A TEMPLATE MATCHING BASED ALGORITHM APPLIED TO AUTOMATIC CALIBRATION OF DIGITAL MEASURING INSTRUMENTS WITHOUT BUILT-IN COMMUNICATION INTERFACE

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ABSTRACT

A common problem found in the calibration laboratories is the reliability of the results obtained in the calibration of instruments especially when they do not have a built-in communication interface. In this case, the time consuming is increased significantly and the calibration may be subject to human error, since this task involves several manual data readings and transcriptions. In this context, many authors have proposed computer systems in order to automate calibration processes. This paper describes an algorithm using template matching with normalized cross correlation for reading the display of digital measuring instruments without built-in communication interface and storing the read ASCII value in a database used in the certification process. Experimental results showed that the proposed algorithm presents a high performance and can be used in real time computer vision systems applied to calibration processes.

KEYWORDS: Calibration. Digital Instruments. Computer Vision. Template Matching.

1. Introduction

A common problem found in the calibration laboratories nowadays is the productivity of their technicians and the reliability of the results obtained in the calibration process and the transcript of the calibration's certificate. This is mainly caused by the fact that, in most cases, the technician who performed the calibration service does not issue the certificate, but only signs it after the filling done by a typist. In some cases the result in the certificate can be different that one obtained during the calibration process, frequently caused by human errors in transcription data.

The calibration processes accuracy may be significantly affected when instruments without built-in communication interface are involved once several manual readings and transcriptions of the data are more subject to human errors. Moreover, this task is time consuming and stressful.

Thus, automated systems play a very important role in the calibration of measuring instruments because they provide greater accuracy, repeatability and cost savings, beyond the reduction of monotonous and complex tasks (Alegria & Serra, 2000).

In this context, many authors have proposed automatic calibration systems using computer vision techniques (Alegria & Serra, 2000; Andria et al., 2009; Vázquez-Fernández et al, 2009; Fracasso, Silva & Selvatici, 2010; He et al., 2007).

Computer vision can be defined as a sub-area of image processing that studies the development of methods and techniques that enable a computer system to recognize objects in images imitating some capabilities of the human visual system, as the ability to describe a scene contained in a digital image (Gonzalez, 2002).

An efficient computer vision system must be able to extract a set of attributes that accurately describe a scene and is small enough to reduce the processing time to be used in practical applications such as robot vision systems, autonomous vehicles, surveillance systems, automatic license plate recognition, industrial inspection and biometrics patterns recognition, among others (Araújo, 2009).

One of the most known technique in computer vision systems is the template matching and is used to find small parts of an image, called template, in another image that has been analyzed (Araújo, 2009; Gonzalez, 2002).

In this paper is presented an approach, based on template matching with normalized cross correlation, to automate the process of calibration of digital measuring instruments without a built-in communication interface. The proposed algorithm uses computer vision techniques and allows the calibration values to be automatically input in a database, reducing the possibility of human errors in reading and transcription data tasks.

The remainder of the paper is organized as follows. Section 2 introduces the template matching technique using normalized Cross Correlation. Section 3 describes in detail the proposed algorithm. Section 4 presents some experimental results on real images and finally, the Section 5 concludes the paper and shows our plans for the future work.

2. Template Matching with Normalized Cross Correlation

Template matching is a technique widely used for finding patterns in digital images. Let A be the image to be analyzed and T the query template. The goal of a template matching algorithm is to find all occurrences of T in A, as illustrated in the Figure 1.

Template matching can be done in two ways: feature-based or template-based. The first way uses the features of the T and A to find the best matching locations of T in A. The second, also called global approach, uses the entire template to determine the matching positions. In both cases, some similarity measure needs to be used. Template-based approaches can be conducted using, for example, sum of square differences (SSD), sum of absolute differences (SAD) or normalized cross correlation (NCC) measures (Hii et al., 2006).

In most cases the instances of T in A may appear rotated, scaled, shifted and with diverse brightness and contrast (Araújo & Kim, 2011). Due this fact template matching technique is well known as an expensive operation and the execution time is proportional to the size of the images *A* and *T*.

(a) Template (***T***)

(b) Image to be analyzed (***A***)

(c) Result of template matching algorithm

Figure 1. Example of template matching.

The simplest implementation of template matching algorithm, using global approach, invariant to rotation and scale is the “brute force” solution. It performs a series of template matchings between the image to be analyzed *A* and the instances of the query template image *T* rotated by every angles and scaled by every scale factors, considering some specified range of angles and scale factors (Kim & Araújo, 2007).

