Introduction of soft computing techniques to welfare devices

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Introduction of Soft Computing Techniques to Welfare Devices

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***Abstract*— This paper introduces our research on the use of soft computing techniques for hearing impairment compensation and physical rehabilitation. Evolutionary computation (EC) is used for fitting hearing aids based on an interactive EC and the user's preferences for sound. This technology allows hearing aid users to optimize their hearing aids in any acoustic environment with out professional assistance. The virtual reality (VR) system for physical rehabilitation allows patients to train their muscles and reflexes according to the level of their physical conditioning. Finally, we discuss our approach to obtain new scientific through analyzing obtained hearing and VR characteristics by these two systems.**

1 Introduction

Welfare devices, such as hearing aids and rehabilitative equipment, have been mainly developed by medical engineers. Since the size of the commercial market is much smaller than that of the consumer electronics market, lower R&D costs have lead to an insufficient introduction of computer science techniques into the welfare industry. For example, the number of hearing aids sold in Japan is approximately 400,000 or 410,000 per year.

Some countries are becoming concerned about their aging population. For example, in Japan, it is predicted that the population of over 65 years old occupies 17% and 25% of all population in 2,000 and 2,015, respectively, and the 20-year-old-and-younger segment decreases yearly [3]. This situation has an impact on social security issues such as medical insurance and pension systems. One effective solution is to increase the number of healthy people who support society by supporting social activity.

Technology for this purpose is now desirable. Companies have come to pay attention to the growing market of an aging society, targeting welfare devices not only for people who are hearing-impaired at birth or who lost their hearing due to illness or accident, but also for those who are hearing-impaired due to aging. This change in market recognition has motivated the welfare industry to develop and apply recent technologies to welfare devices.

In this paper, we introduce two of our on-going areas of research; one is the fitting of hearing aids using an interactive EC (IEC) and the other is the use of physical rehabilitation equipment developed using VR.

The interactive EC is a technology which optimizes systems based on human evaluation. Simply stated, it is an EC whose fitness function is replaced by a human. It has been applied to several fields in the 1990's, including CG graphics, industrial design, music creation, speech processing, hearing aids, VR, data-mining, database retrieval, education, and games [7].

Since the optimization searching surfaces of these tasks exist in the human mind, it is impossible to calculate the gradient information of psychological space and apply gradient methods to them. Generally, optimization methods which require a numerical goal cannot be applied to these kinds of tasks. As the EC is a fitness-based search, it is applicable to a search of psychological space such as preference space when subjective evaluation is given as the fitness values.

VR is a technology that artificially stimulates at least one of five human senses. VR research is primarily visual and secondarily auditory. The amount of VR research on the sense of touch or force is small, and VR research on the senses of smell or taste is very rare.

VR sense of force, however, is the main research theme for physical rehabilitation. In the VR audio & visual environment, a person is only *given* VR vision and sound and does not communicate in this manner. Unlike the VR audio & visual environment, VR sense of force allows us to communicate with an agent or robot in a virtual environment using force; we can change the force according to the force from the VR environment and vice versa. This is one of the indispensable functions for physical rehabilitation.

[0]Hideyuki Takagi, Shin'ichi Kamohara, and Takashi Takeda, "Introduction of Soft Computing Techniques to Welfare Equipment," 1999 IEEE Midnight-Sun Workshop on Soft Computing Methods in Industrial Applications (SMCia'99), Kuusamo, Finland, pp.116–121 (June 16-18, 1999)

2 IEC-based Hearing Aids Fitting

2.1 Conventional approach

Conventional approaches to compensation for hearing impairment require previous measurement of the auditory characteristics of hearing aid users using pure tones or band noise and try to adjust the differences between the hearing-impaired and persons of normal hearing.

However, these approaches have several problems: (1) it is fundamentally impossible to compensate for hearing based on preference using the characteristics of auditory sense and perception measured by sound in non-daily life such as pure tones or band noise, (2) it is difficult to fit a hearing aid with mutual effects among auditory characteristics measured independently, and (3) it is doubtful that adjusting to bring the characteristics of a hearing-impaired person close to those of a person with normal hearing will result in the best quality of compensated sounds.

Essentially, nobody can know how other people hear, and conventional approaches limit our ability to fit hearing aids for others (see Figure 1 left.)

2.2 Proposed approach: IEC fitting

We propose an IEC fitting method that is unlike conventional fitting approaches [4, 8]. The proposed method optimizes the fitting parameters of a hearing aid based on the end user's evaluation of heard sound (see Figure 1 right.) This approach can solve several difficulties contained in the conventional approaches mentioned above.

