Novel BiasFeed Cellular Neural Network Model for Glass Defect Inspection

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***Abstract*—In this study, an effective segmentation method is presented for defect detection on the glass surface. Defect detection on the glass surface is compelling and strenuous job for human eyes. Transparency and reflection properties of the glass surface reduce success of image processing algorithms using detection of the factors that unwanted and affecting quality of products such as crack, scratch, bubble. Traditional methods have limited success and long processing time in this process. Therefore, fast and effective method has been proposed. In the proposed method (BiasFeed CNN), bias input which is single number value traditional CNN algorithm is converted bias template. Bias template is used to balance the brightness level of the image. Input image and bias template convolution is applied bias input. Through the contribution from bias input, background reflections and negative effects arising from transparency are decreased. The developed method is fast as traditional CNN, because it does not cause significant changes in the structure of traditional CNN. 35 pieces of glass was tested using the algorithm. Damages in the glass surface and location of these damages were determined. Accuracy rates of inspected images are; sensivity %91, specificity %99, accuracy %98. BiasFeed CNN algorithm was tested on various images and it is more successful than traditional CNN algorithm.**

Keywords—cellular neural network; biasfeed; glass defect detection; texture inspection; cnn

I. Introduction

Nowadays, use of the glass continuously increase, thus glass industry is growing very fast. To supply demand for glass which uses in so many areas (kitchen, mobile phones, mirrors, bathroom, television screens etc.) faster manufacturing requirement has emerged. Production speed is increased use of computerized mechanic systems. However, product quality has decreased. This problem occurs because of the quality-control procedures performed by the human eye. Human eye cannot keep up with speed of machine systems and it cannot catch some defects [1]. For this reason, an idea of using machine vision systems that faster and more effective than human eye is developed. These systems work fast, fault tolerances remain fixed values, tireless and it can measure in challenging situations. Thanks to the advantages, these systems can be used many areas such as manufacturing [2-4], medical [5,6], cultivation [7], security systems [8]. Especially dangerous areas that are difficult to work for man and reflected areas, machine vision systems are widely preferred. Glass surface is one of these areas. Reflection and transparency feature of glass makes it difficult to examine.

When inspecting glass surface to find defects by cameras, glass background is misleading for cameras. So, cameras do not focus glass surface. Various lighting systems have been proposed in the literature in order to overcome this situation. Background lighting [9], parallel lighting [10], infrared lighting [11] systems some of these are. Another common encountered problem is that camera see his own reflection on surface and other objects in environment. This problem can be partially solved by several preprocessing algorithm.

Markow random field [12], wavelet transform [13], edge detection algorithms [14], threshold [15], neural network [16] methods are commonly used for glass defect detection. These methods are used for locating and determining the shape of damages in the glass. But, the implementation of the mentioned algorithms in real time systems is difficult. In order to quickly and accurately measuring, used image processing algorithm is not affected by environmental conditions and it can be applied real-time systems. Bias template that used in proposed BiasFeed CNN method is minimize environmental condition effects. Also, because of traditional CNN structure is protected, this method work very fast. Proposed algorithm is applied several different images in order to success of the method.

Rest of this paper is organized as follow; Section II is mentioned about BiasFeed CNN methodology, Section III is presented experiment and experimental results, Section IV contains conclusion.

II. Methodology

A. Problem Definition

Inspection of reflective surfaces have always been challenging for cameras. This situation creates specific difficulties in identifying the location of camera. If camera is placed vertically on the glass, it detect own reflection as a defect. If camera is placed left or right side on the glass, calculation of actual size of defects on glass are difficult. So, selection of camera location is important.

