Character Design Generation System Using Multiple Users’ Gaze Information

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SUMMARY  We investigate an interactive evolutionary computation (IEC) using multiple users’ gaze information when users partially participate in each design evaluation. Many previous IEC systems have a problem that user evaluation loads are too large. Hence, we proposed to employ user gaze information for evaluating designs generated by IEC systems in order to solve this problem. In this proposed system, users just view the presented designs, not assess, then the system automatically creates users’ favorite designs. With the user’s gaze information, the proposed system generates coordination that can satisfy many users. In our previous study, we verified the effectiveness of the proposed system from a real system operation viewpoint. However, we did not consider the fluctuation of the users during a solution candidate evaluation. In the actual operation of the proposed system, users may change during the process due to the user interchange. Therefore, in this study, we verify the effectiveness of the proposed system when varying the users participating in each evaluation for each generation. In the experiment, we employ two types of situations as assumed in real environments. The first situation changes the number of users evaluating the designs for each generation. The second situation employs various users from the predefined population to evaluate the designs for each generation. From the experimental results in the first situation, we confirm that, despite the change in the number of users during the candidate solution evaluation, the proposed system can generate coordination to satisfy many users. Also, from the results in the second situation, we verify that the proposed system can also generate coordination which both users who participate in the coordination evaluation can more satisfy.

key words: interactive evolutionary computation, gaze information, multiple users, partial evaluation, character model

1. Introduction

The interactive evolutionary computation (IEC) method allows the creation of improved objects using human sensitivity [1]. In IEC, the user inputs the evaluation values to assess the candidate solutions of the evolutionary computation (EC), which is an algorithm of the evolution of living things. Using evaluation values from humans is effective for solving problems that emphasize human sensitivity. The systems using IEC method include color scheme search system [2], music recommendation system [3], big data searching support system [4], and so on.

However, there are large evaluation loads on the users providing the evaluation values in IEC. Because the previous IEC systems employ a 5 or 10-stage evaluation method, in which a user manually inputs evaluation values of each candidate solution from 1 to 5 or 10 points. Thus, studies have been conducted to reduce the loads [1]. Some researchers have investigated employing user biological information such as heart rate, electroencephalogram (EEG) signal, and gaze information [5]–[10]. However, in order to acquire heart rate information and EEG signal, the users must wear the measuring device, i.e., the user loads. Besides, we have proposed an IEC system with users’ gaze information for reducing users evaluation loads [10]. User gaze information consists of the potential preferences of users. Therefore, our IEC system can generate objects that can satisfy a user.

Also, we have proposed an IEC system with multiple users’ sensitivity information as a vote [11], [12]. This system can create objects that users feel are good. However, the system found it hard to collect many users votes because users felt bothered for each voting.

To solve this problem, we proposed an IEC system with many users’ gaze information for creating objects that can satisfy users [13], [14]. If an IEC system uses many users’ gaze information, the system can create an IEC system applied to the marketing area for obtaining multiple users’ potential preferences and consensus-building.

In this study, we assume that some users assess candidate solutions partially in the progress of the IEC and we experimented by assuming the number of users participating in the evaluation changed. We also verified the effectiveness of the proposed system from the viewpoint of whether the system creates candidate solutions that satisfy multiple users in the IEC process. The previous study did not assume the change in the number of users participating in the candidate solution evaluation. In real situations, the same users are unlikely to participate in evaluations from the start to the end of the system; during system processing, some users may leave or enter the evaluations.

Hence, in this study, we demonstrate an experiment under the two situations—where users participating in the evaluation are either limited or not. The first situation employs groups of several users, where some users evaluate candidate solutions in every generation. The second situation uses a population of tens of users, where some users evaluate the candidate solutions in every generation. In the first situation, all users in each group participate in the evaluation at least once, while in the second situation, all users may not participate in the evaluation. In both situations, we examined the satisfaction level of user groups of multiple users, and interviewed the subjects to evaluate the system.
2. Related Works

Gaze information can be measured with a non-contact type measuring device, and does not impose the user loads. Some researchers have proposed an IEC system with users’ gaze information, and verified the effectiveness of their methods [7]–[9]. Also, we have proposed an IEC system with users’ gaze information and verified the effectiveness of the system in terms of reducing users evaluation loads [10]. Our previous method was more effective than an IEC system with a manual evaluation method that a user inputs evaluation value for each design. However, these systems used gaze information of only a single person and could not create objects that satisfy many users.

