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Analysis and Evaluation for Interactive Evolutionary Computation-Based Image Processing*

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We apply interactive evolutionary computation technique to processing images in medical and other fields, analyze its performance of image enhancement, and discuss its capability and further improvement. We first show our system scheme and the design of user interface and then show experimental results of image enhancement. We also propose an idea of new interactive genetic programming that has not only arithmetical operators but also image processing operators in generated mathematical equations to increase its performance for image processing.

Keywords: interactive evolutionary computation, image processing, image enhancement, visual evaluation

1 Introduction

The application areas of signal processing have been spread widely. According to the expansion of the applications, the case which signal processing users may not be signal processing experts has increesed. As most of conventional signal processing are based on mathematics, it is difficult for non-signal processing experts to design signal processing systems. At the same time, signal processing experts may not have domain knowledge of the target application fields. Medical image processing is a typical such case.

Interactive evolutionary computation (IEC) is one of solution to allow signal processing users to design signal processing systems based on users' hearing or vision [5, 6, 4].

In this paper, we focus on IEC-based image processing and and evaluate how visual-based image filter design works well without any image processing knowledge. This is a suitable approach for image processing whose users are not signal processing experts. Our approach is to specify the input-output characteristics of a coloring filter with a linear spline functions for each of RGB colors, apply IEC to optimize the parameters of the spline functions based on users' visual inspection, and interactively design the coloring filters.

We describe genetic approach of IEC-based image processing and our experimental system in section 2. We show several experimental results of the IEC-based image processing in section 5. Finally, we introduce our new idea, image processing operators, to create powerful filters with genetic programming (GP) in section 6.

2 IEC-based Image Processing

IEC is EC that an EC human is used instead of *a fitness function* [5]. A basic scheme of an IEC-based image processing applications is illustrated in Figure 1.

Interaction between a human user and a computer side on the right and left sides of Figure 1 is conducted through

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user interface. The user interface displays candidate images to the IEC user and collects user's evaluations for these images.

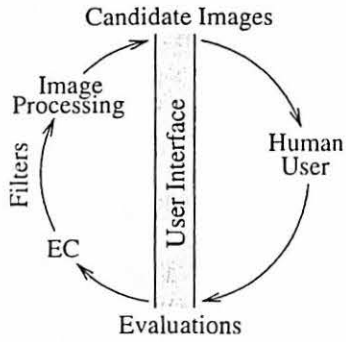

Figure 1: IEC-based image processing loop

Computer part of IEC consists of an EC part and an image processing part. EC uses user evaluation given to individual image processing filters to optimize them. The role of the image processing part is to generate images in the next generation using image filters created by EC. This interactive optimization process loops iteratively.

The advantage of IEC image processing is:

a) if a user is looking for particular filter or features, the user can develop or find it in this process, and
b) if the user wants to find some new unknown features of a certain image – to explore image, the user can accomplish it in this process as well.

The last obtained filter is the result in the case a), while it is an interactive process as whole in the case b). Case a) represents an exploitative behavior, while case b) the explorative one.

3 User Interface

User interface is an essential part among IEC components, which is unlike to other EC algorithms. Several types of user interface for IEC-based image processing can be configured. Basic role of the user interface is to display the sets of images to user. However, the impression of the GUI interface is dramatically different between cases when 10 images are displayed and when 100 images are displayed at once. Sometimes, thumbnails or grouping of images is used for interface structurization, as well.

The trade-off lies between ability to see details in image and ability to see overall appearance of image. This might be balanced by usage of zooming and/or cropping of image (displaying only a part of it). We are constrained by the need to display several images in parallel. If we reduce the the size of population too much, the optimization performance may be limited. If we display only a portion of population at once, the ability of user to compare particular individuals may be limited, as he/she must memorize non-displayed images. Optimal setting of these parameters of IEC-based image processing will be application or task dependent.

Image-evaluation part of interface might be configured in several ways too. The user might search and pick up interesting images, he/she might select best images or precisely evaluate them. Furthermore, there is difference between continuous and discrete evaluation, as well as between 3-value and 5-value ones. If user is looking for any interesting feature of image and wants to see a lot of different views of image, he/she will be frustrated be the need to precisely evaluate every single image. In different scenario, when user knows his target filter behavior, he will want to precisely evaluate slightly different images in order to fine tune the resulting filter.