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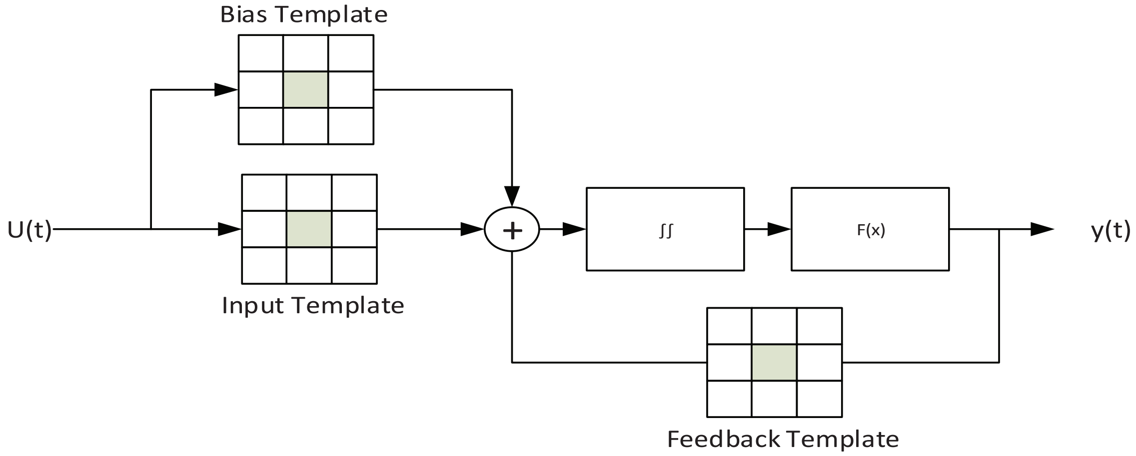
Fig. 1. BiasFeed Cellular Neural Network Model



Glass illumination is other important problem. If the lighting is high, glare will occur. If lighting is low, defects are not detect. Even though lighting source is adequate, usually consist of illumination fluctuation on glass surface. Illumination fluctuations resulting from illumination system should be corrected using illumination correction algorithm. But, illumination correction algorithms are not very effective. Other problems are as follow; many defect detection algorithm speed is not adequate and is not applied real-time systems, many algorithm cannot catch tiny defects. BiasFeed CNN algorithm is designed to remedy all these deficiencies.

B. BiasFeed CNN Method

Cellular neural networks has been found in 1988 by Leon O. Chua and Ling Yang [17]. CNN structure is configured similarly to the human nervous system. In CNN structure, all cells in the network are linked each other according to neighborhood value. Therefore, it can operate very fast. Due to similarity cells in CNN and pixels in image, CNN is widely used image processing applications. Relationship of each cell is determined by neighbored value. *r* radius effect of *C(i,j)* cell is calculated as Equation 1 [18].

$$S_r(i,j) = \left\{ C(k,l) \,|\, \max_{1 \le k \le M, 1 \le l \le N} \left\{ |k-i|, |l-j| \right\} \le r \right\} \tag{1}$$

In the Equation 1, r indicates Radius of the neighborhood. State equation of traditional CNN cell is seen Equation 2 [18].

$$\frac{dx_{ij}}{dt} = -x_{ij} + \sum_{C(k,l) \in S_r(i,j)} A(i,j;k,l) y_{kl} + \sum_{C(k,l) \in S_r(i,j)} B(i,j;k,l) u_{kl} + z_{ij} \tag{2}$$

In Equation 2, x_{ij} represents state of cell, y_{ij} represents output, u_{ij} represents input cell, z_{ij} represents bias value, A(i,j;k,l) represent feedback template, B(i,j;k,l) represents input template. CNN output equation is given Equation 3.

$$y_{ij} = f\left(x_{ij}\right) = \frac{1}{2}\left|x_{ij}+1\right| - \frac{1}{2}\left|x_{ij}-1\right| \tag{3}$$