To create objects that satisfy many users, we proposed IEC systems with many users votes which obtained digital signage advertisements in the city and website [11], [12]. These systems could create candidate solutions using user evaluations that satisfied many users. However, it is difficult for many users to participate in candidate evaluations at the same time and location. This system found it hard to gather users votes because the vote operations in the city or website were troublesome for users.

Thus, we built a system with the users’ gaze information to assess candidate solutions with many users for reducing users troublesome and evaluation loads [13], [14]. We demonstrated the effectiveness of the IEC system with many users’ gaze information in terms of reducing the evaluation load. As a result, the proposed system could create candidate solutions that satisfied many participating users despite their large numbers. However, we only experimented with subjects who evaluated all candidate solutions. In real situations, all users may not participate in evaluating the candidate solutions. Thus, we assumed that some users evaluate candidate solutions partially in the progress of the IEC.

3. Proposed System

3.1 Schematic of the Proposed System

Figure 1 depicts the outline of the proposed system. Firstly, the system randomly creates initial candidate solutions. Then, several users stand in front of digital signage freely. The system presents two kinds of 3D character coordination animation, which the user freely compares to the digital signage by only viewing. Next, the system calculates the evaluation value for each character coordination from the users’ gaze information. If the evaluation values are given for all character coordination generated in the same generation, the system performs EC and creates the character coordination of the next generation. The system repeats these operations for a specified number of repetitions.

In this study, we employed the winner-based paired comparison method (WPC) to assess each candidate solution, similar to our previous study [14]. Moreover, we used Human Vision Component B5T-007001 (OMRON, Japan) to acquire the gaze information. The measuring instrument acquires the position of the user’s face, the angle of the face, and the angle of gaze, then uses them to determine where the user is looking at. The system judges user preference using the position of the gaze and the number of views as the gaze information.

The proposed system decides a winner candidate solution based on the number of gaze samplings. However, users may view the design only because of their interests. Then, a design that has more gaze samplings may not be considered as user preference. In this case, the proposed system may obtain inaccurate evaluation information (noise) on user preferences and generate designs that do not satisfy users. However, our previous study has demonstrated that the IEC system with gaze information can generate designs based on user preferences, even if the user evaluations include inaccurate information from prior experiments [10]. Therefore, in this study, we verify whether the proposed system can generate objects that can satisfy users when using multiple user’s gaze information for evaluating candidate solutions.

3.2 Character Coordination

Figure 2 shows a 3D character coordination model. The 3D model has four parts: hair color, eye color, clothing color and texture, and shoe color. The hair and clothing colors have sixteen parts and 4 bits of gene length. Furthermore, the eye and shoe color has eight parts and 3 bits of gene...
length. The coordination consists of 18 bits and can create 262,144 coordination patterns. Figure 3 shows design parts of character coordination. We coded each part considering the distance of bit strings and part appearance similarity. Moreover, the coordination employs a 3D animation model and can move based on the order of beg, turn, and wave.

3.3 Candidate Evaluation

The system calculates the evaluation values of each candidate for EC operation using the WPC method based on the users’ gaze information. The system determines the winner of the two candidates presented using the number of user views.

Figure 4 shows the candidate evaluation of the proposed system. The black and white circles indicate the users’ gaze positions. The proposed system uses total gaze counts of all users who participated in the evaluation to decide the winner coordination. Moreover, the gaze counts indicate the number of measured gaze samplings by the device. In each round, the system divides the interface into two: left and right sides. Firstly, the system measures all users’ gaze information who stand in front of the designs while viewing the presented designs. Then, the system calculates the users viewing position from the user’s gaze information and determines the individual viewing from each position. Finally, the system chooses the most viewed coordination for about 11 [sec] (play time of the animation).

