

An Intelligent Inspection System for Template-Based Change Detection

T. Alexandropoulos¹, S. Boutas², V. Loumos³, E. Kayafas⁴

National Technical University of Athens
School of Electrical and Computer Engineering
Multimedia Technology Laboratory
9 Heroon Polytechniou st, 15773, Zographou Campus
Tel-Fax: +30 210 7722538

{¹thalexan,²sboutas}@medialab.ntua.gr, {³loumos,⁴kayafas}@cs.ntua.gr

Abstract-This paper presents a template-based inspection application for change detection. This implementation aims to the inspection of targets which appear at an arbitrary orientation, such as undervehicle surfaces in vehicle inspection stations. The operation of the application is divided in two phases: image registration and change detection. Image registration aims to accurately detect the spatial transformation parameters which describe the orientation of the target with respect to its template. Change detection separates content changes from sensor noise fluctuations through noise model estimation.

I. Introduction

Template guided inspection refers to the comparison of the present image of a target against its archived template. This process may address problems such as undervehicle inspection for the detection of malicious alterations. The inspection process encounters two difficulties. The first difficulty lies in the difference in the orientation of the target with respect to the image acquisition system. This may be the case in undervehicle inspection where the orientation of the vehicle is always expected to differ in subsequent reentries. The second difficulty lies in the separation of content alteration from sensor noise fluctuations. This fact requires the employment of a change detection method.

This paper is structured as follows: Section II describes a block based approach to wavelet registration. Section III presents a clustering approach to noise model estimation, which was adopted for the isolation of content changes. A detailed description of the system architecture and its experimental results are presented in Section IV.

II. Wavelet-based registration

The image registration task aims to detect the spatial coordinate transformation which provides the optimal fitting of the compared image pair. Obviously, the complexity of the underlying transformation depends on the degrees of freedom introduced in the image acquisition environment. In the present approach, it is assumed that the underlying spatial displacement is accurately approximated by a *rigid transformation*, which is expressed in terms of homogenous coordinates as follows.

$$\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \begin{bmatrix} \cos \theta & -\sin \theta & x_{tr} \\ \sin \theta & \cos \theta & y_{tr} \\ 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

The registration problem lies in the determination of the parameter set (θ, x_{tr}, y_{tr}) which provides the optimum spatial fitting of the examined image pair. Its detection is performed through an optimization procedure. A similarity metric is defined and the parameter combination which maximizes it corresponds to the optimum solution. In the present work, the normalized cross-correlation of the image pair has been employed.

The utilization of the normalized cross-correlation as a similarity metric requires time-consuming operations when applied exhaustively over the search space of high resolution images. This proves true even in the simple case of a rigid transformation. This drawback is overridden through wavelet-based multiresolution analysis. This procedure extracts four subbands of the source image through combinations of low-pass and high-pass filtering along the rows and the columns of the source image,

followed by subsampling, as illustrated in Figure 1. The LL subband is a half-resolution approximation of the source image, while the subbands HL, LH and HH contain horizontal, vertical and diagonal edge information respectively. Cascaded wavelet decompositions of the LL subband extract a series of image approximations at a progressively decreasing resolution.