The key technology of the proposed method is an interactive EC. The IEC fitting method does not require medical doctors or hearing aid engineers to take preliminary measurements of the auditory characteristics of users and allows the users to fit their hearing aids wherever and whenever they like using any sound source. Another advantage is that it does not depend on signal processing used in hearing aids. This allows several makers to adopt the method without significant changes in their hearing aid systems.

2.3 Experimental system

2.3.1 Construction of a 3-D loudness space

The proposed IEC fitting is not a compensation method of hearing impairment but an optimizing method for the compensation method. This allows it to be applied to any hearing aid by any maker. We propose construction of a 3-D loudness space whose axes consist of input SPL (sound pressure level), frequency, and amplification level to compensate for hearing impairment [4, 5]. Our experimental hearing aid adopts this method.

Since the dynamic range of hearing in hearing-impaired people is narrower than that of people with normal hearing, low SPL sound should be amplified,

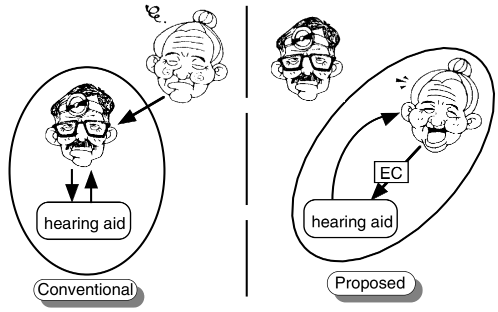

Figure 1: Conventional (left) and proposed (right) approaches for fitting hearing aids.

and high SPL sound should be attenuated. Furthermore, this compression characteristic depends on both frequency and the person. Conventional approaches require previous measurement of the characteristics of every octave band and fits the characteristics of a hearing aid to each person. Our proposed 3-D loudness space is directly constructed by combining multiple 3-D Gaussian distribution functions without previous measurement (see Figure 2.)

The interactive EC forms the best 3-D loudness space (which means the best compensation for hearing impairment) by finding the combination of the best parameters of Gaussian shapes.

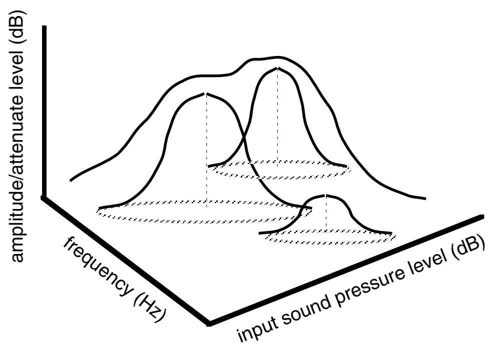

Figure 2: Loudness space obtained by combining 3-D Gaussian functions. The interactive EC changes the parameters of the functions based on hearing preferences. The shape of the loudness space is used as the characteristics of a fitted hearing aid.

2.3.2 GA conditions

In our experiment, a 3-D loudness space is formed by five 3-D Gaussian functions that have seven parameters such as mean coordinate, variances, height, etc. The seven parameters are 1 to 5 bits long, and the total parameter length of a Gaussian function is

36 bits [the length of a chromosome is 180 bits (= 36 bits $\times$ 5)].

We adopt genetic algorithms (GA) for the interactive EC. Our GA conditions include the binary GA coding and the GA operations of roulette wheel selection, one-point crossover, elitist strategy, 80% crossover rate, and 2% mutation rate.

2.4 Evaluation with speech

2.4.1 Subjects

Subjects consist of eight people with normal hearing with six kinds of simulated hearing-impaired characteristic filters [1] and three auditory nerve-impaired subjects—two with mild nerve impairment and one of moderate impairment.

The speech source for the experimental evaluation consists of a male and female voice for all subjects and a male and female voice with noise from multiple speakers for hearing-impaired subjects and a total of four kinds of speech.

2.4.2 Evaluation with the index of ease of hearing

Subjects compare the pair of speakers using: (1) loudness compensation based on proposed IEC fitting and 3-D loudness space, (2) conventional loudness compensation based on previously measured loudness characteristics, and (3) no compensation. The comparison results are statistically tested by the sign test and are shown in Table 1.

Table 1 clearly shows the superiority of the IEC fitting method.