Also, Fig. 4 shows that the system records six views on the right side and eight views on the left side. In this case, the system judges that the users prefer the left character coordination given that it is more often seen. Then, the system leaves the left character coordination and changes the right character coordination for the next comparison.

After viewing the designs for the same generation, the system assigns evaluation values to each design using the WPC method. Figure 5 shows the WPC method’s design evaluation process. In advance, the system allocates one point to all designs created for the same generation. The system determines the outcome of a round based on the users’ gaze information and adds the losers’ evaluation value to that of the winners’.

In Fig. 5, firstly, the system allocates one point for each created design. Here, Coordination A beats Coordination B in the first round. Hence, the system adds the evaluation value of Coordination B to that of Coordination A. The evaluation value of Coordination A will now become 2 points. If Coordination A beats Coordination C in the second round, the system adds the evaluation value of Coordination C to that of Coordination A, which makes it 3 points. Assuming Coordination D beats Coordination A in the third round, the system then adds the evaluation value of Coordination A to that of Coordination D. Hence, the evaluation value score of Coordination D is 4 points. With these, the final evaluation values of Coordinates A, B, C, and D are 3, 1, 1, and 4 points, respectively. Then, the system uses these evaluation values for EC operations.
4. Evaluation Experiments

4.1 Assumed Real Situation

In real situations using the proposed system, we assume that users who participate in the evaluation of designs may vary from the starting to ending. In this study, we assumed two real situations as follows and verify the effectiveness of the proposed system.

**Situation A.** Some users who are randomly selected from a group participate in evaluating the designs for every generation.

**Situation B.** Some users who are randomly selected from a large group participate in evaluating the designs for every generation.

In Situation A, users who participate in coordination evaluation are limited, and no user participates in the evaluation from the outside. However, there are various users who participate in the evaluation from the beginning to the end, or halfway, and from halfway to end.

In Situation B, users who participate in coordination evaluation are not limited, and some users may participate in the evaluation from the outside, but in the subjects population. There are users who participate in the evaluation multiple times, just once, as well as the ones who do not participate.

We investigate the effectiveness of the proposed system in the situations while varying users who participate in the evaluation.

4.2 Outline of the Experiments

We performed the experiments to investigate the effectiveness of the system while varying the number of users participating in the design evaluations and processing the IEC operations. We assume two environments of the proposed system described in Sect. 4.1. The first environment is to limit the users who can participate in the design evaluations for every generation, and 15 generations, respectively. Exp. A performs EC operations using evaluations of a limited number of subjects (each group). Therefore, Exp. A reflects subjects’ evaluations for generating candidate solutions even if the number of generations is small. Then, we set five generations at Exp. A. Moreover, more numbers of all subjects should participate in the evaluations of candidate solutions. Since the number of subjects of Exp. B is more than that of Exp. A, we set 15 generations at Exp. B. Furthermore, we used the evaluations of each generation and only three users in each group participating in evaluations of each generation. We set the order of the two patterns randomly in each group. We compare the satisfaction levels of the subjects for the created designs between all subjects in a group and three different subjects in a group participating in the design evaluations for each generation. Table 1 shows the pattern of participating users when the three different subjects in a group participate in the design evaluation. For the first generation, Subjects A, B, and C participated in the design evaluation. Upon completing the first generation, all subjects in a group evaluated the design that had the highest evaluation value. Then, in the second generation, Subjects B, C, and D participated in the design evaluation. When all the subjects in a group participated in the design evaluations for every generation, we conduct the experiment with similar conditions.

In Exp. B, we assume the second environment. The subjects in the Exp. B comprise 83 students who belong to the department of system management at Fukuoka Institute of Technology. Exp. B uses randomly selected five subjects from all subjects to assess the designs for each generation. Some subjects participated in multiple evaluations or never participate in any evaluations. After completing Exp. B, all subjects evaluated the satisfaction levels of the designs that had the highest evaluation value in the first, fifth, tenth, and fifteenth generation, by 5-stage evaluation.

