Object recognition using coupled filters

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Abstract. There are many advantages using artificial vision systems to implement quality control systems, in particular those processes where it is impossible to use other methods. However, efficient real-time vision algorithms depend on appropriate relationship between speed and computation cost. Coupled filters applications have produced remarkable results due to its efficiency for real-time object recognition. In this work, one pattern recognition application using coupled filters is implemented. Some results during an industrial-nutritious process assembling are presented.

1 Introduction

Some industries have been looking for to automate their processes to improve quality products. There are different alternatives: using pattern recognition [1], [2], [3], [4], to calculate sausage quality according to their scab, using a vision system and fuzzy logic techniques for extraction sausages' characteristics [5], [6], wood quality analysis based on information on color and texture [7], and wood inspection based on color and texture without supervised grouping [8], [9]. Originally these processes could only be assured by human beings due to the heuristic nature of the quality evaluation procedure.

This work presents the application of algorithms for pattern recognition, using coupled filters; its intended purpose is to identifying a toothpick's assembling quality in chocolate pops.

This work is organized as follows: section 2 presents a brief description of coupling filters theory. Section 3 describes implementation while section 4 shows results obtained. Section 5 discusses some conclusions and comparisons.

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2 Coupling filters

An important problem within the image analysis field is the detection of changes or presence of an object in a given scene. Such problems normally appear in remote sensors when monitoring patrons of growth in urban areas, climate prediction starting with images from a satellite, diagnosis of illnesses starting from medical images, detection of objects starting from radar images, and automation using vision robotics and such. Variation detection is also useful in alignment or space registration of two image scenes of different instants or using different sensors.
Presence of a well-known object in a scene can be detected looking for coupling localization among object's reference image *h(m,n)* and test pop *f(m,n)*. Reference image coupling can be conducted by looking for *h(m,n)* displacement where coupling energy is minimum. A displacement *(p,q)*, is defined as coupling energy.

$$\sigma_{\eta}^{2}(p,q) \triangleq \sum_{m}\sum_{n}\left[f(m,n)-h(m-p,n-q)\right]^{2}$$
$$=\sum_{m}\sum_{n}\left|f(m,n)^{2}\right|-2\sum_{m}\sum_{n}f(m,n)h(m-p,n-q)+\sum_{m}\sum_{n}\left|h(m,n)^{2}\right| \quad (1)$$

In order to make $\sigma_{\eta}^{2}(p,q)$ able to reach a minimum, it is enough to maximize cross-correlation

$$\text{Max}\, c_{fh}(p,q) \triangleq \sum_{m}\sum_{n} f(m,n)h(m-p,n-q) \quad \forall(p,q) \quad (2)$$

From Cauchy-Schwarz inequality, we obtain

$$\left|c_{fh}\right| = \left|\sum_{m}\sum_{n} f(m,n)h(m-p,n-q)\right| \leq \left[\sum_{m}\sum_{n}\left|f(m,n)\right|^{2}\right]^{1/2}\left[\sum_{m}\sum_{n}\left|h(m,n)\right|^{2}\right]^{1/2} \quad (3)$$

Where equality happens if and only if $f(m,n) = \delta h(m-p, n-q)$; δ is an arbitrary constant and it can be similar to 1. This means that cross-correlation $c_{fh}(p,q)$ achieves the maximum value when displaced position of reference image matches to the observed image. It is calculated as:

$$\max c_{fh}(p,q) = \sum_{m}\sum_{n}\left|f(m,n)\right|^{2} > 0 \quad (4)$$

Thus, a given object *h(m,n)* is able to search within the scene by searching cross-correlation function peaks (see Fig. 1).

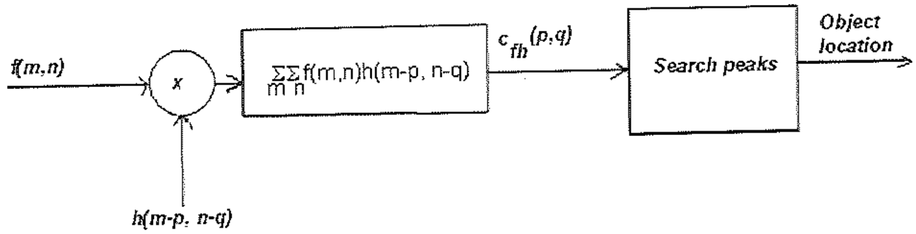

Fig. 1. Image reference coupling using area correlation.