Feedback template and input template on CNN structure are greatly influence results. Updating or changing values of these templates can be performed basic image processing operations such as edge detection, noise removal, corner detection, line detection etc. Template values are different for each application. So, optimization algorithms used to find the optimum template values. Some optimization algorithms are used to update the CNN templates in the literature are; template optimization with PSO [19], template optimization with genetic algorithm [20], template optimization using differential evolution algorithm [21]. Mentioned optimization algorithms usually focused on input template and feedback template updating. Also, the bias is always considered as a single numerical value. Since bias input was used as a positive or negative number, contribution from bias input to output has been limited. İmage luminance can be changed using bias input. Therefore, it can be used noisy images that taken from real world. But, adding same bias value each pixel on image does not fix luminance fluctuations. For this, bias template is created. Bias template take differently effect in each pixel of input image based on neighborhood (*r*) value and luminance fluctuation can be fixed. BiasFeed CNN structure is shown is Figure 1. Only difference from traditional CNN structure is bias template. Convolution of bias template and input image is applied bias input. So, contribution of bias input change depending on luminance difference in image. Thus, noise and luminance fluctuations in image be minimum. New bias value calculation is shown in Equation 4.

$$I_{ij} = C\left(i,j;k,l\right) u_{ij} \tag{4}$$

C(i,j;k,l) template is bias template that update luminance of image. New state equation is shown Equation 5.

$$\frac{dx_{ij}}{dt} = -x_{ij} + \sum_{C(k,l)\in S_r(i,j)} A(i,j;k,l)y_{kl} + \sum_{C(k,l)\in S_r(i,j)} B(i,j;k,l)u_{kl} + I_{ij} \quad (5)$$

III. Experiment and Experimental Results

35 pieces glass which have various product defects are inspected and 6 pieces of these glass are not damaged. Thickness of these glass varies 3mm and 5mm. Used glass are flat and size 35x40cm. Camera features are; 2 MP and 30 fps. The camera is placed vertically above of glass an angle of 90 degrees. Prototype used in the glass surface analysis should be illuminated by controlled illumination systems. If external light enters prototype, the uncontrolled light can unstable illuminate glass background. In this case, measurement results will fail. In order to achieve successful results; background material of glass must be selected simple and single color. Also, external light entry must be prevented. Based on these information, a prototype was created. Prototype size is 50x70cm. Prototype partially isolated from external light using a cover. Parallel lighting system is used in the prototype. Distance between glass and camera other important issue for prototype. The camera moves closer to the glass, area to be analyzed becomes smaller. If the camera is placed too far, the detection of minor damage will be difficult.

The experiment is implemented in MATLAB on a computer with an Intel Core i5-5200u CPU (2.2 GHz) and 4 GB RAM. Average runtime of each test is 1 s. In addition, the algorithm has been tested on two different images and results is shown Figure 3.

A. BiasFeed CNN Method and Updating Templates

Almost all algorithm same traditional CNN except for bias input in the developed BiasFeed CNN algorithm. Bias input which is single number value traditional CNN algorithm is converted bias template and convolution with input image. Created the new bias input is offset luminance fluctuations of input image. This illumination stabilization is used to overcome numerous problems in image such as reflection of camera, background problems, gray level corruption, noise etc. These problems has negative impact on work of traditional segmentation algorithms. Bias template values is designed to suppress regions whose density is high. For this, lighting noise often must come from a similar direction. Same prototype is used in the experiments, and so similar illumination problems occur.

The input template, the feedback template and the bias template are updated using particle swarm optimization algorithm [22] that is commonly used optimization problems. To reduce the processing load when calculating the values of a templates, some template values must be chosen equal to each other. This situation does not make important difference on the results. So, matrix values is selected as; $a_{11}= a_{12}= a_{13} = a_{21}= a_{23}= a_{31}= a_{32}= a_{33}= a_0$, $a_{22}=a$, $b_{11}= b_{12}= b_{13}= b_{21}= b_{23}= b_{31}= b_{32}= b_{33}= b_0$, $b_{22}=b$, $c_{11}= c_{21}= c_{31}= c_1$, $c_{12}= c_{22}= c_{32}= c_2$, $c_{13}= c_{23}= c_{33}= c_3$.

$$A = \begin{Bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{Bmatrix}, B = \begin{Bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{Bmatrix}, C = \begin{Bmatrix} c_{11} & c_{12} & c_{13} \\ c_{21} & c_{22} & c_{23} \\ c_{31} & c_{32} & c_{33} \end{Bmatrix}$$

The used PSO algorithm steps are as follow;