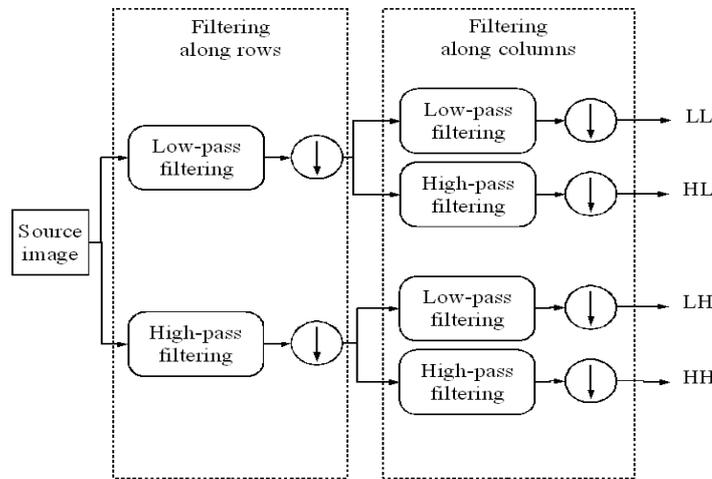


Figure 1: Diagram of the 2D wavelet decomposition algorithm

In wavelet-based registration, progressive rigid transformation approximations are acquired in a coarse-to-fine analysis. The transformation results of each stage provide to the successive stage an initial search point for further refinement. Furthermore, the algorithm may be dispatched over parallel processing environments, thus reducing the overall execution time. [1]

Another drawback of the normalized cross correlation as a similarity metric lies in its tendency of disorientation when image regions lack salient features.[2] Moreover, it is not tolerant to local distortions.[3] In order to cope with these issues, a block-based voting approach, which relies on localized cross-correlation calculations, is adopted in the present work. Instead of searching the optimal spatial transformation parameters at a global level, *the proposed algorithm is based on localized searches for the selection of the optimum rigid transformation parameters.* The optimal transformation set is selected through parameter voting. For the latter task, the *transformation parameter histogram* $h(\theta, x, y)$ is defined. Each value $h(\theta_i, x_i, y_i)$ represents the number of image blocks selecting the transformation parameter set (θ_i, x_i, y_i) as optimal. Hence, the voting approach selects as optimum the transformation parameters which maximize the registration parameter histogram. The process is performed successively at each level of decomposition.

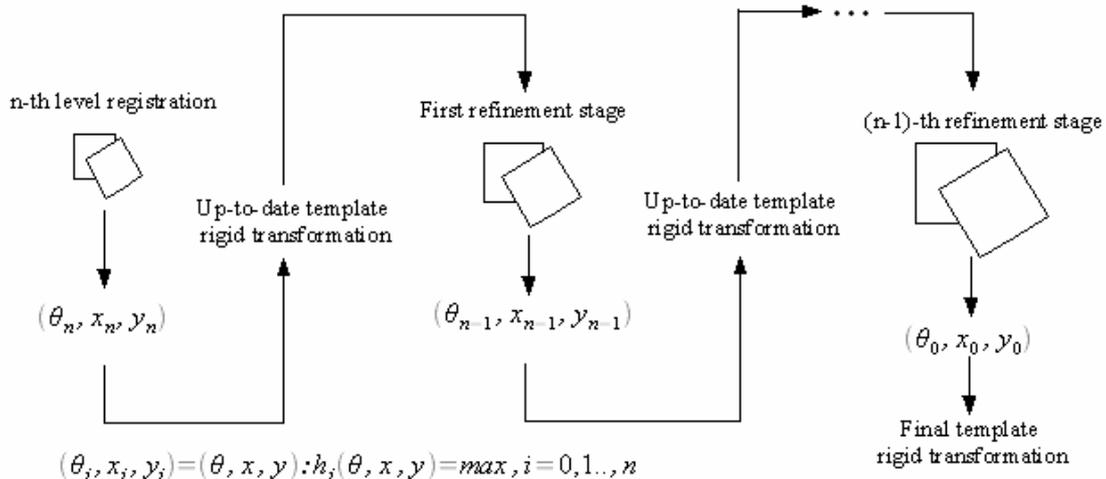


Figure 2: Flowchart of block-based hierarchic image registration

III. Change detection through block clustering

The second stage of the application copes with the aspect of content change detection. In this stage, the separation of content alterations from noise-level alterations is attempted. This task is achieved through a block-based clustering approach which groups blocks into clusters according to the similarity of their mean values and aims to the calculation of noise statistic parameters. The noise model estimation is based on the following definitions.