Cross-correlation $c_{fh}(p,q)$, it is also called *area correlation*. It can either be evaluated directly or using the Fourier inverse transform of Equation 5.

$$C_{fh}(\omega_1,\omega_2) \underline{\underline{\Delta}} \Im\{c_{fh}(p,q)\} = F(\omega_1,\omega_2)H^{*}(\omega_1,\omega_2) \tag{5}$$

The problem of coupling filters turns out finding a linear filter *g(m,n)* which maximizes signal to noise relationship of output (SNR)

$$SNR \underline{\underline{\Delta}} \frac{|s(0,0)|^2}{\sum_m \sum_n E\left[|g(m,n)\Theta\eta(m,n)|^2\right]} \tag{6}$$

Where, it is defined such that

$$s(m,n) \underline{\underline{\Delta}} g(m,n)\Theta h(m-m_0, n-n_0) \tag{7}$$

being Θ the cross- correlation operation. Here *s(m,n)* represents the signal content at the output, filtering *g(m,n)*Θ*f(m,n)*. The result using the coupled frequency filter is:

$$G(\omega_1,\omega_2) = \frac{H^{*}(\omega_1,\omega_2)}{S_\eta(\omega_1,\omega_2)} e^{(-j\omega_1 m_0 + \omega_2 n_0)} \tag{8}$$

While such a result might be an impulse signal.

$$g(m,n) = r_\eta^-(m,n)\Theta h(-m-m_0,-n-n_0) \quad (9)$$

Considering that

$$r_\eta^-(m,n)\underline{\Delta}\mathfrak{I}^{-1}\left[\frac{1}{S_\eta(\omega_1,\omega_2)}\right] \quad (10)$$

Due to all above-mentioned output of coupled filter can be written as

$$g(m,n)\Theta f(m,n) = h(-m-m_0,-n-n_0)\Theta f(m,n) \quad (11)$$
$$= \sum_i \sum_j f(i,j) h(i-m-m_0, j-n-n_0)$$

Where *cfh(m + m0, n + n0)* is area correlation of *f(m,n)* with *h(m + m0, n + n0)*. If *(m0,n0)* were known, then SNR would be maximized in *(m,n)=(0,0)*, as it would be expected in equation 11. In practice these displacement values are known. Therefore, we calculate correlation *cfh(m,n)* and we look for localization of maximum that gives *(m0,n0)*. Consequently, *coupled filter can be implemented as an area correlator with a pre-processing filter* that can be, in some cases, a high pass filter. Highly correlated random fields, usual monochrome images $r_\eta^-(m,n)$ represent a high pass filter.

3 Implementation

Methodology to use consists basically of a pre-processing stage followed by an application stage of cross-correlation. Preprocessing stage consists of two steps: first vision system that needs to identify toothpick position inside optic system view field. Second step vision system is to identify sub image that represents to toothpick and separate it of marshmallow bar. This operation is carried out with segmentation of original image in gray levels, applying a threshold T to image. According with human inspectors, quality pops depends on factors that include errors in toothpick position and rotation. Consequently, these characterization parameters have to be evaluated to determine quality pop norms. In correlation plane, toothpick localization input scene is achieved finding maximum to plane and its respective coordinates [x_max, y_max] that determine maximum correlation respect to center. These coordinates define first two characterization parameters. Valor_max of correlation diminishes when input patterns strays of reference. Therefore, the third characterization parameter is maximum correlation magnitude defined as valor_max. This parameter is used to determine relative toothpick lateral and angular position.

Coupled space filter simulates the correlation against a holographic filter. For example let us take case of chocolate pop. At Fig. 2(a) is shown the pop that will be the reference image, and 2(b) show test pop with toothpick rotated 5 degrees.