Table 2 shows the genetic algorithm (GA) parameters of the proposed system. We used the GA method as an EC technique of the proposed system. We used 10 candidate solutions in both Exps. A and B. Exps. A and B operated 5 and 15 generations, respectively. Exp. A performs EC operations using evaluations of a limited number of subjects (each group). Therefore, Exp. A reflects subjects’ evaluations for generating candidate solutions even if the number of generations is small. Then, we set five generations at Exp. A. Moreover, more numbers of all subjects should participate in the evaluations of candidate solutions. Since the number of subjects of Exp. B is more than that of Exp. A, we set 15 generations at Exp. B. Furthermore, we used the

| Subjects | A | B | C | D | E |
|----------|---|---|---|---|---|
| 1st generation | * | * | * | | |
| 2nd generation | * | * | * | | |
| 3rd generation | * | * | * | | |
| 4th generation | * | * | * | | |
| 5th generation | * | * | * | | |

| Candidate solutions | 10 |
|---------------------|----|
| Gene length | 18 bits |
| Generation | Exp. A: 5, Exp. B: 15 |
| Selection | Roulette selection |
| Elite preservation | Available |
| Crossover | Uniform crossover |
| Mutation rate | 20% |
| Present time | 11[sec] |
higher mutation rate than the normal EC methods (usually used less than 5%) to create various designs with random effects of mutation operation and prevent the loss of user’s interest in the design evaluation. Moreover, Exp. A randomly creates the initial designs. Exp. B uses optimized designs by each group in Exp. A as initial designs. Subjects of Exp. B are as old as those of Exp. A. Therefore, in Exp. B, the proposed system will generate coordination that satisfies subjects’ preferences using coordinates optimized by each group of the same age in Exp. A rather than coordination generated randomly.

5. Experimental Results

5.1 Results of Exp. A

Figure 6 shows the average satisfaction levels of each group of coordination for each generation. When three subjects evaluated the designs for each generation, the average satisfaction level of the final generation is 3.68. Similarly, when all subjects evaluated the designs for each generation, the average satisfaction level of the final generation is 3.88. From this result, we confirmed that the satisfaction level when all subjects participated was higher than the satisfaction level when three subjects participated. Therefore, if the number of subjects participating in the evaluation increases, the proposed system can generate designs that satisfy the users.

Next, we discuss the satisfaction levels of the generated coordination for each group. In Fig. 6, the satisfaction levels of all groups, except Groups 4 and 10, are more than 3. Then, in this case, the proposed system can generate designs preferred by the users. However, the satisfaction level of Group 4 at the final generation is less than 3 when there are three participating subjects. Moreover, in Group 10, the satisfaction levels at the final generations are less than 3 in both cases (three and all). When all subjects participate in the evaluations, the satisfaction level for the final generation, except Group 10, is also more than 3 because of the differences in the subject’s preferences in each group. Therefore, we describe the decreasing satisfaction level of Groups 4 and 10 for the final generation.

Table 3 shows the satisfaction levels of the three and all participating subjects in Groups 4 and 10. The underlined numbers in Table 3 show subjects that participated in the design evaluations for the generation.

Table 3 Results of satisfaction levels for each subject (Exp. A)

| (a) Group 4 (three subjects) | 1st | 2nd | 3rd | 4th | 5th |
|-----------------------------|-----|-----|-----|-----|-----|
| Subject A                   | 4   | 2   | 4   | 4   | 4   |
| B                           | 4   | 4   | 4   | 4   | 4   |
| C                           | 4   | 4   | 4   | 1   | 1   |
| D                           | 5   | 4   | 3   | 3   | 2   |
| E                           | 5   | 3   | 3   | 5   | 2   |
| Average                     | 4.2 | 3.2 | 3.4 | 3.8 | 2.6 |
| Variance                    | 0.56| 0.56| 0.24| 0.56| 0.64|