User interface handles two information flows: from computer to human and from human to computer. The total bandwidth of information flow through the user interface is then a sum of these two flows. We may assume that the higher bandwidth means the deeper interaction. However, the information exchanged in interaction may differ dramatically in quality. With the more expressive image presentation the user evaluations may be more correct and may lead to faster convergence of the search. To measure this quality of information, the sum of future evaluations might be used.

We may tell, that user interface is better if:

a) with the same type of presented images and the same type of evaluation, the bandwidth of information flow through user interface is higher,
b) with the same bandwidth, the overall sum of evaluations through time is better.

Note that overall performance of algorithm depends not only on the performance of the user interface, but also on the performance of EC algorithm, the performance of image processing part of algorithm and the abilities of particular user as well.

4 Image Processing Filters

The main loop on the Figure 1 illustrates that in the IEC-based image processing the human and the computer interact in synchronized manner. Consider the higher computational performance of human brain, compare to the computer, we should expect the human waiting for computer, not the computer waiting for human evaluations. A practical realization of such a behavior might prove difficult, as performance of computer is screwed by the limited bandwidth of display. Even if the CPU of computer may produce more images, we can display only a limited number of them. To utilize full CPU power of camputer we should employ techniques to improve quality of produced images or to assist the user in any other way. For overview of such a techniques see [5], section on reducing the human fatigue. In summary, for better utilization of the computer in the IEC-based image processing we may consider to:

a) compute and display more candidate images for user to evaluate,
b) use idle CPU power to assist the human user.

Choice of the EC algorithm itself is related to the type of image processing filters used. If filters are realized by arbitrary mathematical functions then the natural choice is to use genetic programming (GP), however if filters are limited to the linear spline functions, or the similar, the genetic algorithm (GA) optimization will be sufficient. Retroactively, the choice of type of filters enlarges or shrinks the search space for EC and thus affects search performance.

We will discuss following types of image processing filters for IEC-based image processing:

a) algebraic filters,
b) parametric filters with fixed structure,
c) structured filters.

4.1 Algebraic Filters

Algebraic filters compute the output pixel value using input pixel information and arbitrary mathematical function to describe the input/output relation. To evolve such a filter the natural choice is to use GP methods, as they are able to build the structure of function and also optimize parameters. However, it's possible to build such a filter with predefined type of structure and use simple GA for its optimization.

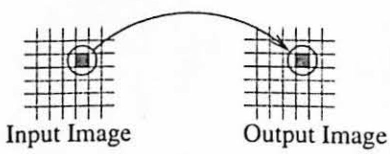

Figure 2: Arbitrary mathematical function may be used as image processing filter, to map input pixel value to the corresponding output pixel value.

Following mathematical function might be an example of discussed algebraic filter:

$$r_{out} = 100\sin(r_{in}/20) + 50\log(g_{in}) - 120 + r_{in}/b_{in} \quad (1)$$

The r_{out} is the intensity of output pixel in red channel and r_{in}, g_{in} and b_{in} are its intensities in red, green and blue channels. This filter realize one pixel-to-one pixel mapping of images. To be able to achieve edge detection or another operation which rely on relations between different pixels in input image, we must include several input pixels in filter function.

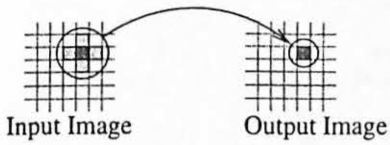

Figure 3: Multiple pixels-to-one mapping filter

Multiple pixels-to-one algebraic filter function may be for instance:

$$r_{out} = 0.2r_{-1,0} + r_{0,0} + 0.1g_{0,-1} + 0.2g_{0,0} - 0.1g_{0,1} \quad (2)$$

Where $r_{-1,0}$ is the red channel intensity of pixel on the position $(-1, 0)$ (left) to the current pixel.

The maximal value of pixel intensity is usually limited, they are 8 bits, 12 bits, 16 bits, etc. per pixel images. When using arbitrary mathematical functions to compute pixel value this maximal value of pixel might be easily exceeded. To deal with this problem we must limit output of filter back to the dynamic range of image. We may use limiting functions to do this, for instance these from Figure 4. All these functions are nonlinear and may have dramatic impact on the function of filter.

