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Takagi, Hideyuki
Kyushu Institute of Design : Associate Professor

Hayashida, Norimasa
Kyushu Institute of Design

出版情報：Asia-Pacific Conference on Simulated Evolution And Learning. 2002, pp.375-379, 2002-11-18
バージョン：

INTERACTIVE EC-BASED SIGNAL PROCESSING

Hideyuki Takagi *Norimasa Hayashida*[1]

Kyushu Institute of Design
4-9-1, Shiobaru, Minami-ku, Fukuoka, 815-8540 Japan
takagi@kyushu-id.ac.jp TEL & FAX +81–92–553–4555

ABSTRACT

We introduce new types of signal processing for which the characteristics of the signal processing filters are designed automatically by interactive evolutionary computation (IEC) based on human perception, such as hearing or vision. We first describe our existing works that use this approach, such as recovering distorted speech and hearing-aid fitting, as well as other related works in this field. Next, we evaluate the capabilities of visual-based image signal processing using IEC and compare it with conventional linear filters for the tasks of edge detection, high pass filtering, and horizontal / vertical component filtering. The experimental comparisons show that the performances of both methods are similar, which means that the new approach, without a priori knowledge on signal processing, is useful when signal processing users are not signal processing experts such as is the case in medical image processing or photo-retouch design.

1. INTRODUCTION

We have received the benefits of an advanced information and communication society supported by signal processing technology. The cases where domain experts are not signal processing experts and vise versa have thus increased according to the expansion of applied signal processing fields; for example, medical doctors who make diagnosis using medical images are not image processing experts. It is difficult for the approaches that use the conventional mathematical-based or rule-based signal processing to bridge this gap.

One way to solve this problem is by developing new approaches that allow domain experts to conduct signal processing without a priori knowledge of signal and signal processing, but by only evaluating whether the processed signal is aurally or visually superior based on their domain knowledge and preference. This solution allows medical doctors to design or modify image filters by themselves to improve the ease of detecting diseased parts in medical images based on their visual inspection. It also allows graphic designers to create their own retouch filters which change the character of photographs or images.

[1]Now working for IBM Japan.

Interactive evolutionary computation (IEC) is one of these solutions; domain experts iteratively design filters for their purposes based on their auditory or visual perceptions using IEC. IEC is an EC that tries to find the optimum solution to an application task based on human subjective evaluations as shown in Figure 1. IEC application fields have widely expanded, especially over past 10 years, and include: graphic arts and animation, 3-D CG lighting, music, editorial design, industrial design, facial image generation, speech processing and synthesis, hearing aid fitting, virtual reality, media database retrieval, data mining, image processing, control and robotics, food industry, geophysics, education, entertainment, social system, and so on [11].

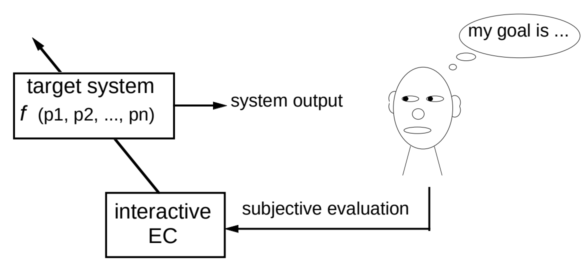

Figure 1: General framework of an IEC system: system optimization based on subjective evaluation.

In this paper, we discuss this new approach of IEC-based signal processing. We first introduce our works on auditory-based speech processing in section 2. We also review works on visual-based image processing. Then, we evaluate the capabilities of this new approach in section 3, where four image processing filters designed by this approach are compared with classical image processing filters.

2. SOME WORKS OF IEC-BASED SIGNAL PROCESSING

Some applications of IEC-based signal processing are recovering speech from distorted speech, hearing aid fitting, and image enhancement filtering.

Our first trial was to design a filter that recovers speech from distorted speech by optimizing the coefficients of an eighth order FIR filter using genetic algorithms based on subjective evaluations of perceptual distortion (see Figure 2). Statistical test for the subjective tests' results showed that the speech recovered with the filter designed by the IEC was significantly better than the original speech, not only for the IEC user who designed it, but also other subjects who did not design the filter [13]. This result demonstrated that the filter was not designed without deep bias against the IEC user but that this IEC approach was a useful technology for speech processing.