- Create an initial population of random values and initial velocity values assigned at each particle.
- Objective function is calculated according to the values assigned to the particles. Objective function of CNN is state equation and output equation.
- The highest value of the objective function is assigned as *gbest*, the highest value of each cycle is assigned *pbest*. When each cycle is finished, *pbest* value and *gbest* value is compared and big value is assigned as *gbest*. So, the objective function is maximize.
- If *gbest* value is higher than desired error tolerance or cycle number is not achieved determined iteration number, the velocities of the particles are updated. The new particle velocity and the old location are added and new velocity and new location of each particle are determined. Go to step 2.
- If *gbest* value is lower than desired error tolerance or cycle number is achieved determined iteration number, the algorithm is ended.

After the optimization process, new template values are;

$$A = \begin{Bmatrix} -0.012 & -0.012 & -0.002 \\ -0.012 & 2.13 & -0.012 \\ -0.012 & -0.012 & -0.012 \end{Bmatrix}, B = \begin{Bmatrix} -1.07 & -1.07 & -1.07 \\ -1.07 & 8.42 & -1.07 \\ -1.07 & -1.07 & -1.07 \end{Bmatrix}, C = \begin{Bmatrix} 2.8 & 0.001 & -2.8 \\ 2.8 & 0.001 & -2.8 \\ 2.8 & 0.001 & -2.8 \end{Bmatrix}$$

B. Experimental Results

The obtained template values (input template, feedback template and bias template) was applied glass. Application results are shown in Figure 2. Most of defects in glass is very tiny. So, human eyes is failed to notice these defects. Firstly, traditional CNN algorithm is applied these glass. Input template of traditional CNN is *A* matrix. Feedback template of traditional CNN is *B* matrix and bias value is -0.5. Some defects could not be determined by traditional CNN and defect size is not determined. Secondly, developed BiasFeed CNN model is applied these glass. Input template and feedback template are same traditional CNN. But, bias template is *C* matrix. BiasFeed CNN algorithm has identified almost all the defects. Image drawn by an expert and the obtained images are compared and sensivity is calculated as Equation 6, specificity is calculated as Equation 7 and accuracy is calculated as Equation 8. *TP* is true positive, *FP* is false positive, *TN* is true negative and *FN* is false negative.

$$Sensivity = \frac{TP}{TP + FN} \quad (20)$$

Fig. 2. BiasFeed CNN Application. a) Defective glass images, b) Segmentation with traditional CNN, c) Segmentation with BiasFeed CNN

(a) (b) (c)

$$Specificity = \frac{TN}{TN + FP} \qquad (21)$$

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \qquad (22)$$

The obtained results is shown in Table 1.

TABLE I. COMPARISON RESULTS

Method	Parameters		
	Sensivity	*Specificity*	*Accuracy*
CNN	0.63	0.96	0.94
BiasFedd CNN	0.91	0.99	0.98

As seen from Table 1, sensitivity is very low in the experiments conducted by traditional CNN. This mean that traditional CNN is ineffective in determining thin defects. Sensivity, specificity and accuracy values of BiasFeed CNN are very high.

C. Other Implementation of BiasFeed CNN

Developed algorithm is applied in various different areas and it is quite successful in revealing defect details. It is seen Figure 3.

Fig. 3. BiasFeed CNN results in different applications, a) original images, b) CNN implementation, c) BiasFeed CNN implementation

a

b

c

IV. Results

In this study, it is explained that BiasFeed CNN which is a new CNN structure. BiasFeed CNN structure is briefly as follow; a template is added to the bias input, this template has different impact on each pixel in the image, so more useful than single number (traditional CNN). Many image processing application such as luminance correction, noise removal, edge detection, line detection can be done by updating bias template. A prototype was made and glass surface inspection that challenge for computer vision applications was made. Obtained results are quite successful, accuracy rate is 98%, specificity 99% and sensivity 91%. The method has been very fast, average runtime of each test is 1 s. Because of traditional CNN structure is protected, this method can be embedded real-time systems. Also, the method is used various images, and it is more successful in revealing the image details. It is studied about calculation general template values for using different purposes in future works.

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