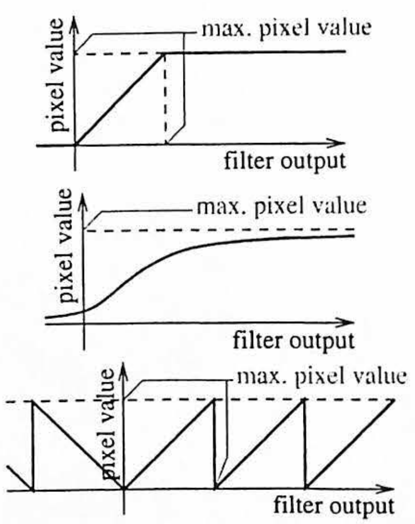

Figure 4: Functions to limit the pixel value

An autoscale method may be used instead of these limiting functions to overcome this nonlinear behavior. However, the autoscale method is specific to given filter and may be image specific. This may prohibit the use of given filter with another images and/or may affect the dynamics of the IEC search process. Also, the dynamic range of output image will be fixed when using autoscale method, the brightest and darkest pixel will be always of the same intensity.

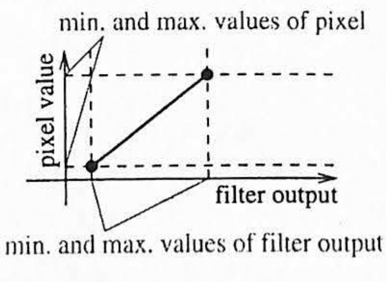

Figure 5: Autosgcaling of pixel value

Why not employ IEC optimization method also to optimize limiting function? In the ideal situation the output of filter function will never exceed the maximal value of pixel, thus we don't need any limiting function. However, the initial filters in IEC image processing are not optimal (usually random) and the optimal solution is to be found in optimization process. To take care of this process we must explicitly limit the pixel values to correct range, if we use the filters which are able to exceed this range.

For more details about algebraic filters in IEC image processing see [6].

4.2 Parametric Filters

Parametric filters with fixed structure are based on parametric functions, and IEC is used to optimize only their parameters. If the number of parameters is fixed, a simple GA algorithm will be sufficient for optimization of such filter. An example of this type of filter might be one consisting from three functions for adjusting pixel intensities in red, green and blue (R,G,B) channels, where every of these functions is linear spline function with fixed number of "joints".

Figure 6: Linear spline based RGB filter

Filter on Figure 6 is severally limited in function compare to the algebraic filter of the type from equation (1). Filter from equation (1) is of type:

$$r_{out} = f_r(r_{in}, g_{in}, b_{in}) \quad (3a)$$
$$g_{out} = f_g(r_{in}, g_{in}, b_{in}) \quad (3b)$$
$$b_{out} = f_b(r_{in}, g_{in}, b_{in}) \quad (3c)$$

Example spline based RGB filter (Figure 6) is of type:

$$r_{out} = f_r(r_{in}) \quad g_{out} = f_g(g_{in}) \quad b_{out} = f_b(b_{in}) \quad (4)$$

Note that however the "simplicity" of filter will limit it in function, it will also reduce search space for IEC and may accelerate search. Furthermore, this type of limitation of filter abilities might be useful just to not allow IEC to change the image too much.

To overcome limitation of given simple filter we might build more capable parametric filter from modules of the type $r_{out} = f_r(r_{in}, g_{in})$, as on Figure 7.

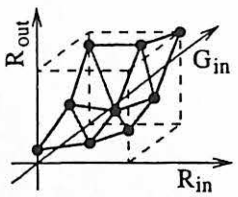

Figure 7: Two-dimensional linear spline filter

Finally, to build parametric filter fully compatible with equation (3) we must use three-dimensional spline functions. Such a 3D parametric filter may still not be fully equivalent to the algebraic filter from equation (1). Linear spline functions have a rough shape compare to functions like x^2 or $\sin(x)$ which may be used in algebraic filter. To smooth shape of spline cubic splines may be used or the number of "joints" should be increased. Instead of splines another functions may be used for parametric filters as well, for instance Taylor series or Fourier series functions.