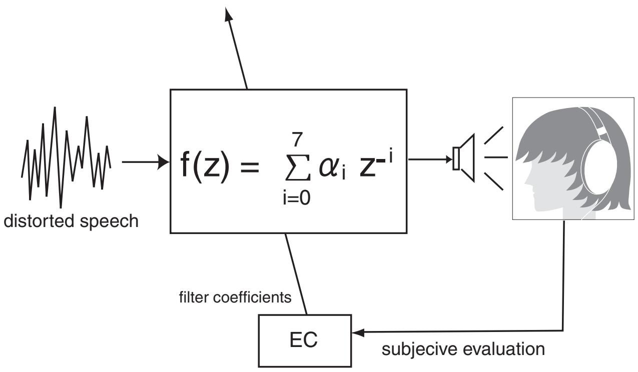

Figure 2: IEC-based filter design recovering speech from distorted speech.

We also investigated applications of the IEC interface for speech, music, or other sounds that must be presented to an IEC user sequentially in time. Unlike with images, it is almost impossible to evaluate sounds by comparing them at the same time, and this introduces the problem of user fatigue. We proposed three methods to reduce the fatigue of an IEC user who deals with sound signals and evaluated them using subjective tests [12].

Our second application was IEC Fitting; that is, the optimization of hearing aid parameters using EC based on the hearing of a hearing-aid user [4, 8, 5, 9]. As nobody can know how other people hear, it is fundamentally impossible for third parties to fit hearing aids to their users' hearing satisfaction; conventionally, all we could do was to fit hearing aids using the knowledge and experience of fitting experts.

We have developed a visualized IEC that maps n-D EC landscape onto a 2-D space for visualization [10, 1, 2]. We combined this technique with the IEC Fitting and installed the Visualized IEC Fitting on a Personal Digital Assistant (PDA). See Fig. 3. To take advantage of the biggest feature of IEC Fitting, i.e. fitting at any time at anywhere with any source, it is important to realize the IEC Fitting system in portable equipment. Now this new fitting technology is in the field test stage with the assistance of hearing aid companies.

Figure 3: Photo of and illustration of the user interface of an IEC Fitting system on a PDA.

In the field of image processing, Poli et al. applied IEC to design a color filter that enhances MRI images to help the decision making of a medical doctors and to design an image synthesis filter that makes it easy to see when two echo-cardiograms are mapped onto one [7]. Otoba et. al applied IEC to design a filter to detect the edges of plants in remote monitoring images [6] and Muto et. al used IEC to decide the order of image filters used for retouching images, because retouching with filters of different orders results in differently retouched images [3].

In this paper, we focus on demonstrating the capabilities of IEC-based signal processing by designing image filters whose characteristics are the same as those of conventional linear filters and by comparing these characteristics to the conventional originals.

3. EVALUATION OF VISUAL-BASED FILTER DESIGN

Image enhancement is a process that visually enhances certain parts of images to meet the desires of domain experts, for example, enhancement of disease parts in medical images or certain features in geological images. Domain experts are not always image processing experts and cannot design such image enhancement filters; at the same time, image processing experts may not have domain knowledge.

By introducing IEC, we have come to be able to visually design image filters. Genetic Programming (GP) is used as

