PHASE INPUT JOINT TRANSFORM CORRELATORS ROBUSTNESS TO ADDITIVE NOISE*

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Face recognition implies that the scene images are mixed with additive noise. The modified (MPJTC) and preprocessed modified phase input joint transform correlator, (preMPJTC), have better detection efficiency and their setup parameters are: the amplitude premodulation domain, *dfPRE*, and the phase modulation domain, *dfPSLM*. Computer simulations were done to find out the combination of the amplitude premodulation domain and phase modulation domain that has the best detection efficiency for all image resolution and noises.

Key words: pattern recognition optics (42.30.Sy), imaging and optical processing (42.30.-d), optical correlators (42.79.Hp).

1. INTRODUCTION

This work refers to two hybrid models: modified phase input joint transform correlator (MPJTC) and preprocessed modified phase input joint transform correlator (preMPJTC). These correlators have the best detection efficiency in optical pattern recognition.

The classical joint transform correlators [1–7] have a poor efficiency when the target is mix with additive noise and the pattern discriminability is limited by the phase – modulated spatial light modulators (PSLM's) constrains. To alleviate these problems hybrid correlators were created, which implies that at a certain moment computer processing is used. The author suggests some original modifications to (MPJTC) in the second correlator model [8–12] in order to improve the light efficiency and pattern recognition in presence of additive noise.

1.1. COMBINED AMPLITUDE FILTERING AND PHASE TRANSFORMATION

This method assumes that the intensity image $IntensityOB(x, y)$ is somehow transformed from intensity gray levels (usually from 0 to 255) in phase

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levels (usually $dfPSLM \equiv \pi - 0$ and $dfPSLM \equiv 2\pi - 0$), using a transformation function $Tf[\cdot]$. Thus one obtains a phase image $PhaseOB(x,y)$ [1, 3] that mathematically is described by:

$$PhaseOB(x,y) = \exp\left[i \cdot Tf\left[IntensityOB(x,y)\right]\right] = \\ = \exp\left[i \cdot \left(\frac{IntensityOB(x,y) - Min}{Max - Min}\right) \cdot dfPSLM\right], \quad (1)$$

where *dfPSLM* is the phase depth, *Max*, *Min*, are the maximum and the minimum values of the intensity object. After the phase transformation of reference, scene and joint images are optically Fourier transformed to obtain the reference $RPS(u,v)$, scene $SPS(u,v)$ and joint $JPS(u,v)$ power spectrum.

One of the correlators' major problems is that after the correlation process is performed a very high term occurs in the output plane, the dc term. The dc term has to be removed in order to enable the examination of the correlation useful peaks. There are some ways to remove the dc term; one of these is done in the first Fourier plane, where the three power spectrum is obtained by [2–4]

$$JmPS(u,v) = JPS(u,v) - SPS(u,v) - RPS(u,v) \quad (2)$$

where $JmPS(u,v)$ is the modified joint power spectrum.

Furthermore, to improve the pattern discriminability of the correlation process, the cross-correlation peaks must be reduced and the autocorrelation peaks increased. This operation can be done by applying an intensity-modulated filter $Flt(u,v)$ to the modified joint power spectrum [2]. The filter is defined by

$$Flt(u,v) = \begin{cases} \dfrac{1}{\left|REF(u,v)\right|}, & \left|REF(u,v)\right| > \varepsilon \\ \dfrac{1}{\left|REF(u,v)\right| + Z(u,v)}, & \left|REF(u,v)\right| \le \varepsilon \end{cases}, \quad (3)$$

where ε is the lowest real positive value that computer recognizes, and $Z(u,v)$ is a real non-zero function. In the first Fourier plane the two-dimensional function is

$$H(u,v) = Flt(u,v) \cdot JmPS(u,v). \quad (4)$$

Finally, in order to obtain the correlation peaks it will be optically Fourier transformed. The modified phase input joint transform correlator (MPJTC) is the correlator that provides this kind of correlation process, equations (1) to (4).

1.2. MODIFIED FRINGE AND INPUT PHASE TRANSFORMATION

The phase input joint transform correlator is reported to be noise sensitive. The combined joint transform correlator alleviates this problem, but in certain conditions a better pattern discriminability and better light diffraction efficiency is needed. The light diffraction efficiency will be improved if the dc term (which is the zero order diffraction term) of the power spectrum drops and the high spatial frequencies increase. The high spatial frequencies are connected to the object details in spatial coordinates. If the three power spectra have a thin dc term and large high spatial frequencies, the correlation process, which "compares" the reference object with the scene objects, will provide a better pattern discrimination because the objects will be "compared" more in their details. To achieve this goal the author suggests an alternate correlator, which consists in applying a function before the first Fourier transform is performed, that stretches the dc term and enlarges the high spatial frequencies [8–12]

$$PhaseOB(x,y) = \exp\left[i \cdot \sin\left[Tf\left[IntensityOB(x,y)\right]\right]\right] =$$
$$= \exp\left[i \cdot \left[\sin\left(\frac{IntensityOB(x,y) - Min}{Max - Min} \cdot dfPRE + fPRE_1\right) \cdot dfPSLM\right]\right]. \qquad (5)$$

where $dfPRE = fPRE_2 - fPRE_1$ is the amplitude premodulation domain.