The brute force algorithm yields the most precise solution to this problem. Nevertheless, it is very time consuming and thus is not feasible to be used in practical applications. However, this technique can be very efficient if does not have the necessity of rotation and scale invariance (Araujo & Kim, 2011).

Normalized cross correlation (NCC) is widely used as a similarity measure in template matching and is the most robust correlation measure for determining similarity between points in two or more images (Hii et al., 2006).

Considering an image *A* of size M × N pixels and a template *T* of size I × J pixels, then the cross correlation between *A* and *T*, denoted by $\mathrm{CC}(A,T)$, is defined as:

$$\mathrm{CC}(A,T) = C(m,n) = \sum_{i=-a}^{a} \sum_{j=-b}^{b} T(i,j) A(m+i, n+j) \tag{1}$$

where: $a = (I-1)/2$, $b = (J-1)/2$, m=0,...,M-1 and n=0,...N-1, *C* is the result matrix, with the same size of *A*, in which the peaks indicating the occurrences of *T* in *A* (matching positions).

In many applications the brightness of the images can vary due to environment lighting conditions. In these cases, the images can be first normalized. Thus, NCC(*A*,*T*) can be defined as:

$$\mathrm{NCC}(A,T) = C(m,n) = \frac{\sum_{i=-a}^{a} \sum_{j=-b}^{b} [T(i,j) - \bar{T}][A(m+i,n+j) - \bar{A}]}{\sqrt{\sum_{i=-a}^{a} \sum_{j=-b}^{b} [T(i,j) - \bar{T}]^2 \sum_{i=-a}^{a} \sum_{j=-b}^{b} [A(m+i,n+j) - \bar{A}]^2}} \tag{2}$$

The computation of NCC(*A*,*T*), defined in Equation 2, generates a matrix *C* in which the values range from -1 to +1. Depending on the application, we can use either the absolute value $|C(m,n)|$ to allow matching negative instances of the *T* in *A* or the value of $C(m,n)$ with signal for not allowing the matching of negative instances of *T*.

The Figure 2 depicts the result of NCC between *T* and *A*. The highest peeks indicate the occurrences of instances of *T* in *A*.

(a)
Template
(***T***)

(b)
Image to be analyzed (***A***)

(c)
Result of NCC between ***A*** and ***T***.

Figure 2. NCC between a display image and the template of digit 3.

In the practice, template matching with NCC is performed by moving the center (or the origin) of the template *T* over each (m, n) point in the *A* and calculate the sum of products between the coefficients in *A*(m, n) and *T*(i, j) over whole area spanned by *T*.

The NCC computation is high costly in time. However, the most available library implementation is optimized and makes use of Fast Fourier Transform (FFT), where the correlation sums are reduced to matrix products, accelerating the processing time. It is the case of the OpenCV library (Intel, 2007) used in our implementations.

3. The proposed algorithm

The algorithm proposed in this paper was implemented in C/C++ language using OpenCV and Proeikon libraries (Intel, 2007; Kim, 2010). It is divided in two main steps: i) Regions of Interest (ROIs) determination and ii) Recognition of the digits. After two steps, the ASCII data representing the digits are stored in a database.

