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Multiple filter. A new method to improve the response of a character recognition system*

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In problems of character recognition the role of multiple matched filters has become fundamental. Since these filters are sensitive to the range of sizes of the characters and to rotations, a new coherent multiple matched filter with performace better than the classical one is proposed. In our case, when recording the filter, the characters are rotated by a certain angle, each being different from the other, and have different sizes. Using a variable scale Fourier transform system, the detection of a fixed character in the input is obtained only when the input has been conveniently rotated and its Fourier transform has the suitable size.

1. Introduction

Spatial filtering technique in the Fourier plane is frequently used in optical processing. Its fundamental theory has been formulated by several authors [1, 2]. The type of filter to be employed depends on the objective of the processing. In fact, in problems of pattern and character recognition, the matched filter [3] has been successfully employed. A very useful way to obtain it is the Vander Lugt technique [4], which essentially consists in the recording of a Fourier hologram of a given signal.

If, for a certain problem, we want to obtain a "bank" of n matched filters, it is possible to synthesize n single Vander Lugt filters, applying subsequently the input to each filter. However, making use of the possibilities of information storage by holographic methods, we can synthesize the filters on the same recording medium; that is to say, we can obtain a multiple filter.

Such a hologram can be obtained through succesive expositions of different signals, by changing the angle Ψ between the object and reference waves before every exposition (incoherent recording) or by making only one exposition of the totality of those signals that are present in different positions (coherent recording). As, for a multiple hologram, the maximum total efficiency, in the case of only one exposition is n times greater than in that of multiple expositions [5, 6], we are interested in the second method.

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Using the last technique, BUCKHARDT [7] combines the two previous methods, placing diverse signals in different positions, as well as VANDER LUGT [8], but repeating the process as many times as required to record all the signals. These methods show lateral modulation, each character being recorded in a different carrier.

On the contrary, VIÉNOT et al. [9] suggest to record each signal in the same carrier, the signals being located in a circle around the reference beam. Then, the angle between the reference beam and that corresponding to each signal remains constant. This method shows angular modulation. In fact, Viénot et al. combine both methods, the different signals being located in concentric circles.

Any of these methods present a generalized inconvenience: if the separation between symbols, when the filter is recorded, is not adequate to get the entire input to fit between them, there is overlapping in the output plane, which can lead to errors in the recognition.

To avoid this generalized limitation, we have proposed, in a previous paper [10], a new multiple filter in which the characters, when recording the filter, form a certain angle each different from the others. As the matched filter is rotation-variant – in contrast with others recently developed [11, 12] – the detection of a fixed character in the input is only obtained when the input has been rotated to the adequate angle.

To improve these results, we propose in this paper a modification of the preceding filter. Now, the characters are not only rotated but have different sizes. As the response of the recognition system is also sensitive to the size relation between the characters to be recognized and the character the filter is matched to, then using a variable scale Fourier transform system, we only obtain the recognition of a symbol in the input only when the input has been conveniently rotated and the Fourier transform of the input has the suitable size.

2. Basic theory

Let us suppose that a multiple filter matched to n characters s_i of different sizes is to be recorded. To do this, the Fourier hologram of a transparency with the n transparent characters on dark background is recorded. We take as size origin the height of the smallest character. Let M_i $(i = 1, 2, \ldots, n)$ be the ratio of the height of each character to that of the smallest one. Then we can write

$$M_1 > M_2 > \ldots.. > M_n = 1.$$

The expression representing these characters, when they are not rotated, can be written as follows

$$S(x, y) = \sum_i s_i(x/M_i, y/M_i) \otimes \delta(x + a_i, y),$$

a_i being the separation of a character from the origin of coordinates and $\otimes$ representing a convolution.