After this modified phase-only transformation of the input images, the previous algorithm can be performed. The preprocessed modified phase input joint transform correlator (preMPJTC) is the correlator that provides this kind of correlation process, equations (2) to (4), and equation (5) instead of equation (1).

2. COMPUTER SIMULATIONS

Real world face recognition has to deal with the presence of additive noise in the scene images. In this paper there are studied three kinds of additive noise: gaussian, random and uniform. Also there are introspected two kind of image resolution: low resolution images, that means 256 × 256 pixels joint input images, and high resolution images, that means 512 × 512 pixels images.

A high accuracy face recognition conclusion implies statistical approved results and thus building a face database. The face database consists in about eleven faces of males between 20 and 30 years old. Face images were captured with a Philips PCVC 540 CCD camera, cropped at 100 × 122 pixels in 256 grey levels and indexed like in Fig. 1.

Face with index F0 represents the reference image. This image was cropped in such matter that the result has only the face in it (Fig. 2 upper half). This constrain was introduced in order to obtain a better pattern recognition of human faces.

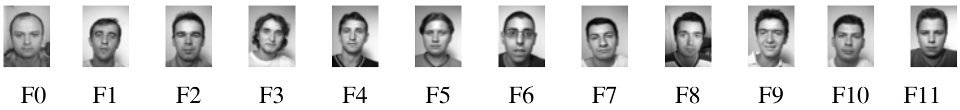

Fig. 1 – Human faces images used for pattern recognition process.

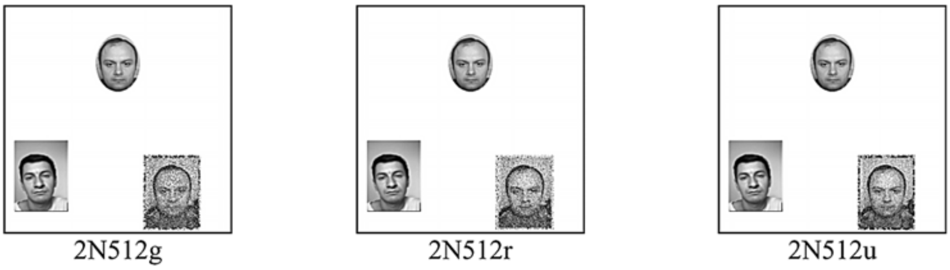

Fig. 2 – Joint input images with three kinds of additive noise: g – gaussian, r – random, u –uniform.

In the scene image (Fig. 2 lower half) are present two face images: a non-reference image (left one) and a reference type image (right one). This is the reason the images are coded with prefix "2N". The next part of the code represents the image resolution and the last part of the code represents the additive noise type: g for gaussian, r for random and u for uniform noise. The reference images from scene image have 50% level of each additive noise type. The joint input image built like this can perform parallel pattern recognition of these two images from the scene image. Thus was generated a set of eleven joint input images for each kind of additive noise and one set of joint input images without additive noise.

Preprocessed modified phase input joint transform correlator has two freedom degrees: premodulation domain, *dfPRE*, and phase domain, *dfPSLM*. In

Table 1

Phase modulation domain classes, *dfPLSM*, and amplitude premodulation domain classes, *dfPRE*, for the preprocessed phase joint transform correlator (preMPJTC)

	dfPSLM		*dfPRE*
1	$[0; \pi/2]$	1	$[-\pi/4; \pi/4]$
2	$[0; \pi]$	2	$[-\pi/2; \pi/2]$
3	$[0; 1.2\pi]$	3	$[-3\pi/4; 3\pi/4]$
4	$[0; 1.4\pi]$	4	$[-\pi; \pi]$
5	$[0; 1.6\pi]$	5	$[0; \pi/2]$
6	$[0; 2\pi]$	6	$[0; \pi]$
		7	$[0; 3\pi/2]$
		8	$[0; 2\pi]$

the computer simulation there was considered combinations of six *dfPSLM* domains with eight *dfPRE* domains, from Table 1, for each one of the freedom degrees.