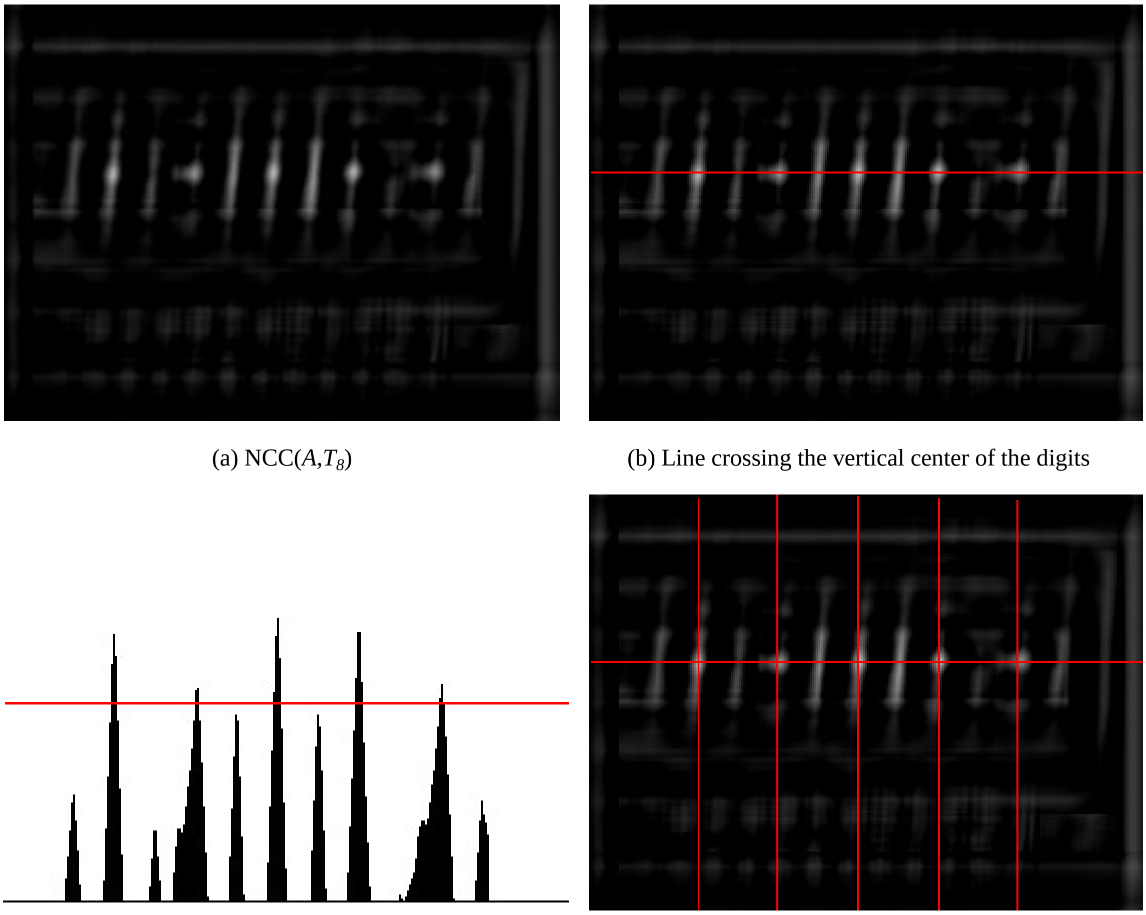
3.1 ROIs determination

In the first step of the algorithm a color image of size 851×638 is acquired by a conventional low cost webcam, converted at 256 gray levels and reduced to 30% of its original size. One example of input image is showed in the figure 2b.

Since the template matching technique may be an expensive operation concerning the time processing, the reduction of search area is important to accelerate the algorithm.

To detect the ROIs automatically, firstly NCC between input image and the template of digit 8 (T_8), denoted by NCC(A, T_8), is computed generating the image *C*, illustrated in the Figure 3a, in which the highest peeks give the coordinates of the line crossing the vertical center of the digits (Figure 3b).

In addition, by determining a threshold value *t*, it is possible to select the five highest peeks (Figure 3c), which indicate the horizontal center of each digit (Figure 3d).



(a) NCC(A,T_8)

(b) Line crossing the vertical center of the digits

(c) The five highest peeks over the line (t=128)

(d) Lines crossing the vertical and horizontal center of each digit

Figure 3. ROIs determination process.

Using the coordinates that denote the center of the digits, the initial and final position of each subregion S_0,.., S_4 is finally calculated, as shown in the Figure 4.

Figure 4. Detected subregions.

However, it is valid to remember that the decimal point need not be recognized because it is always fixed after the second digit.

3.2 Recognition of the digits

In this step, the digits of the display are recognized and stored in a database. For this purpose, first the NCC is calculated between each S_i (Figure 4) and each one of the templates T_i (Figure 5) and the maximum value of correlation is stored in the matrix *P*, containing 5 rows (subregions of *A*) and 10 columns (templates), as follows:

$$P[l,c] = \mathrm{MAX}[NCC(S_l, T_c)] \tag{3}$$

where l=0,…,4 and c=0,…,9.

The index c of the highest value of each line in the matrix P indicates the value displayed in the analyzed instrument on the position l. Thus, the output data consists of an integer vector D containing 5 elements. This vector is obtained as follows:

$$D[l] = \underset{c=0}{\overset{9}{\mathrm{ARGMAX}}} \left[P[l,c]\right] \tag{4}$$

where c is the argument that maximizes $P[l,c]$.


(a) T_0

(a) T_1

(a) T_2

(a) T_3

(a) T_4

(a) T_5

(a) T_6

(a) T_7

(a) T_8

(a) T_9

Figure 5. Query templates used in the recognition step.

The Figure 6 illustrates the matrix *P* calculated to recognize the display digits depicted in the figures 1, 2 and 4.