Let us consider now that the characters s_i have been rotated by the angles θ_i $(i = 1, 2, \ldots, n)$. The new signal can be written

$$S(x, y) = \sum_i s_i(x^i/M_i, y^i/M_i) \otimes \delta(x + a_i, y) \tag{1}$$

where

$$\begin{pmatrix} x^i \\ y^i \end{pmatrix} = \begin{pmatrix} \cos\theta_i & \sin\theta_i \\ -\sin\theta_i & \cos\theta_i \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix}. \tag{2}$$

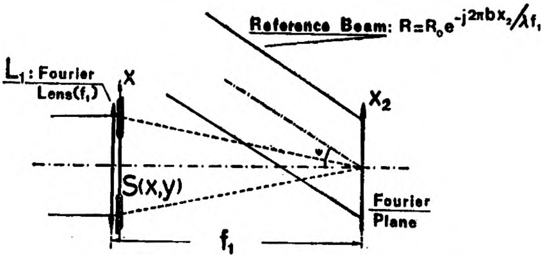


Fig. 1. Set-up for the recording of the filters

Figure 1 shows the sep-up for the recording of the Fourier hologram.

Lens L_1 takes the Fourier transform of $S(x, y)$, indicated by $\tilde{S}(x_2, y_2)$, multiplied by other factors of which we only consider the quadratic one is considered. Therefore, in the plane of the plate, we have

$$A_0(x_2, y_2) \propto \{\exp[jk(x_2^2 + y_2^2)/2f_1]\} \cdot \sum_i M_i^2 \tilde{s}_i(M_i u^i, M_i v^i) \exp(j2\pi x_2 a_i/\lambda f_1), \tag{3}$$

with

$$\begin{pmatrix} u^i \\ v^i \end{pmatrix} = \frac{1}{\lambda f} \begin{pmatrix} \cos\theta_i & \sin\theta_i \\ -\sin\theta_i & \cos\theta_i \end{pmatrix} \begin{pmatrix} x_2 \\ y_2 \end{pmatrix}. \tag{4}$$

Considering now the reference beam, the resulting amplitude on the plate is

$$A_p(x_2, y_2) \propto R_0 \exp(-j2\pi b x_2/\lambda f_1) + \tilde{S}(x_2, y_2) \exp[jk(x_2^2 + y_2^2)/2f_1]. \tag{5}$$

Supposing that we are working in the linear zone of the t–E curve, the amplitude transmission of the developed plate is

$$\begin{aligned} t(x_2, y_2) \propto R_0^2 + |\tilde{S}(x_2, y_2)|^2 + R_0 \tilde{S}(x_2, y_2) \exp[jk(x_2^2 + y_2^2)/2f_1] \exp(j2\pi x_2 b/\lambda f_1) \\ + R_0 \tilde{S}^*(x_2, y_2) \exp[-jk(x_2^2 + y_2^2)/2f_1] \exp(-j2\pi x_2 b/\lambda f_1). \end{aligned} \tag{6}$$

The fourth term of the expression (6) contains the filters matched to the characters that can be recognized in a text. If we take into account (3), this term can be written

$$t_4(x_2, y_2) \propto R_0\{\exp[-jk(x_2^2+y_2^2)2f_1]\}$$

$$\times\Big[\sum_i M_i^2 \tilde{s}_i^*(M_i u^i, M_i v^i)\exp(-j2\pi x_2 a_i/\lambda f_1)\Big]\exp(-j2\pi x_2 b/\lambda f_1). \tag{7}$$

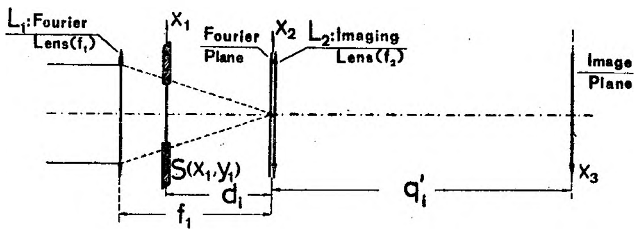


Fig. 2. Coherent filtering set-up for character recognition

We get the character recognition using a coherent filtering set-up, as shown in Fig. 2. For the sake of simplicity, we choose an input solely with the characters to which the filter is matched, but with a distance c_i from the origin. Their size is the same as that of the smallest one to which the filter is matched. Then, the input for $\theta = 0°$ can be written

$$S_0(x_1, y_1) = \sum_i s_i(x_1, y_1)\otimes\delta(x_1+c_i, y_1). \tag{8}$$

A reflected coordinate system is introduced in the output plane to avoid the sign change due to the double Fourier transform.