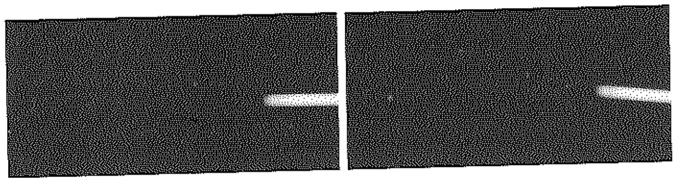

Fig. 2 (a) Reference object. (b) Test pop with toothpick rotated 5 degrees.

We want to find toothpick position to determine if test pop, shown in Fig. 2(b), passes quality control by means of parameters defined in this work: coordinates of maximum position, their value and correlation factor.

We make a space coupled filter for test pop applying the bidimensional discreet Fourier's transformation, changing previously component of frequency zero to spectrum center with Fast Fourier Transform (FFT), and later we return to original domain with the inverse FFT. Then we simulate optic correlator applying to the corresponding algorithm, which consists on changing the component of frequency zero to spectrum center with Fast Fourier Transform (FFT), and then we apply the bidimensional discreet Fourier Transform, at once we return it to its original domain with the inverse FFT. Lastly, we obtain square magnitude multiplying optical correlation with its conjugated complex (using a detector of square law) where we can observe that correlation maximum is a little wide. See Fig. 3.

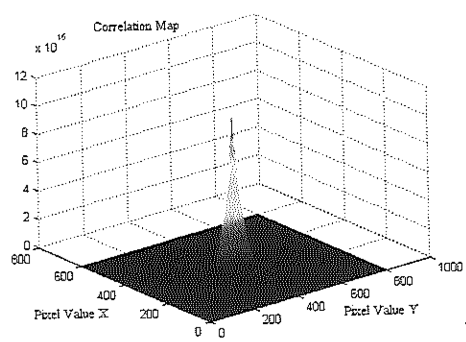

Fig. 3. Maximum correlation.

If coupled filters algorithm is now considered, according to the following block diagram in Fig. 4a, it can be noticed that Coupled Space Filter consists of an object conjugated complex version of the Fourier Transform multiplied by a proportional factor, giving us as a result correlation parameters pick which will provide us the correct letter E identification (See Fig. 4b). Parameters used for identification were coordinated x and y of the pick to identify letter E case. In this case the following values were obtained: x_peak=177 y y_peak = 190.