Let B_{ij} denote an image block of the absolute difference and m_{ij} , σ_{ij} denote its corresponding mean value and standard deviation. Each cluster G_k with N_{G_k} member blocks is defined by its centroid $C_k(m_{G_k}, \sigma_{G_k})$, where:

$$m_{G_k} = \frac{\sum_{i=1}^{N_{G_k}} m_i}{N_{G_k}}, \quad \sigma_{G_k} = \frac{\sum_{i=1}^{N_{G_k}} \sigma_i}{N_{G_k}}$$

Apparently the centroid of each cluster corresponds to the averaged mean value and standard deviation of its member blocks.

Additionally, for each block B_{ij} and cluster G_k , their *mean value distance* is defined as:

$$d_{ij, G_k} = |m_{ij} - m_{G_k}|$$

The block clustering procedure is based on the following iterative procedure:

- i) An arbitrary block is initialized. ($m_{G_1} = m_{11}, \sigma_{G_1} = \sigma_{11}$)
- ii) For each image block B_{ij} , the corresponding mean value distances from all existing clusters are estimated.
 - a) If $d_{ij, G_k} < \sigma_{G_k}$ for at least one cluster, the block is grouped into the cluster which yields the minimum mean value distance.
 - b) If $d_{ij, G_k} > \sigma_{G_k}$ for all clusters, a new cluster G_m is initialized: $C_m(m_{ij}, \sigma_{ij})$

The flowchart of the clustering operation is shown in Figure 3.

Upon completion of the clustering procedure, content change detection is performed through application of noise-based thresholding. The classification procedure is based on the assumption that *the largest cluster carries noise model information*. Specifically:

$$m_n = m_{G_{\max}}$$

$$\sigma_n = \sigma_{G_{\max}}$$

This assumption proves true for content changes which occupy up to half of the surveyed region.[4] In this case, a noise based classification rule is expressed as follows:

$$\text{If } d_{ij, G_{\max}} > \sigma_{G_{\max}}, \text{ block } B_{ij} \text{ is changed.}$$

Therefore the binary change mask consists of the image block set which satisfies the aforementioned condition:

$$C = \{B_{ij} : d_{ij, G_{\max}} > \sigma_{G_{\max}}\}$$

When compared frames are shot under varying ambient illumination, luminance normalization

precedes image differencing. [4]

In colour images the process is performed on each colour channel of the absolute difference and the three partial masks are merged into a single binary change mask through an OR operator. Further refinement of the change mask is performed through application of median filtering at block level.

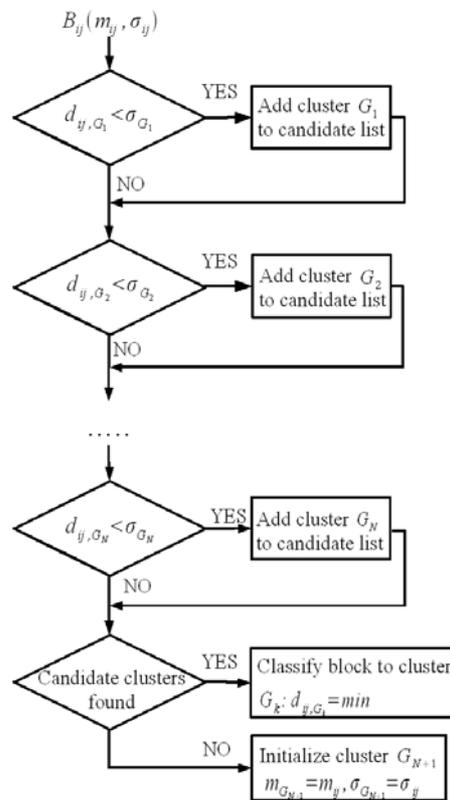


Figure 3: Block clustering flowchart

IV. System architecture - Results

The proposed template-guided inspection algorithm has been developed in the LabVIEW programming environment. Testing of the algorithm involves colour digital images shot at a resolution of 640x480 pixels. The module was tested on a 3 GHz computer unit while the image registration algorithm has been deployed over a Beowulf cluster of four 3GHz nodes. Interprocess communication has been based on the Message Passing Interface (MPI).