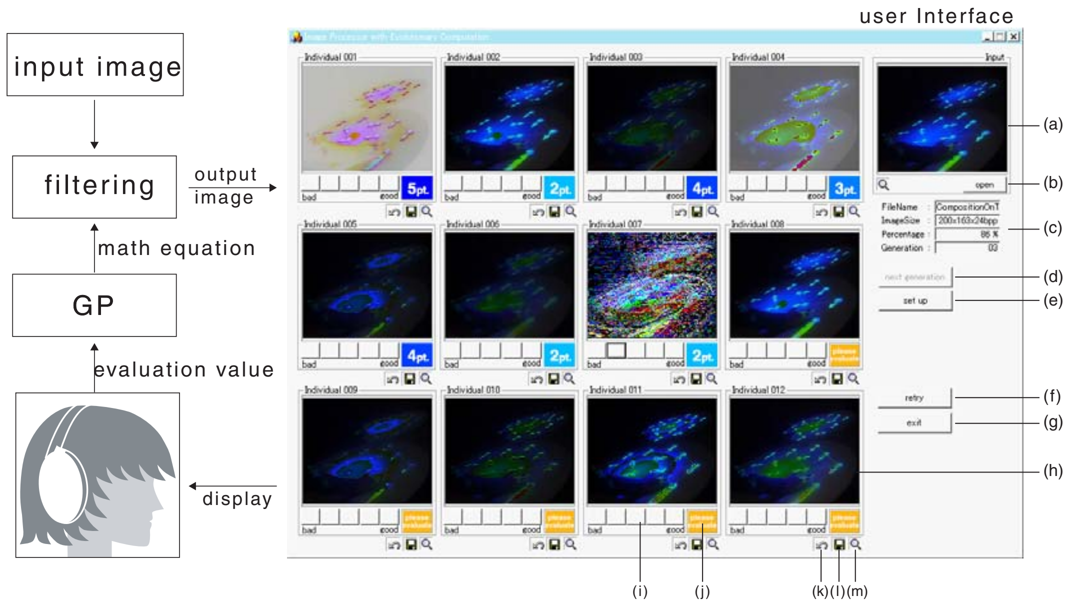

Figure 4: User interface of IGP-based image processing and its processing flow. (a) input image, (b) open button of input image, (c) information of input image file and IGP generation number, (d) jump button to the next GP generation, (e) to a setting window, (f) reset button, (g) exit button, (h) images processed by filters generated by IGP, (i) input buttons of subjective evaluation, (j) display of input evaluation value, (k) button to apply the obtained image filter to another image, (l) button to save image, and (m) button to enlarge an image.

the EC, and generates mathematical equations that determine the characteristics of the filters. Concretely speaking, for example, numerical values assigned to each pixel are input to the generated mathematical equation, and the calculated value becomes the numerical value of a pixel in an enhanced image.

We experimentally designed image filters based on our vision to investigate how the IEC-based approach can design filters whose characteristics are similar to those of a conventional, mathematically specified filter. The user interface of the IEC-based image filter design for this experiment is shown in Figure 4. Target tasks are to design filters for edge detection, high-pass, and X/Y component detection and compare them with conventional linear filters. The original input image is shown at the right upper corner of the IGP user interface. An IGP user compares 12 images processed by 12 mathematical equations generated by the GP. According to his/her intention of how to emphasize a given input image, subjective evaluations of each image are given by clicking the five levels of input buttons under each image. The evaluation values are fed-back to the GP, and the GP creates new mathematical equations, i.e. image enhancement filters. This process is iterated until satisfactory images are obtained.

Figure 5 shows the filter characteristicsf input-output relationship. $G()$, which is a conventional linear filter or the mathematical equation generated by GP inputs numerical values from 3×3 input pixels, weights them according to the filter characteristics, and outputs a new value at the center pixel among the input pixels. $G()$'s of conventional liner filters used in our comparison are shown in Figure 7. For example, the output of the Laplacian filter in the figure is given as:
$y = f(i,j-1)+f(i-1,j)+f(i+1,j)+f(i,j-1)-4f(i,j)$.

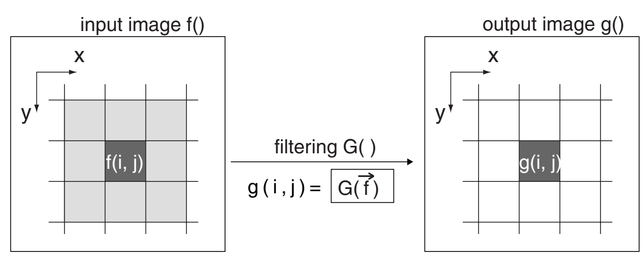

Figure 5: Output $g(i,j)$ is calculated by a filter whose characteristics are given by $G()$ and input pixel $f(i,j)$ and its neighbor pixels. As we use 3×3 input pixels in our experiment, $g(i,j) = \sum_{i=-1}^{1} \sum_{j=-1}^{1} G(f(i,j))$.

Filters generated by IGP sometimes output bigger numbers, exceeding the quantization bit length. As we use 8-bit quantization levels in our experiment, we suppress the value of the filter output by the modulus of 256, whose characteristics are shown in Figure 6.

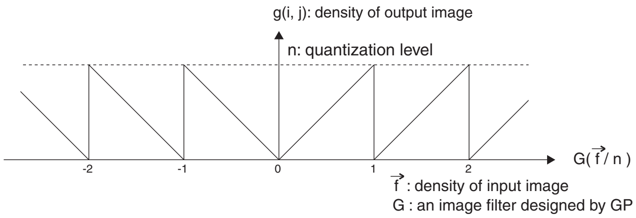

Figure 6: Modulus characteristics to suppress the output values of a filter generated by GP to within quantization levels.