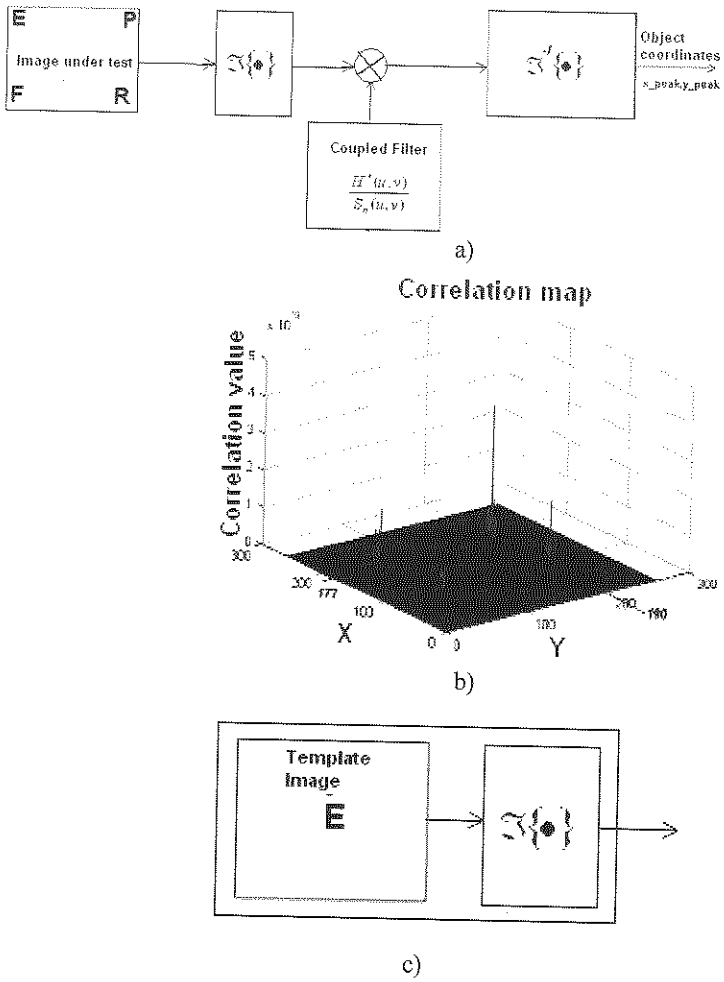

Fig. 4 Coupled Filter Algorithm for the correct letter E identification case a) block diagram b) correlation map c) template image.

4 Results

In this section, algorithms results are described used in this work. We begin with results obtained using crossed correlation algorithm where we consider three cases that are presented in production of chocolate pops and that they consist on the position, in rotation and in overlapping of pop's toothpick. At once we show results obtained applying coupled filters algorithm to pop's toothpick cases of position and rotation. Finally we show results obtained when applying adjournment and rotation algorithms, also applied to toothpick cases of position and rotation. For last two mentioned algorithms, toothpick case overlapped was not considered because any pop with the toothpick overlapped passes required quality control by the candy company. The results obtained when applying coupled filters to groups A and B are shown in Figs. 5 and 6. Table 4.1 contains these results. The values in boldface in second column of Table 4.1 indicate that those pops didn't pass the quality control, that is to say, they are rejected for smaller abscissa values of 244, corresponding with threshold settled down by the candy company.

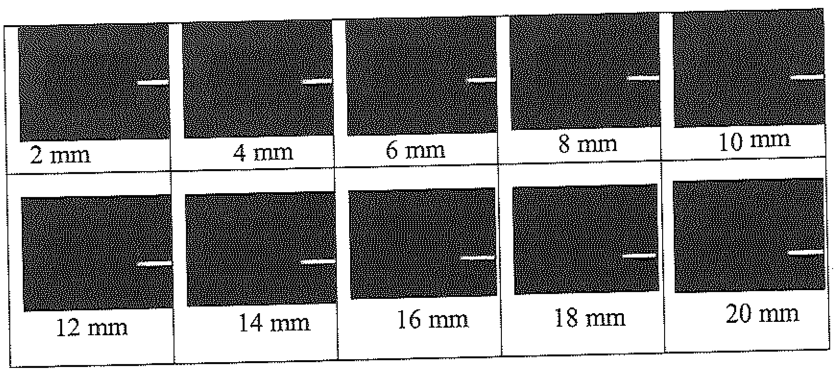

Fig. 5. Group A chocolate pops where from position of 2mm at 10mm of central position are pops with the toothpick with acceptable quality, and of 12mm at 20mm of the central position present an unacceptable quality.

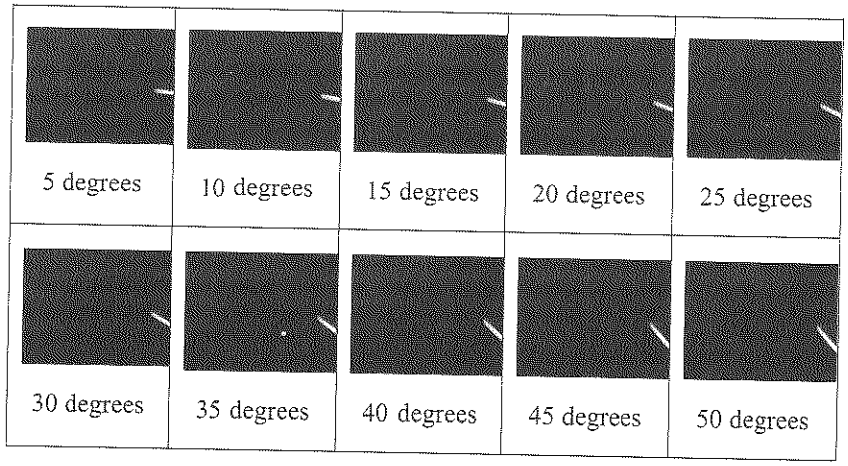

Fig. 6. Group B of chocolate pops where orientation of 5 to 45 degrees of central position are toothpick pops with acceptable quality, and more than 45 degrees, one with toothpick to 50 degrees of central position orientation presents an unacceptable quality.