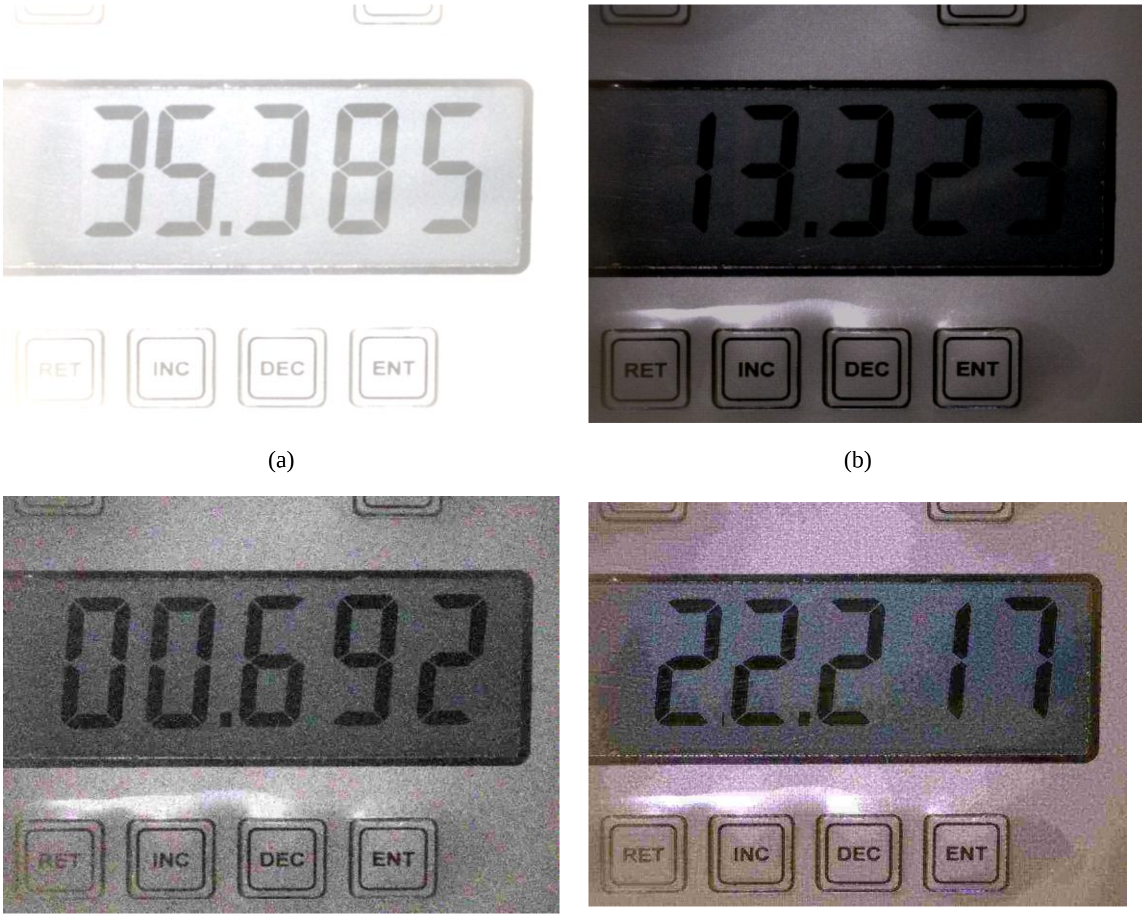
	0	1	2	3	4	5	6	7	8	9
0	**215**	149	106	122	112	93	148	184	176	127
1	133	144	137	**219**	103	124	101	163	139	163
2	**223**	150	104	130	100	112	162	178	181	136
3	146	152	80	126	93	188	**227**	168	171	125
4	114	150	127	**225**	110	129	97	162	138	164

Figure 6. Matrix *P* calculated in the recognizing of the display containing the digits “0”, “3”, “0”, “6” and “3”. The correlation values ranging from -1 to 1 were converted to the interval [0, 255].

Finally, the ASCII values from vector *D* representing the displayed digits, a display image’s copy and other data about the calibration process are stored in a database to be used in the instrument certificate or to identify some mistake occurred in the digits recognition.

4. Experimental results

In order to evaluate the robustness of the proposed algorithm we have conducted experiments using a set of 50 images affected by illumination changes (Figure 7a and 7b); noise (Figure 7c) and JPEG compression (Figure 7d). In these experiments all 250 matchings were perfect, without any false positive or false negative, even in the presence of some faintly visible digits (e.g. Figure 7b).



(a) (b) (c) (d)

Figure 7. Examples of images used in the experiments.