Let us achieve the filtering. To do this, we put the input behind the lens L_1, at a distance of d_i from its back focal plane, and we introduce the hologram, given by (6) in the Fourier plane (x_2, y_2). In this plane the amplitude distribution is

$$U_2(x_2, y_2) \propto \{\exp[jk(x_2^2+y_2^2)/2d_i]\}\tilde{S}_0(x_2/\lambda d_i, y_2/\lambda d_i)t(x_2, y_2). \tag{9}$$

Taking into account the term t_4, given by (7), which is of our interest we have

$$U_{24}(x_2, y_2) \propto R_0\{\exp[jk[(1/d_i)-(1/f_1)](x_2^2+y_2^2)/2]\}\tilde{S}_0(x_2/\lambda d_i, y_2/\lambda d_i)$$

$$\times\sum_i M_i^2\tilde{s}_i^*(M_i u^i, M_i v^i)\exp[-j2\pi x_2(a_i+b)/\lambda f_1]. \tag{10}$$

The quadratic term of the expression (10) provides the output plane (x_3, y_3), when the lens L_2 has taken the Fourier transform of $U_{24}(x_2, y_2)$. The distance, q_i, between Fourier and output planes is given by

$$1/q_i' = [(f_1+f_2)/f_1 f_2] - 1/d_i, \tag{11}$$

that is, the output plane is the image plane of the input plane through a lens, located in the plane (x_2, y_2), equivalent to the coupling of lenses L_1 and L_2 with no separation.

Also, from expression (10), we can get the recognition of the character s_i when the input has the adequate orientation and d_i fulfils the equality

$$d_i = f_1/M_i, \; i = 1, 2, \ldots, n. \tag{12}$$

In this case, q_i' has the value

$$q_i' = f_1 f_2/[f_1 - (M_i - 1)f_2]. \tag{13}$$

Thus, the output plane coincides with the image plane, through the lens L_2, of the input located at a distance $f_1/(M_i - 1)$ from it. Therefore, that plane really exists only for the values of M_i satisfying

$$1 \leqslant M_i < 1 + (f_1/f_2), \tag{14}$$

that plane has real existence.

If, for a specific problem of recognition (the given values of M_i), it is relevant that the output planes be relatively close to one another, it is convenient that f_2 be small in comparison to f_1.

So, the recognition of the character represented by s_k is achieved when the input has the adequate orientation (θ_k) and has been moved to a distance $d_k = f_1/M_k$. In this case

$$U_{34}(x_3, y_3) \propto \Big\{\sum_i M_i^2 s_i^*(x_3^i/M_i, y_3^i/M_i) \otimes \delta[x_3 - q_i'(a_i + b)/f_1]\Big\} \otimes$$
$$\otimes \Big\{\sum_i s_j(x_3^k/M_k, \; y_3^k/M_k) \otimes \delta(x_3^k + q_k' M_k c_j/f_1)\Big\}, \tag{15}$$

with $i, j = 1, 2, \ldots, n$.

So, only when $i = j = k$, the term

$$\{M_k^2 [s_k(x_3^k/M_k, y_3^k/M_k)^* s_k(x_3^k/M_k, y_3^k/M_k)] \otimes$$
$$\otimes \delta(x_3^k + q_k' M_k c_k/f_1)\} \otimes \delta[x_3 - q_k'(a_k + b)/f_1] \tag{16}$$

is the autocorrelation (*) of $s_k(x_1, y_1)$, while the other terms are cross-correlations due to the rotation and size of the character in the filter.

Then, to recognize a general character represented by $s_i(x_1, y_1)$, the input is rotated by an angle θ_i and moved to a distance $d_i = f_1/M_i$ of the back focal plane of the transforming lens. Again, the output plane is behind the lens L_2 at a distance from it given by (13).

Finally, for $s_n(x_1, y_1)$, the input is rotated by θ_n and moved to the distance $d_n = f_1$. Only in these conditions, the recognition is strictly achieved in the back focal plane of the lens $L_2 (q_n' = f_2)$, since $M_n = 1$.

3. Experimental results

To obtain the filters, a set-up for recording a Fourier hologram, as that of Fig. 1, was used. The recognition was achieved in a two lenses filtering system, shown in Fig. 2.

In our case, in making the hologram, we have employed, a transparency with the characters *m*, *a*, *r* (the last being the smallest one) in which the first remained in horizontal position, the second and third being rotated by 45° and 90°, respectively, as can be seen in Fig. 3.