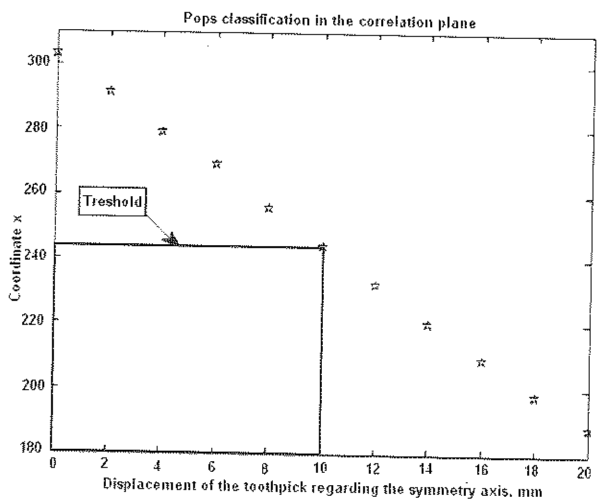

Fig. 7 Rate among displacement Δx and maximum abscissa.

In Fig. 7 is shown coordinate x in function to toothpick distance regarding their wanted position. These results correspond to variations in position of each 2 mm to observe their behavior.

Table 4.1. Represents parameters obtained for certain displacement Δx regarding toothpick of central position.

Δx Mm	Maximum Coordinates *x_max*, *y_max*	Maximum value *valor_max*	FC
0	303, 403	1.0636e+016	7.5545e+018
2	291, 425	1.0435e+016	1.7539e+019
4	279, 452	9.5644e+015	1.3052e+019
6	269, 435	9.1866e+015	1.2740e+019
8	256, 434	8.6584e+015	1.2062e+019
10	244, 434	9.1991e+015	1.2806e+019
12	**232**, 436	8.6343e+015	1.1302e+019
14	**220**, 449	7.8206e+015	1.1162e+019
16	**209**, 439	7.1238e+015	1.0180e+019
18	**198**, 450	7.6832e+015	1.0214e+019
20	**188**, 462	7.5357e+015	9.7052e+018

The statistical procedure of the results is now presented: The most important thing for this work is the statistical R^2, the determination coefficient, which represents the quality pattern and it indicates what so well the movement of the toothpick is explained by the pattern.

Table 4.2 Characterization of coupled filters algorithm by means of regression analysis using Statgraphics software.

Method	Data Set	P-Value for Pattern parameters	Determination Coefficient R^2
Coupled Filters	A	C: 0.0000 X: 0.0000 Y: 0.7660	99.9505 %
Coupled Filters	B	C:0.0012 X: 0.0000 Y: 0.1633	99.9505 %

As it is appreciated, in both cases the coefficient R2 is bigger than 90%, what is considered a model of good quality.

5 Conclusions

The proposed system has been able to discriminate between objects that can be accepted, or those that present good assembling quality, and those that should be rejected by not fulfilling quality requirements. That is how it has been able to determine the thresholds that mark difference between the quality and the non quality products. These values have been expressed in pixels and they have been established in the following way:

For coupled filter, the acceptance threshold of displaced toothpicks is 244 pixels in abscissas axis (this is equal to the 10 mm settled down by the candy company), the acceptance threshold regarding toothpicks orientation is given by an ordinate of 425 pixels and 219 pixels for the abscissa (these values represent the limit settled down by candy company and they correspond to a maximum rotation of 45 degrees).

Coupled filters are best fitted for this usage, values obtained with traslation and rotation filters provided the following results [10]: displacement limit was established at 196 pixels, corresponding to a 10 mm maximum boundary set by the candy company. Rotation limit is 35 pixels, which represents maximum rotation admitted (equal to 45 degrees), for angle measures over 45 degrees, rotation filters don´t discriminate on a wide range basis.

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