Structure on figure 8 represent multiple pixels-to-one parametric filter. However, the sum on figure 8 is not general enough, in general case we have to use multidimensional splines. For 5 pixels in input image and 3 channels (red, green, blue) we have to use 15-dimensional spline function.

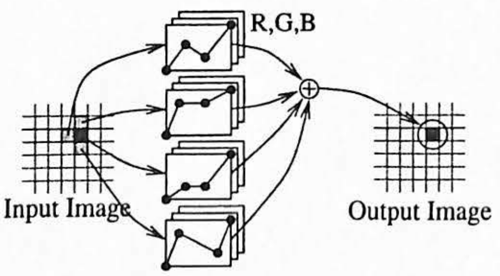

Figure 8: Multiple pixel spline filter

4.3 Structured Filters

Structured filters are filters build from the set of parametric or algebraic filters. This allows to achieve structured character of algebraic filters while using parametric filters as building blocks. See Figure 9 for example.

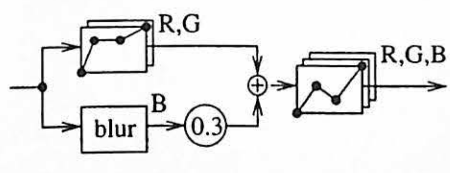

Figure 9: Structured filter

This type of filters mimics conventional approach, where image processing is accomplished by combining of several predefined types of filters. Thus advantage of this type of filter is similarity to traditional approach, this might be welcome to many of potentials users. Furthermore dynamics of the IEC search might be controlled when using structured filters, by enabling/disabling of particular building blocks.

To evolve this type of filter, an GP like algorithm is necessary to adapt the structure of filter.

5 Experimental Evaluation

In our experiments we used the scheme on Figure 10 with parametric filters (algebraic filters are discussed in [6]).

The input image is filtered by initial random set of filters (F1,F2,...F9) and filtered images are displayed for evaluation. After the user evaluate those pictures, an EC algorithm is used to generate new set of filters (F10,F11,...F18). These are constructed by application of crossover and mutation operations on the previous set of filters according to user evaluation of them. New filters are again applied to the input image and displayed for further evaluation. This process loops until the user is satisfied with the result, in general user's fatigue will become a problem after maybe 20 generations.

The second image on the Figure 11 is the output of described IEC image processing. Our objective was to enhance details in input image and the result is from the 7th generation. Input image itself had already enhanced contrast by histogram equalization method, it means that the distribution of grey-scale levels in it is somewhat optimal and further enhancement may be not trivial. To further enhance contrast and detail in particular area of image, manual manipulation of color intensity curves of image might be used. However, to maintain good contrast in several areas of image might be difficult.

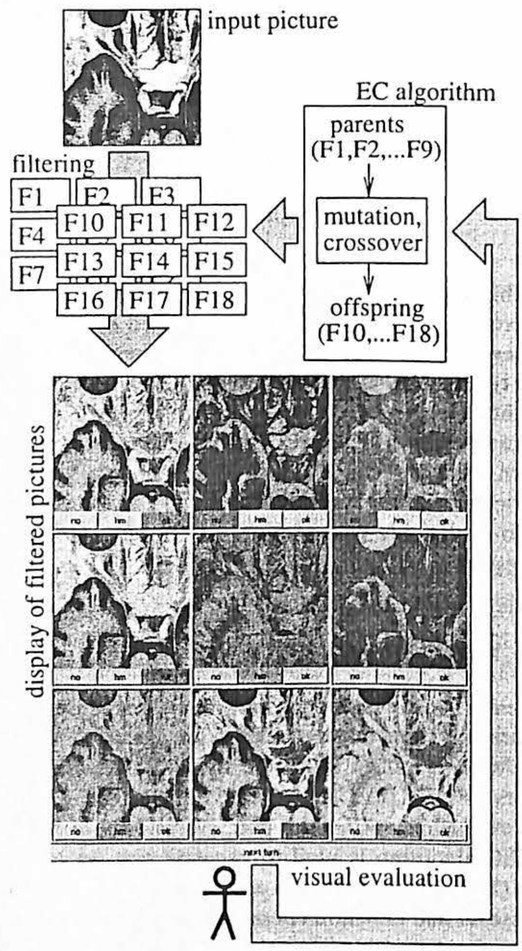

Figure 10: Experimental setup of IEC image processing application

Parametric linear spline filter of the type from equation 4 was used to create image on Figure 10 The input picture is grey-scale, and because the curves of splines for red, green and blue channels are different the resulting filtered image is color one. Because of this "colorization", the appearance of image is slightly worse on the grey-scale print compare to the color display appearance. The detail in grey-scale image might be encoded only by intensity differences between pixels, in color image the detail might be also encoded using color information.