3. RESULTS AND DISCUSSION

By introducing some coefficients any correlation process (*i.e.* pattern recognition process) can be qualitatively classified. This coefficients are the autocorrelation peak intensity, *API*, highest cross-correlation peak intensity, *CPI*, and the signal to clutter ratio [5, 9–12]

$$SCR = \frac{API}{CPI}\,. \tag{10}$$

When the detection efficiency coefficient, *SCR*, is greater, a better pattern discriminability is achieved and the correlation process is more successful. Pattern recognition fails when the signal to clutter ratio is below the threshold $SCR_{threshold} = 1.200$. Assume that the pattern recognition is done for a set of n joint input images with different scene images, but with a reference image inside. Then several of $\{SCR_i\}_{i=\overline{1,n}}$ are performed. The overall detection efficiency (*i.e.* pattern recognition) coefficient will be the smallest SCR from the $\{SCR_i\}_{i=\overline{1,n}}$, denoted $SCR_{\min}$, because this is the best performance that the correlator can do.

Detection efficiency coefficient, $SCR_{\min}$, drops 46.08% for (MPJTC) and 48.93% for (preMPJTC) by introducing the additive noise in low resolution images (Table 2). Detection efficiency coefficient drops 67.23% for (MPJTC) and 82.71% for (preMPJTC) by introducing the additive noise in high resolution images (Table 2). This reveals that the (preMPJTC) is more sensitive to additive noise than (MPJTC).

In absolute value of detection efficiency coefficient, $SCR_{\min}$, the (preMPJTC) is still better than (MPJTC) (Table 2 and Fig. 3), because there is a detection efficiency gap between the best results from the smallest $SCR_{\min} = 11.0403$ for (preMPJTC) to the highest $SCR_{\min} = 8.0324$ for (MPJTC). This means that the

Table 2

Best results for face recognition at low and high resolution images with (MPJTC) and (preMPJTC)

SCRminim	2N256	2N256g	2N256r	2N256u	2N512	2N512g	2N512r	2N512u
dfPSLM	[0; 2π]	[0; 2π]	[0; 2π]	[0; 2π]	[0; 2π]	[0; 2π]	[0; 2π]	[0; 2π]
MPJTC	*4.0745*	*5.4328*	*6.5060*	*7.5570*	*17.2697*	*6.7971*	*5.6587*	*8.0324*
dfPRE	[0; 2π]	[0; 2π]	[0; 2π]	[0; 2π]	[0; 2π]	[0; 2π]	[–3π/4; 3π/4]	[–3π/4; 3π/4]
dfPSLM	[0; 1.2π]	[0; 1.2π]	[0; π]	[0; 1.2π]	[0; 1.6π]	[0; π]	[0; 2π]	[0; π]
preMPJTC	*21.6183*	*11.0403*	*12.2341*	*14.8470*	*69.2053*	*11.9630*	*21.5558*	*13.2527*

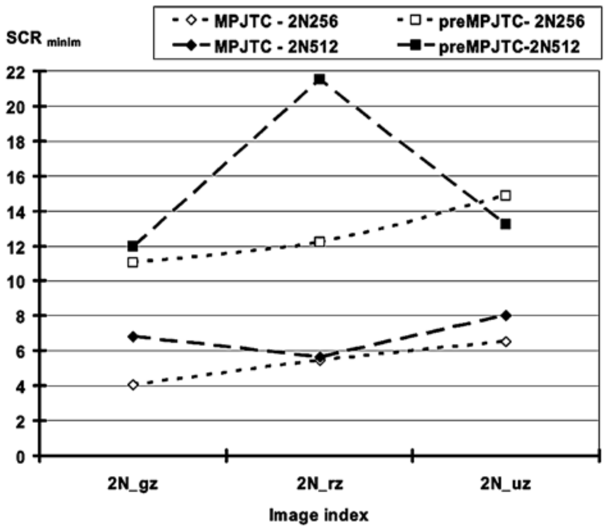

Fig. 3 – Comparison of best results for face recognition at low and high resolution images with (MPJTC) and (preMPJTC).

(preMPJTC) has better pattern discriminability than (MPJTC) related to all three kinds of additive noise.

Another notice that can be drawn from Fig. 3 is that in terms of detection efficiency, there is no big difference between working with low or high image resolution for both phase input joint transform correlators.

4. CONCLUSIONS

In this paper there was investigated the face recognition performances of two modified phase input joint transform correlators in presence of three kinds of additive noise. It was compared the face recognition detection efficiency for all freedom degrees: eight premodulation domains and six phase domains, with a set of eleven joint input images for each additive noise. The results for face recognition give better additive noise robustness for preprocessed modified phase input joint transform correlator (preMPJTC) than the modified phase input joint transform correlator (MPJTC). Another conclusion that can be drawn is that it can be used low resolution images without loosing in detection efficiency. Thus the original correlator model, (preMPJTC), can be used in applications that imply face recognition at low image resolution at high speed.

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