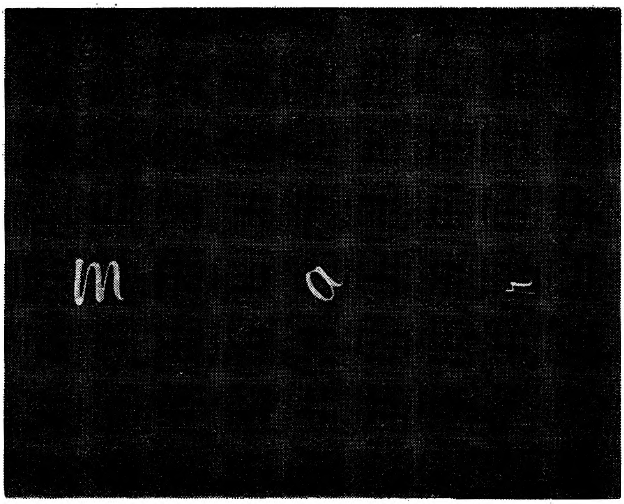


Fig. 3. Signal to implement the multiple filter

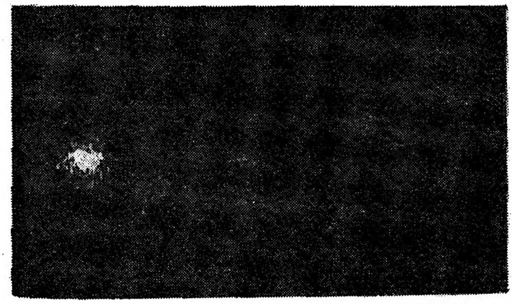
Figure 4 shows the successive detection of the characters *m*, *a*, *r* obtained with our filter, when the input is a transparency containing only these three characters.

The detection, when the recognition has been carried out in a more complicated input, can be seen in Fig. 5. In any case, a bright point appears in the place corresponding to the detected character. Note that only with fixed orientation and position of the input, a given character is recognized.

4. Conclusions

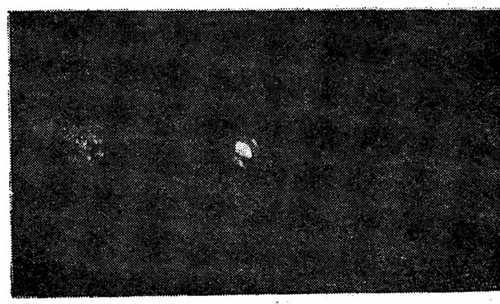
In a previous paper, we have proposed a multiple filter for character recognition, to avoid the overlappings associated to classical techniques. Now, to improve its performance, we propose a new multiple filter where the characters to which the filter is matched, are not only rotated but they have different sizes.