Table 1: Subjective test results. Speech quality is compared using (1) the proposed IEC fitting method, (2) conventional fitting method, and (3) no compensation for hearing impairment. The numbers of "significantly better" evaluations by the sign test with ($p < 0.05$) among 75 pairs are listed.

(1) is significantly better than (3)	53/75
(3) is significantly better than (1)	4/75
(1) is significantly better than (2)	58/75
(2) is significantly better than (1)	0/75
(2) is significantly better than (3)	13/75
(n) is significantly better than (c)	42/75

2.4.3 Test for VCV syllable articulations

Impaired hearing frequently causes phonetic confusion, which renders communication difficult. To evaluate how the proposed IEC fitting prevents this phonetic confusion, we compare the VCV (vowel-consonant-vowel) syllable articulation test between (1) the proposed IEC fitting method and (2) conventional fitting method.

Table 2 shows how proposed and conventional fitting methods reduce the confusion. This table clearly shows the superiority of the IEC fitting method, too.

Table 2: The results of 210 VCV syllable articulations among (1) the proposed IEC fitting method, (2) conventional fitting method, and (3) no hearing impaired compensation.

(a) From (3) to (1).

changes in confusion	increased	decreased
20%–40%	13/210	16/210
40%–60%	0/210	13/210
60%–100%	0/210	16/210
total	13/210	45/210

(b) From (3) to (2).

changes in confusion	increased	decreased
20%–40%	14/210	13/210
40%–60%	14/210	11/210
60%–100%	13/210	14/210
total	41/210	38/210

2.5 Evaluation with music sound

We evaluated how the sound quality of music is improved by the IEC fitting through subjective tests. Subjects consisted of three persons with normal hearing with three kinds of simulated compensation characteristics [1] and three with auditory nerve impairment. The music source was a 4-second symphony from an audio CD.

2.5.1 Quality evaluation with training source

Subjects are first requested to optimize an experimental compensation system, the 3-D loudness space mentioned in section 2.3.1, for the symphony music sound based on their *preference*. Then, the pair of compensated and original non-compensated sounds are blindly compared, and one is chosen based on the subjects' preference. The 15 pairs are compared, and the result are statistically tested by the sign test.

Table 3 shows the number of subjects who significantly chose either music sound compensated by the IEC fitting or non-compensated sound. This result shows that the proposed IEC fitting improves not only the quality of speech as shown in Table 2 but also that of music.

Table 3: Subjective test result for a same sound source. The 15 pairs of the same musical selection compensated by (1) the IEC fitting method and (3) no compensation are compared by six subjects. The numbers of the significantly superior method with ($p < 0.01$) are shown.

(1) is better than (3)	5/6
(3) is better than (1)	0/6
no significant difference	1/6

2.5.2 Quality evaluation with different kinds of music

In this evaluation, the compensation characteristics obtained by the IEC fitting method in section 2.5.1 are applied to three different kinds of 4-second music sounds—saxophone solo, Latin female vocal, and rock style male vocal. Other experimental conditions are same with those in section 2.4.

Table 4 shows the number of choices that are evaluated significantly better with ($p < 0.01$) in 18 comparisons (= 6 subjects $\times$ 3 kinds.)

Table 4: Subjective test results for three different kinds of music sources. The 18 pairs of the same musical selection compensated by (1) the IEC fitting method and (3) no compensation are compared by six subjects. The numbers of the significantly superior method with ($p < 0.01$) are shown.

(1) is better than (3)	13/18
(3) is better than (1)	1/18
no significant difference	4/18

The musical sound compensated by the proposed IEC fitting is chosen in most cases, which shows that the IEC fitting method has universal effectiveness for several kinds of music. Of course, this experimental result does not deny the possibility that the fitting for each musical sound might be better than unified fitting. We will examine it in a future experiment.

2.6 Summary of IEC fitting evaluation

Normal hearing subjects with pseudo-impaired characteristics and hearing impaired subjects compared the IEC fitting method with the conventional method. Comparisons have shown: (1) both word clarity and sound quality of the IEC fitting method is superior to those of the conventional one [4, 5], (2) the proposed method has significantly improved the sound quality of music more than the conventional one [4, 6], and (3) the compensation characteristics fitted by IEC fitting with symphonic music is still effective when it is applied to other kinds of music [4, 6].

The IEC fitting time depends on the subjects in our experiments and ranged from 20 minutes to one hour. The required number of EC generations was several generations less than 10.