| (b) Group 10 (three subjects) | 1st | 2nd | 3rd | 4th | 5th |
|-------------------------------|-----|-----|-----|-----|-----|
| Subject A                    | 3   | 4   | 4   | 5   | 2   |
| B                             | 4   | 3   | 4   | 4   | 4   |
| C                             | 4   | 4   | 4   | 4   | 3   |
| D                             | 4   | 4   | 3   | 3   | 2   |
| E                             | 4   | 4   | 4   | 4   | 3   |
| Average                      | 3.8 | 3.8 | 3.8 | 4.0 | 2.6 |
| Variance                     | 0.16| 0.16| 0.16| 0.40| 0.56|

| (c) Group 10 (all subjects) | 1st | 2nd | 3rd | 4th | 5th |
|-----------------------------|-----|-----|-----|-----|-----|
| Subject A                   | 4   | 2   | 2   | 3   | 2   |
| B                            | 4   | 2   | 4   | 3   | 3   |
| C                            | 5   | 5   | 3   | 4   | 3   |
| D                            | 2   | 2   | 4   | 4   | 3   |
| E                            | 4   | 2   | 3   | 3   | 3   |
| Average                     | 3.8 | 2.6 | 3.2 | 3.4 | 2.8 |
| Variance                    | 0.96| 1.44| 0.56| 0.24| 0.16|

Fig. 6 Results of the average satisfaction levels
generations increased. Furthermore, we confirmed that the satisfaction levels of the four subjects, except for Subject A, decreased from the fourth to the final generations. Subjects A and E participated in the design evaluations for the fourth and final generations. Therefore, for the fourth and final generations, the preferences of Subjects A and E were reflected in creating the designs.

Moreover, Fig. 7 illustrates the created coordination in Group 4 (three subjects). In Fig. 7, the coordination trend for all generations that reflected the preference of Subject A is different from the coordination until the third generation. Therefore, there are differences in subjects’ preferences in Group 4, and the preference of a specific subject directly reflects the design creation of the proposed system. Finally, the satisfaction level for the final generation decreased.

In Table 3(b), only the satisfaction level of Subject B was higher than those of other subjects for the final generation, but other subjects, except Subject B, assigned low satisfaction levels. Moreover, Subject B participated in design evaluation for the final generation. Hence, the preference of Subject B was strongly reflected in the design creation of the proposed system.

Figure 8 shows that the coordination trend for all generations in Group 10 (three subjects). In Fig. 8, the coordination trend at the final generation that is reflected in the preference of Subject B was different from coordination trends until the fourth generation. Therefore, in Group 10, the satisfaction level at the final generation decreases because there is a difference in preference trends among subjects, and the preference of the specific subject was strongly reflected in design evaluations.

In Table 3(c), only the satisfaction level of Subject C was higher than those of other subjects for the second generation, but four subjects assigned neutral satisfaction levels for the final generation. The satisfaction level of Subject C decreases when passing the generations. Also, satisfaction levels of all subjects, except Subject C, were higher after passing the generations. Then, we confirmed that the preference of Subject C was strongly reflected in the created coordination for the second generation, but after the second generation, preferences of all the subjects were reflected in the created coordination.

Figure 9 shows the coordination trend for all generations, in Group 10 (all subjects). In Fig. 9, the coordination trend after the second generation was similar; however, hair, eye, and shoe colors were different. Therefore, in Group 10 that has difference of preferences among subjects, since the proposed system employs preferences of all the subjects, and then hard to generate coordination that has the highest satisfaction level. Therefore, the satisfaction level at the final generation was low.

5.2 Results of Exp. B

In Exp. B, we used the selected five participating subjects of each generation from all subjects, at random. Table 4 shows the participating subjects in the evaluations. The underline in Table 4 shows subjects who participated in the evaluations for multiple generations. Also, the bold character in Table 4 illustrates subjects who skipped for some generations. The number of subjects who participated in the design evaluations for multiple generations is 24 (underlined subjects in Table 4). Then, a total of 29% of all the subjects participated at most five times in the design evaluations for multiple gen-

Fig. 7 Coordination results of Group 4 (Participating: three subjects)

Fig. 8 Coordination results of Group 10 (Participating: three subjects)