Upon completion of the image registration task, the LabVIEW workstation performs block-based change detection on the registered image pair and displays the inspection results to the system operator. The architecture of the proposed system is illustrated in Figure 4.

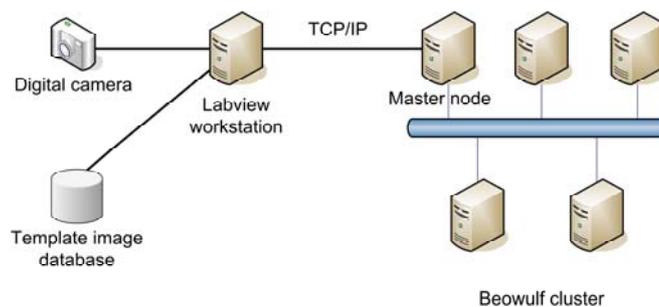


Figure 4. Operation diagram of the template-guided change detector

A sample template-guided inspection application focuses on change detection in vehicle images. This scenario addresses vehicle inspection in areas of limited access such as government facilities and

embassies. Its operation requires prior archival of the template of each vehicle in a database. Figures 5a and 5b display two images of the same vehicle surface. The former corresponds to the vehicle template and the latter corresponds to the present vehicle image acquired in the vehicle access point. For the identification of the present vehicle, license plate recognition is employed.

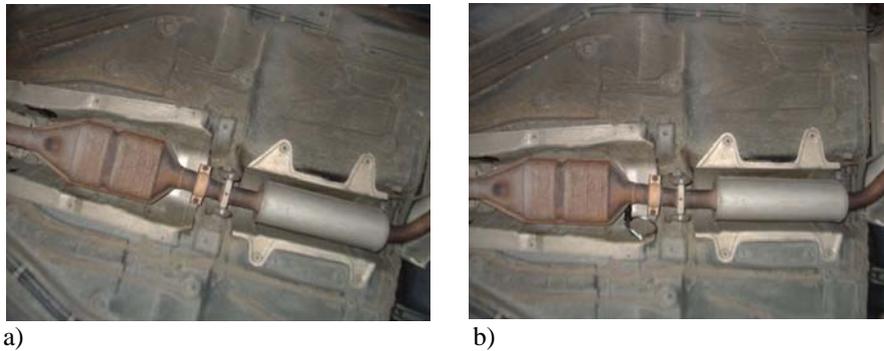


Figure 5: Sample Vehicle inspection test set

The extent of the search space at each level of registration is described in Table 1, while the corresponding execution times of the algorithm, for a variable number of active processors, are shown in Table 2. A screenshot of the implemented change detection module is displayed in Figure 6.

Level of registration	Maximum angular displacement (degrees)	Angular step (degrees)	Maximum translation (pixels)
4	16^0	1^0	$x = \pm width / 4$ $y = \pm height / 4$
3	8^0	1^0	$x, y = \pm 2$
2	4^0	0.5^0	$x, y = \pm 2$
1	2^0	0.2^0	$x, y = \pm 2$
Full image resolution	1^0	0.2^0	$x, y = \pm 2$

Active processors	Registration execution time (sec)	Change detection execution time (msec)	Overall execution time (sec)
1	30.6	180	30.8
2	15.3		15.5
3	10.6		10.8
4	8.7		8.9