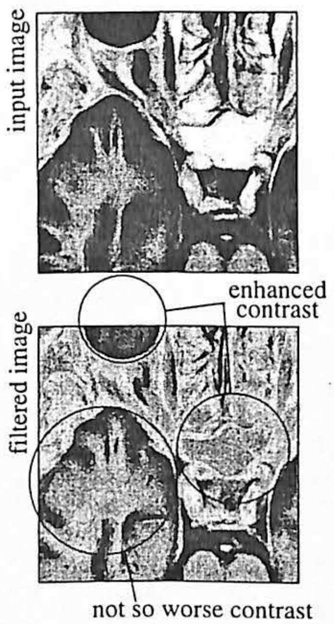

Figure 11: Experiment

We did experiment with medical and aerial pictures, our aim was to explore IEC image processing method, to identify problems and to improve it eventually, this is still in progress. Basic advantage is the IEC idea itself, the feedback based on the subjective visual evaluation and no need for the expert level knowledge from image processing area. Using expert knowledge the result similar to that from Figure 11 might be achieved by application of locally adaptive contrast enhancement filter. However, to do this, user must know which filter to apply, what is the behavior of this filter and how it will match to his impression of good result. Furthermore, in the case of "image exploration" the user does not know what exactly he/she is looking for in advance. In such a case he/she might just try random filters and random combinations of filters. Using IEC image processing will bring some sophistication to this process. Also note that pure contrast enhancement will not bring the color information to the image compare to our IEC image processing approach.

6 Future Expansion with Image Processing Operators

The user fatigue in IEC is interesting topic. The response of EC algorithm is important for the user experience with this method. User wants to see results of his evaluations immediately in the next generation. The features of EC algorithm may be important to enhance this type of dynamics of optimization. Also important is the choice of the type of filter, as it influence characteristics of EC search space. In future we want to use structured filters (see Figure 9) as they allow great configuration flexibility, and thus are well suited for study of search space impact on dynamics of IEC search in image processing.

Dynamics of IEC image processing might be described by three stages. In initial stage user looks for any meaningful filters. In second stage user evolves set of filters to meet his wishes or to find any interesting hidden features of image. In third, final stage user fine-tunes filters to obtain perfect result. We observed difficulties in the third stage of search, hopefully the better understanding of dynamics of this process will help to improve it.

User interface is another interesting topic in IEC research. Consider information flow computer-human, increasing the information bandwidth here may improve IEC performance. One idea how to do this is to use client-server architecture of IEC image processing software and use multiple displays to feed information to the user. Another idea is to employ motion video pictures and use time-encoding of image information to increase the bandwidth of this information flow. Further motivation for client-server architecture is initialization in IEC search. We use random initializations, however the good image processing filters from previous users experience may be stored by server and used as initialization for next searches. This might be useful as the number of generations for IEC search is limited, and speedup in the start of search is welcome.

On the human-computer side of information flow, the increase of quantization of evaluation over 5 values is maybe not very interesting. However, it is possible to increase user's feedback by giving him ability to directly modify filter parameters. This ability doesn't make much sense when using algebraic filters or more then two-dimensional parametric filters, but it is viable option when using structured filters. This is another motivation for using structured filters in IEC image processing. When using complex algebraic or parametric filters, visualization of search space as in visualized IEC [1] may help to enrich user's feedback.

7 Conclusion

We analyzed the problem of choosing the type of filter in IEC-based image processing. Application of algebraic, parametric or structured filters have several consequences on the behavior and performance of system as whole. We discussed also the configuration of a user interface and the explorative versus exploitative mode of IEC operation. Our experiments with parametric filters based on the linear splines showed usefullness of method. Next step after application of parametric and algebraic filters in IEC-based image processing are structured filters. We see several potential advantages of this type of filters and we plan to use them in our future work.

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