INPUT



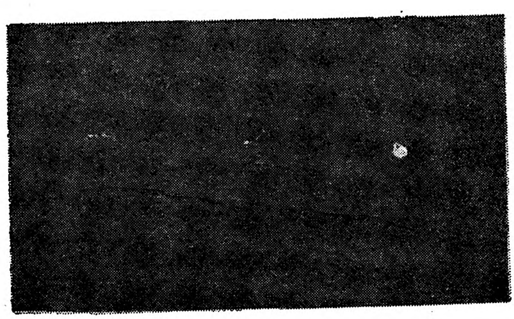
DETECTION OF SYMBOL *m*

$d_1 = f_1/M_1$, $\theta_1 = 0°$



DETECTION OF SYMBOL *a*

$d_2 = f_1/M_2$, $\theta_2 = 45°$



DETECTION OF SYMBOL *r*

$d_3 = f_1$, $\theta_3 = 90°$

Fig. 4. Successive detection of characters *m*, *a*, *r* in the input *mar*

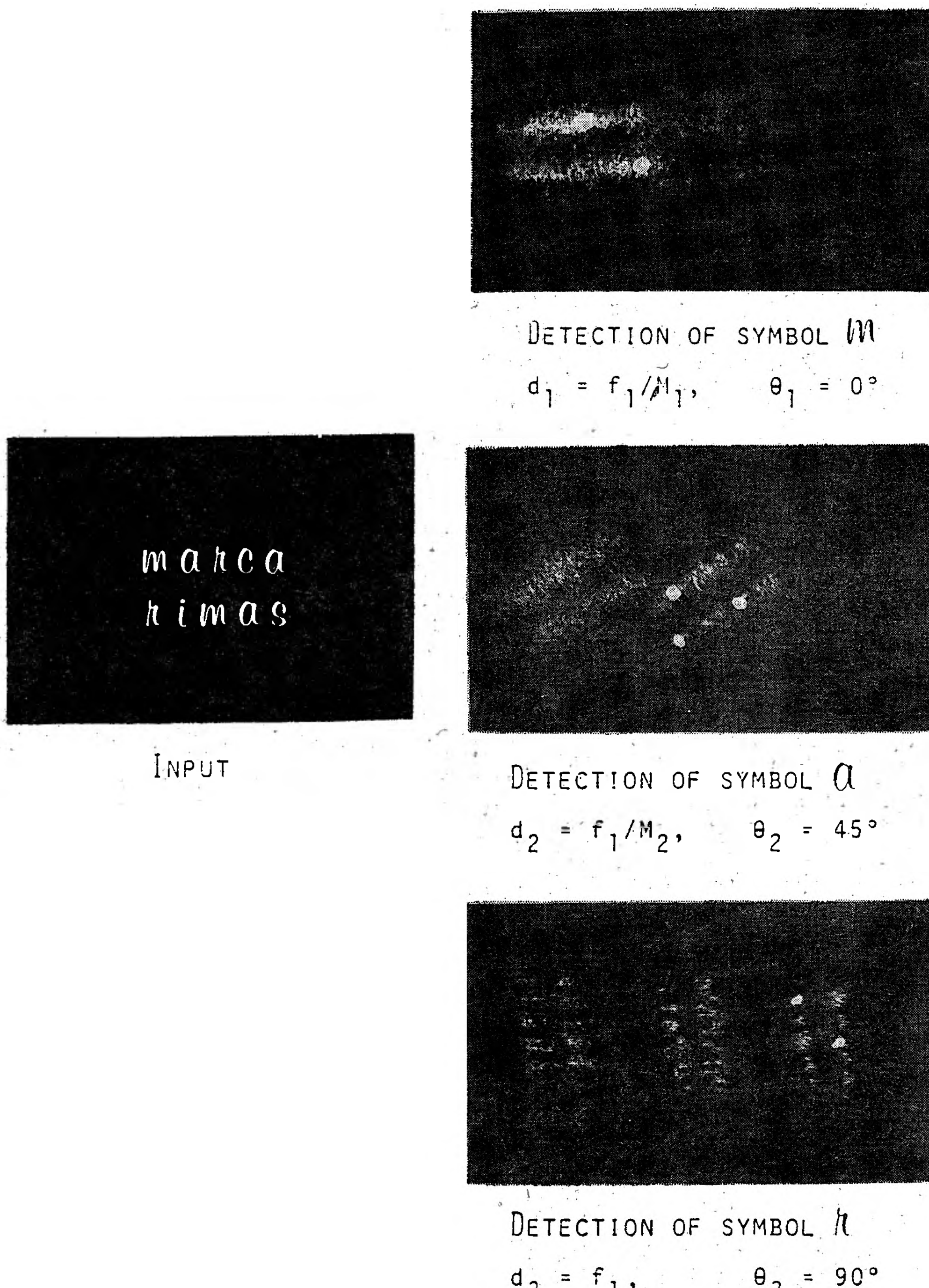


Fig. 5. Successive detection of characters *m*, *a*, *r* in a more complicated input

We take as size origin the height of the smallest character and we indicate by M_i the ratio of the height of each character to that of the smallest one.

The detection is achieved only when the input is rotated by the adequate angle θ_i (the same as that when the filter was recorded) and is moved to a distance $d_i = f_1/M_i$ of the back focal plane of the transforming lens (focal length f_1). When these conditions are not satisfied, an autocorrelation term cannot be obtained due to different rotation and size of the characters in the filter.

The output plane is different for each character, is located at a distance q_i' of the imaging lens L_2, and given by Eq. (13). The brightness of the autocorrelation point depends on the character and is proportional to M_i^2.

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