The distribution of the digits in the image set is showed in the Table 1. As can be seen all 10 digits appear at least 7.6% in the images.

Table 1. Distribution of the digits in the set of images.

Digit	0	1	2	3	4	5	6	7	8	9
%	14.4	13.2	10.0	10.0	7.6	7.6	9.6	9.2	9.6	8.8

The robustness of the proposed algorithm can be addressed to the fact that, differently from most used techniques like (Alegria & Serra, 2000; Vázquez-Fernández et al, 2009), it does not discard the rich grayscale information through operations such as detection of edges or segmentation/binarization of the images. The main problem is that these image-simplifying operations throw away the rich grayscale information, are sensitive to noise and JPEG, decreasing the robustness of the matching (Kim & Araújo, 2007).

Concerning the time of processing, the algorithm takes, in average, 0.3 sec using a Pentium 4 2.8GHz to read the numbers appearing in the display image. Nevertheless, this time could be further reduced by performing the template matching operation, in the second step, only in a few pixels around the peaks representing the center of the digits instead all pixels inside each subregion S_i. This reduction in processing time can allow the use of the algorithm in real-time computer vision systems applied to calibration processes.

5. Conclusions

This paper describes an algorithm using template matching technique with normalized cross correlation for reading the display of digital measuring instruments without built-in communication interface and storing the read ASCII values in a database used in the certification process.

In the experiments using a set of 50 images affected by illumination changes, noise, and JPEG compression all 250 digits were correctly recognized, showing the robustness of proposed algorithm. In addition, its performance could be further improved by reducing the ROIs. Besides, the algorithm could be used in several kinds of digital measuring instruments using a set of templates previously stored in a database.

In future works we intend to improve the proposed algorithm making it feasible to be applied in a real-time automated calibration system and also studying and applying computer vision methods in the automation of other types of measuring equipment such as analog instruments.

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References

Alegria F. C. & Serra, A. C. (2000), *Automatic Calibration of Analog and Digital Measuring Instruments Using Computer Vision*, IEEE Transactions on Instrumentation and Measurement, 49 (1), 94-99.

Andria, G. et al. (2009), *Automatic Calibration System for Digital Instruments Without Built-In Communication Interface*, Anais do XIX IMEKO World Congress, 857-860, Lisbon, September 6-11.

Araújo, S.A. (2009), *Casamento de padrões em imagens digitais livre de segmentação e invariante sob transformações de similaridade* – Tese de doutorado, USP, São Paulo.

Araújo, S.A. & Kim, H. Y.(2011), *Ciratefi: An RST-invariant template matching with extension to color images*. Integrated Computer-Aided Engineering, 18, 75-90.

Borges, R.O.; Silva, R.A.A. & Castro, S.S. (2007), *Utilização da classificação por distância euclidiana no mapeamento dos focos de arenização no setor sul da alta bacia do Rio Araguaia*, Anais do XIII Simpósio Brasileiro de Sensoriamento Remoto, Florianópolis, Brasil, 21-26 abril 2007, INPE, p. 3777-3784.

Fracasso , P. T.; Silva, T. J. & Selvatici A. H. P. (2010), *Bancada inteligente para calibração de hidrômetros*, Anais do XIV Congresso Internacional de Automação, Sistemas e Instrumentação, São Paulo, 1-10.

Gonzalez, R. C. & Woods, R. E. (2002), *Digital Image Processing*. Massachusetts: Addison-Wesley.

He, W. et al. (2007), *Intelligent reading method for analog meter based on computer vision*, Chinese Journal of Scientific Instrument, 28 (7), 1234-1239.

Hii, A.J.H. et al. (2006), *Fast normalized cross correlation for motion tracking using basis functions*, Computer Methods and Programs in Biomedicine, 82 (2), 144-156.

Intel. (2007), *OpenCV - Open Source Computer Vision Library*. Disponível em: <http://www.intel.com/technology/computing/opencv/>. Acesso em: 09 out. 2007.

Kim, H.Y. (2010) *ProEikon - Rotinas e programas em C++ para processamento de imagens e visão computacional*, São Paulo, 2006. Disponível em: <http://www.lps.usp.br/~hae/software>. Acesso em fev. 2010.

Kim, H. Y. & Araújo, S. A. (2007), *Grayscale Template-Matching Invariant to Rotation, Scale, Translation, Brightness and Contrast*. Lecture Notes in Computer Science, 4872, 100-113.

Vázquez-Fernández, E. et al. (2009), *A machine vision system for the calibration of digital thermometers*, Measurement Science and Technology, 20 (6), 1-7.