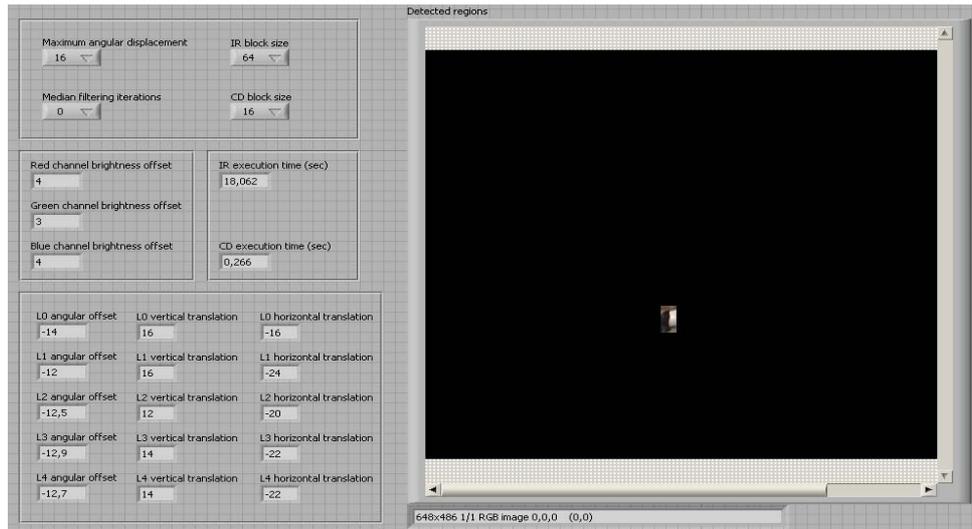


Figure 6: Screenshot of the implemented inspection application

The absolute difference of the registered image pair is presented in Figure 7a while the result of the statistic change detection procedure is displayed in Figure 7b. It is clear that the proposed noise model estimation provides an accurate representation of noise properties as the classification results isolate content changes and suppress noise sensor fluctuations.

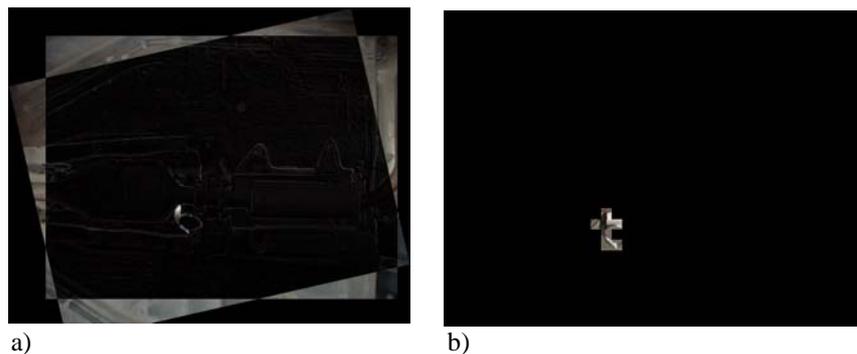


Figure 7: Change detection results in undervehicle surveillance

V. Conclusions

A template-guided inspection system has been presented. Its operation principle is divided in two phases. The first phase performs spatial alignment of the compared image pair through a wavelet-based image registration procedure. The second phase separates content changes from sensor noise fluctuations through statistic change detection. This approach achieves estimation of the noise model by employing a block based clustering procedure. The system has been tested on vehicle image inspection and the respective experimental results have verified its ability to detect content alterations, thus efficiently addressing the problem.

References

- [1] Tarek A. El-Ghazawi, Prachya Chalermwat, and Jacqueline Le Moigne, "Wavelet based image registration on parallel computers", *Proceedings of the 1997 ACM/IEEE conference on Supercomputing*, San Jose, CA, 1997, p.p. 1-9, ISBN: 0-89791-985-8
- [2] Barbara Zitova, Jan Flusser, "Image registration methods: a survey", *Image Vision and Computing* 21, p.p. 977-1000, (2003), Elsevier
- [3] Lisa Gottesfeld Brown, "A survey of Image Registration Techniques", *ACM Computing Surveys (CSUR)*, Volume 24, Issue 4, p.p. 325-376, ISSN: 0360-0300
- [4] Theodoros Alexandropoulos, Vassili Loumos, Eleftherios Kayafas, "Block-based change detection in the presence of ambient illumination variations", *Journal of Advanced Computational Intelligence and Intelligent Informatics*, Vol. 9, No. 1, p.p. 46-52, 2005, Fuji Technology Press