The four linear filters shown in Figure 7 are compared in our experiment. The numerical values in each box of Figure 7 are the filter weight values used for each input pixel. Figure 7(a)–(d) are a Laplacian filter for edge detection, a high-pass filter, a Prewitt filter to detect horizontal (X) components, and (d) a Prewitt filter to detect vertical (Y) components. In our experiment, we design filters whose processed images are similar to those produced by the four linear filters based on our vision and using IGP, and then compare the images processed by both filters.

(a)

0	1	0
1	-4	1
0	1	0

(b)

-1	-1	-1
-1	9	-1
-1	-1	-1

(c)

1	0	-1
1	0	-1
1	0	-1

(d)

1	1	1
0	0	0
-1	-1	-1

Figure 7: Filter characteristics of (a) Laplacian filter, (b) high-pass filter, (c) horizontal component extraction filter, and (d) vertical component extraction filter used in the experimental comparisons.

Figure 8 (b) shows the original image of Figure 8 (a) processed by a conventional Laplacian filter, and Figure 8 (c) shows the same original image processed by a filter visually designed based on the IGP approach. The filter characteristics of Figure 8 (c) was $g(i,j) = f(i-1,j-1) - max[f(i,j),\ f(i+1,j)]$ and was obtained at the second generation. Comparing the four figures, it appears that the edges detected by the IGP filter are smoother than those of the Laplacian filter, which implies that the IGP approach created a better edge detection filter in this case.

We also compared the characteristics of filters designed by IGP with those of a conventional high-pass filter, vertical component detection filter, and horizontal component detection filter. See Figure 9. Filters of Figure 9 (b1), (b2), and (b3) were obtained at the sixth generation and are much more complex than the filter of Figure 8 (c). In these cases, the performance of the filters visually designed by IGP did not reach the perfect level of the conventional filters, but

(a) (b) (c)

Figure 8: (a) original image, (b) edge detection using the Laplacian filter, and (c) using a IGP filter.

they are similar.

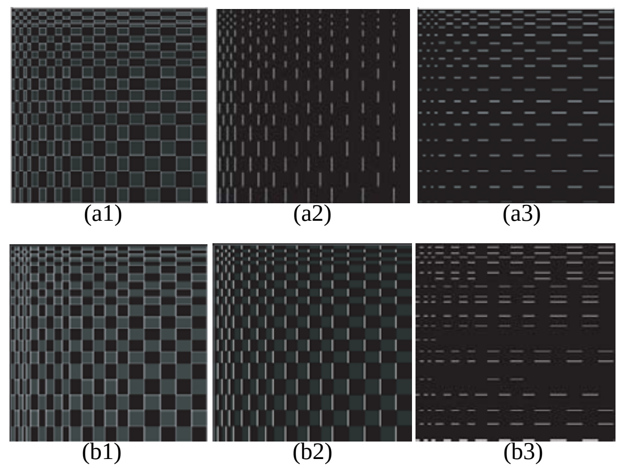

Figure 9: Comparison of images processed by conventional linear filters and filters generated by IGP. Images processed by (a1) linear high-pass filter, (a2) Prewitt filter to detect horizontal component, and (a3) Prewitt filter to detect vertical component, and images processed by filters generated by IGP corresponding to images (a).

4. CONCLUSION AND FUTURE WORKS

We experimentally evaluated a new signal processing approach for which we do not use any a priori knowledge on the task signal or signal processing knowledge, but only our auditory or visual evaluation of the processed signal. The experimental results demonstrate that even non-experts of signal processing can quickly design filters for domain fields by using this IEC-based signal processing approach. These experimental results show the capability of this visual-based signal processing and imply similar capabilities for perception-based signal processing in general.

We accept this conclusion as the first step in researching this new approach. Our second step will be to show its usefulness with real-world practical tasks, and the third step will be to show examples for which conventional signal processing approaches are difficult to implement but that can be easily solved using this approach.

Acknowledgements

This research was partially supported by the Ministry of Education, Science, Sports and Culture, Grant-in-Aid for Scientific Research No. 13680451, 2001–2002.

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