor on the y-axis. The

Figure 4: Score plots on the first and second factor plane

broken line denotes the confidence ellipse where 80% of measured values lie. On the y-axis of the most important factor, the degree of “mildness,” the more factor points which are positive, the better. For this reason, to generate “mild” and “lively” motions, it is also desirable that factor points be distributed in the second quadrant. Observing Fig. 4 from this perspective, more factor points of G32 and G51 are distributed in the second quadrant than those of other transfer functions. Thus, by waveform shaping of human command motions through those transfer functions, the target motion characteristics can be obtained. The transfer function G32 is the first-order delay element with a time constant of 0.4 sec., a transfer function of G51, a second-order delay element with a damping ratio of 1 and an undamped natural frequency of 5rad/sec. Despite the difference in the two transfer functions, both generate motions acceptable to human state of mind. That is why it is necessary to clarify its cause.

4.2. Study by motion characteristics

As mentioned previously, as a pilot test, the command motions of the subjects were measured to analyze why two transfer functions of different shapes both generate

motions acceptable to humans. As a result, the motions could be expressed with the minimum-jerk model[11], in which the peak position of the velocity profile was nearly at the center of the movement time. The minimum jerk model can reproduce the motion trajectory when the human simply moved his hand between two points. The mean of the correlation coefficient between the measured command motion and the minimum-jerk model was 0.926. Ogawa et al.[12] concluded from linear motions of the upper limb holding an object that the velocity peak is located in the first half of the movement time and the velocity profile would decrease gently in the second half. The clarification of this difference will also be a future task. Figure 5 shows the velocity profile of typical command motions by the subjects and the model (solid line: observed value; broken line: the minimum jerk model). We will continue to study this model.

Figure 5: Velocity patterns of measured value and minimum jerk model

We next gave the position data from this model as simulated input to the intelligent machine and obtained the time response and the response speed of each transfer function. Figure 6 shows the results. Time, position and velocity were normalized by the movement time, the maximum position and the maximum velocity of the simulated input, respectively.

Figure 6 (a) shows there was no significant difference (significance level 5% in the t test of the mean) in time response between transfer functions G32 and G51. There was a significant difference between those two transfer functions and other transfer functions. While referring to Fig. 6, let us examine the characteristics of each transfer function.

Figure 6: Response of minimum jerk model

As shown in Fig. 6 (b), the maximum velocity of G32 and G51 was approximately 71% and 77% respectively, when that of command motion was deemed to be 100%. When the maximum velocity percentage was greater than this range (G1, G2 and G31), the “lively” factor was strongly expressed while the “mild” factor was weakened. In the case of G42, which is the same as G32 in terms of the maximum velocity percentage, the “lively” factor was extremely weak while there was no difference in the “mild” factor.

As for the location of velocity peak, assuming the movement time of the input waveform was 100%, G32 and G51 were in a range of approximately 71-76% of movement time.

From the above findings, the important factors for generating motion characteristics to achieve the objective of this research are considered to be the maximum velocity rate and the location of the velocity peak. However, in the case of the first-order delay element, the maximum velocity is determined by the time constant, and in the case of the second-order delay element, it is uniquely determined by the undamped natural frequency

or damping ratio. Yet, the location of the velocity peak is variable depending on dead time. Therefore, the main factor which generates motion characteristics to achieve the objective of this research is the rate of maximum velocity. Thus, the objective can be realized by selecting the parameters of the transfer function in the 71%-77% range to the maximum velocity of command motions. Conversely, by adopting the transfer function of the first-order or second-order delay element in the 71%-77% range of the maximum velocity of command motions and by adjusting the velocity peak location to 71%-76% of the movement time of input waveform, the intelligent machine can generate motion characteristics which give a "mild" impression to the humans as well as "lively" motions.

5. CONCLUSION

When developing human-friendly and human supportive intelligent machines, which coordinate with human hand commands, it is necessary to generate intelligent machine motion characteristics acceptable to human state of mind and without intelligent machine's clumsiness. In this research, we proposed several transfer functions to generate these characteristics and investigated the psychological impact of the difference of transfer functions on humans. We also examined the guide to determine the parameter values to match the objectives of this study.

First, as evaluation subjects, we selected proportional elements, human transfer functions, a first-order delay element with three kinds of time constants, a second-order delay element with three kinds of undamped natural frequencies and a damping ratio of 1, and the above transfer functions to which a human dead time was adopted. Second, the relationship of human state of mind and those transfer functions was analyzed using the SD method. As a result, we learned of the form of transfer functions and parameter values that are acceptable to human state of mind. We also learned that the findings of the subjective evaluation were good regarding the adjective pairs and the adopted transfer functions were effective. For the form of the transfer function, the first-order or second-order delay element was favorable. The guidelines for the parameter selection were to have the maximum velocity of tracking motions stay within the 71%-77% range of the maximum velocity of command motions and to adjust the velocity peak

location to 71%-76% of the input waveform movement time.

Furthermore, the results of the factor analysis clarified that "lively," "mild" and "interesting" factors represent human state of mind toward intelligent machine motions that follow command motions. The results also showed that intelligent machine-generated motion characteristics have a "mild" impression on humans and that "lively" motions could be realized by transfer functions, which we had adopted in this research.

In this study, we focused on the movement of objects between two arbitrary points and did not restrict the stop location. However, since the stop location is sometimes required in actual life, we would like to study the case where positioning accuracy is required in the future. In addition, we would like to study two- and three-dimensional motions. Furthermore, we would also like to examine the tasks that intelligent machines perform with objects before and after human commands as well as their relationships.

Considering the application of this research to a robot arm, if the dynamic characteristic of the robot arm is not negligible, it will affect human state of mind. Therefore, the type of transfer function between the movement of the finger and the movement of the end effector of the robot arm, and their parameters should be determined in consideration of the dynamic characteristic of the robot arm. We would like to examine this in the future work.

Moreover, if we try to apply the interface discussed in this research to complicated tasks or multiple degree-of-freedom robots, it is important to analyze several factors which will affect human state of mind in addition to the movement of the end effector (that is, transfer function). We would like to examine these factors respectively and integrate them in the future.

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