Table 4 Participating subjects for design evaluation (Exp. B)

| Generation | Participating subjects |
|------------|-----------------------|
| 1          | a b c d e             |
| 2          | f g h i j             |
| 3          | f g h i j             |
| 4          | a k l m n             |
| 5          | a k l m n             |
| 6          | o p q r s             |
| 7          | o p q r s             |
| 8          | o p q r s             |
| 9          | f t u v w             |
| 10         | f t u v w             |
| 11         | f t u v w             |
| 12         | x y z A B             |
| 13         | b C D E F             |
| 14         | b C D E F             |
| 15         | b C D E F             |
Figure 10 shows the satisfaction levels of the created coordination in the first, fifth, tenth, and fifteenth generations. We collected 49 answers of satisfaction levels for the created coordination. Notably, 49 answers show the number of subjects who answered the satisfaction level questionnaire regardless of if they participated in the design evaluations or not. A total of 67% of all answers came from subjects who participated in the design evaluations, and the remaining 33% came from subjects who did not. The “All” label in Fig. 10 shows the average satisfaction level of all answers. The “Participating” label in Fig. 10 shows the average satisfaction level of the 67% of all the answers. The “Not participating” label shows the average satisfaction level of the 33% of all answers.

The satisfaction levels of all answers for the fifteenth generation of “All,” “Participating,” and “Not participating,” were 3.51, 3.56, and 3.36, respectively. From this result, we confirmed that the satisfaction level of “Participating” was higher than that of “Not participating.” Moreover, in Exp. B, because using the best coordination of each group in Exp. A as initial designs, when passing the generations, we confirmed that the satisfaction levels did not become smaller. Since subjects of the same participate in Exp. A and B, the final coordinations of Exp.s A and B were not different. Figure 11 shows the coordination trend in Exp. B. The best coordination of each generation were similar. Then, the system created a coordination preferred by the “Participating” subjects.

Figure 12 shows the distribution of satisfaction levels for the created coordination for the first, fifth, tenth, and fifteenth generations. For the fifteenth generation, more than 50% of the “Participating” and “Not participating” subjects assigned a value 4 to the created coordination. Moreover, in all generations, the higher evaluation values of participated users were higher than those of users who did not participate. In other generations, the number of higher evaluations was larger than the number of lower evaluations, except for the “Not participating” subjects for the fifth generation.

6. Discussion

From the results of the Exp. A, in Group 4 and 10, the proposed system cannot generate coordination that has higher satisfaction levels because of the discordance of preferences in groups. Therefore, each member evaluation of each group were not reflected in creating better coordination. However, in the other eight groups, the proposed system can generate coordination that can satisfy subjects, when only three subjects in each group participated in the evaluations. We confirmed that in the proposed system, 80% of all groups can create coordination that can satisfy users of each group, even if subjects who participate in evaluations were varying. The proposed system is effective for creating coordination if 60% of all users participate in each evaluation.

Whereas, from the results of the Exp. B, approximately 40% of all subjects participated in the evaluations, for at least one generation. Even if all users did not participate in each evaluation in this situation, the proposed system can create coordination that can satisfy many users. However, the initial coordination of the Exp. B were objects created in each group of the Exp. A. The satisfaction levels were high from the first generation and did not increase after the generations.

Moreover, the satisfaction levels of users who participated in the evaluations were higher than those of users who did not participate in the evaluations. Also, the rate for higher evaluation values of participated users was higher.
than that of users who did not participate when passing generations. Therefore, the gaze information of participated subjects in the evaluations reflected more for generating candidate solutions.

From all the results, the proposed system can create coordination that can satisfy users, even if all users (five members) of small groups did not participate in each of the evaluations. In addition, the proposed system can create coordination that can satisfy more users who participated in evaluations when targeting tens of user evaluations.

7. Conclusion

In this work, we investigated the effectiveness of the IEC system with multiple users’ gaze information while varying the number of users participating in the evaluations. Experiment results show that the proposed system can create coordination that satisfy many users, even if all users do not participate in every evaluation. In future work, we will analyze user’s gaze information and investigate the relations between the user’s gaze information and their preferences.

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