3 Physical Rehabilitation with Force VR

3.1 Advantage of rehabilitation in a VR environment

Most patients become bored when rehabilitation takes a long time. VR rehabilitation allows patients to feel as though they are playing a game and motivates them during their training. Another advantage of rehabilitation in virtual environment is that it is easy for a VR system to adjust the force and speed of rehabilitation equipment to an individual patient's muscular strength. For example, person who cannot move his or her arm smoothly may not be able to dribble a real ball but might be able to dribble a ball if he or she could do so on the moon. It is easy for VR to simulate the ball bouncing in any gravitational environment such as the moon.

Our VR rehabilitation system is realized by combining VR of vision, audio, and force. The movement of a bouncing virtual ball is shown on a 3-D display, which is better than a normal CRT display, to represent the relative position of the ball with respect to the patient's hand. VR rehabilitation patients get into a rhythm of dribbling the ball by hearing the synchronized sound of a bouncing ball. However, the most important factor of the VR rehabilitation system is the tactile sensation synchronized with the bouncing ball. The relative importance of the force in VR arm wrestling is especially significant.

It is easy to realize several VR variations of rehabilitation, such as arm wrestling, dribbling a ball, or kicking a soccer ball or football, using the same pneumatic control. In the following section, we introduce two of our demonstration systems: an arm wrestling robot and ball dribbling simulator.

3.2 Force display

We realized a force display using two pneumatic rubber actuators called *rubbertuator* [9]. Figure 3 shows how rubbertuators move a robot arm. Pneumatic controls simulate the movement of human muscles and can produce a realistic range of power. Our physical rehabilitation systems, including arm wrestling, dribbling or kicking a ball, and exercising with dumbbells, are realized using this force display and visual and audio subsystems.

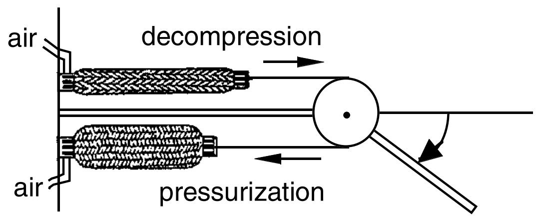

Figure 3: Two rubbertuators pneumatically move a robot arm.

3.3 Arm wrestling robot

Although we can wrestle with an arm wrestling robot without visual and audio stimuli, VR stimuli, such as changing facial expressions and voice inflections according to the wrestling situation and resistive force, allow rehabilitation patients to enjoy their rehabilitation as if playing a game.

The photograph in Figure 4 is a picture of our pneumatically controlled arm wrestling robot [12, 2]. The force and speed can be controlled according to the patient's muscular condition. The facial expression of an opposing arm wrestler is shown to a rehabilitation patient through a head mount display.

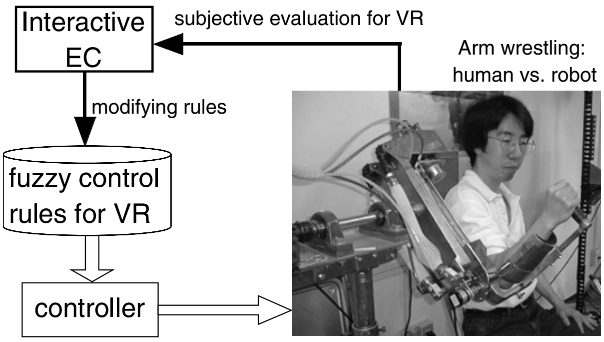

Figure 4: An arm wrestling robot and an interactive EC system to obtain VR fuzzy control rules.

An important aspect of a VR arm wrestling robot is force control rules. Since a VR impression is provided by the natural exchange of force between a human and the arm wrestling robot, movement of the arm obtained from the calculation of physics equations is insufficient for VR arm wrestling. Initial version of our system uses control rules obtained by a classification system and training data measured by actual humans arm wrestling [12, 2]. There are 20,000 rules which may not be VR rules but rules to resist the arm pressure of an opponent.

Then, we are conducting research to obtain control rules for VR from these winner's rules. Automatic design of a fuzzy system using GA and an interactive EC are being used for this rule-modification. First, we compiled the 20,000 classifier rules into a few fuzzy rules [2]. We used an automatic design technique for fuzzy systems using GA. The few fuzzy rules obtained are equivalent to the 20,000 classifier rules; both used to resist an opponent. Next, we are applying the interactive EC to modify the fuzzy rules based on a human arm wrestler's evaluation and obtaining rules for VR sense (see Figure 4). The human arm wrestler gives a higher score to the human-like movement and a lower score to the mechanical movement, and the EC modifies the fuzzy control rules according to the human evaluation [2].

3.4 Ball dribbling robot

Figure 5 shows a pneumatically controlled force display that is attached to the grip of a robot arm in Figure 4 and that is used for dribbling a ball [10, 11]. The patient watches the 3-D CG animation shown in Figure 6 that is synchronized to the force display, and the force display gives the user a sense of resistive force when his or her hand touches the virtual ball.

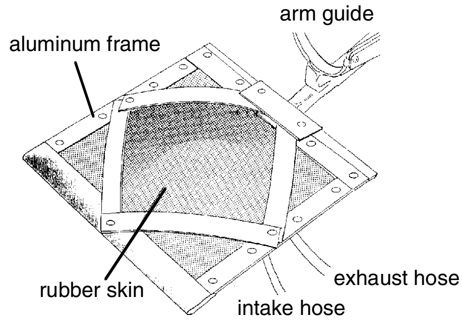

Figure 5: A force display for ball dribbling.

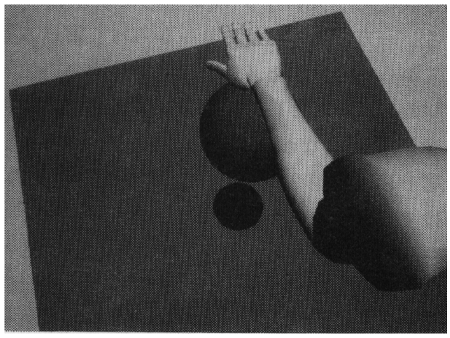

Figure 6: 3-D CG animation synchronizing with a force display for ball dribbling.

Figure 7 shows the movement of a virtual ball and the hands of human subjects who can and one who cannot dribble a virtual ball. The overlapped parts of the two lines represent the time duration when the human hand is in contact with the virtual ball.

The rehabilitation is conducted by changing the VR gravity and weight of ball according to a patient's condition and training progress.

4 Acquisition of Scientific Knowledge

4.1 Discovering new knowledge on hearing

The characteristics of hearing aids fitted by the IEC fitting method are reflected by the total characteristics from peripheral to central auditory. By analyzing these characteristics, we may obtain new knowledge on human hearing. So far, we have found that the best parameters of hearing aid for speech is not the best for music sound, loudness function measured by pure tone or band noise is different from

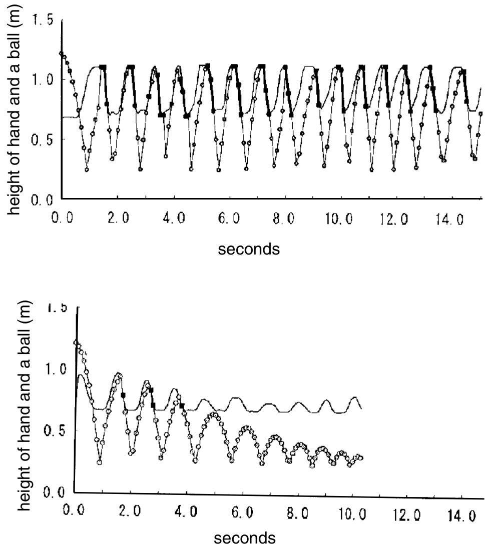

Figure 7: Ball trajectory and hand movement of dribbling a ball in a virtual environment. Solid lines with and without circles indicate the movement of a ball and hand, respectively. The upper and lower figures are represent the trajectories of a skilled subject and that of a beginner, respectively.

that determined by speech and music, and so on [4, 6].

4.2 Discovering the factor of VR

One difficulty is to design a controller which provides VR emotion. We apply an interactive EC to fine-tune an arm wrestling controller because only a human can evaluate how realistically an arm wrestling robot can simulate a human opponent. As mentioned in section 3.3, we apply the interactive EC to modify fuzzy control rules from the winner's rules to the VR's rules. The difference between the initial fuzzy control rules and the obtained fuzzy control rules is the main factor that causes VR sensation. By analyzing the differences, we may be able to analyze our perceived force VR.

5 Conclusion

We introduced an interactive EC-based hearing aid fitting system and a VR physical rehabilitation system as applications of soft computing technologies for welfare devices. Performance evaluation of the proposed IEC fitting method using speech and musical sounds was also shown. We will evaluate the performance of a VR rehabilitation system in the near future. We also described different approaches to acquiring scientific knowledge from the obtained characteristics using these welfare devices and mentioned the possibility of using soft computing technologies as research tools.

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