UNDERSTANDING PAPER FLATTENING (II). AN ARTIFICIAL VISION SYSTEM FOR THE ASSESSMENT OF PRESSURE FLATTENING PROCESSES IN CONSERVATION

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ABSTRACT: *As mentioned in the first part of this paper, paper flattening is a very common treatment in paper conservation. Conservators have developed a number of techniques which allow for the successful flattening of very different paper sheets. However, these techniques often have unwanted effects, which often go unnoticed, or are misunderstood. The alteration of the original size of the flattened paper sheet is one of the most important of these effects. Up to now no research has been done on this problem. This paper describes a custom-designed vision system based on low cost cameras for the real-time monitoring of the size variations of drying paper sheets.*

KEYWORDS: conservation, restoration, paper flattening, control system, computer vision, visual trackin

INTRODUCTION

Artificial vision has several applications in art restoration. It represents a powerful tool which helps restoration personnel in tedious tasks which would otherwise require much more work time. For example Sağıroğlu and Erçil (2005) have used it to reconstruct archaeological findings. They use artificial vision for the automated puzzle assembly problem of reconstruction of archaeological finds using surface texture and pictures from fragments. Additionally, Schär et al., (2005) have used artificial vision for the digital restoration of the appearance of medieval Burgundian tapestries. Such tapestries are well preserved, but much of their colour is highly faded. Thus, their current appearance is very different from the original one, but this can be restored using artificial vision systems.

The *Instituto de Automática e Informática* Industrial (ai2) of the *Universidad Politécnica de Valencia* has carried research on artificial vision for a number of years. The collaborative research project developed along with the "Instituto de Restauración del Patrimonio" was an interesting challenge. Monitoring the small and slow size variations experienced by a drying paper sheet is not an easy task. It was soon decided that an artificial vision system could be a technically adequate solution to the problem of determining the sheet size variation. This solution represents a new approach into the field of restoration based on vision systems.

GOALS

The artificial vision system was designed to monitor size changes in drying paper sheets, and to store the acquired data on the magnitude of the deformation detected in a easily-readable format, such as an MS Excel-compatible file. In this way the size variations in a drying paper sheet can be tracked; in turn, this data will allow for the creation of a theoretical model of the paper drying process, which could hopefully help to optimize the paper flattening techniques used in conservation.

In order to be actually usable, the system must fulfil a strict set of requirements:

- It must detect extremely slow movements of a paper sheet under both an upper thin transparent plastic sheet (which is extremely shiny and has small wrinkles all over its surface), and a lower translucid non-woven plastic sheet.
- It should be able to record the time and extent of the movements.
- The system should be able to detect variations of at least 0.5 mm in sheet size.
- It should be a low-cost system.
- It should be physically unobtrusive. The detecting device should be as small and light as possible.
- Its installation and operation must be reasonably convenient for conservators, that is, a computer vision expert engineer must not be required for its use.

A machine vision system can be used in this case, because by using a set of cameras, an automated tracking process can be performed, without any kind of subjective human help, to obtain better results whilst continuously monitoring the canvas (Vidal et al., 2006).

MATERIALS AND METHODS

1. The vision system

A typical image acquisition and processing system has four essential components. A camera which converts the light signals into an image; an interface to transfer the image from the camera to the workstation; a workstation that provides the processing power; and the image processing software that provides the tools to manipulate and analyze the images.

The vision system designed in this work is composed of several low-cost web cameras, which are connected to a standard USB PC port.

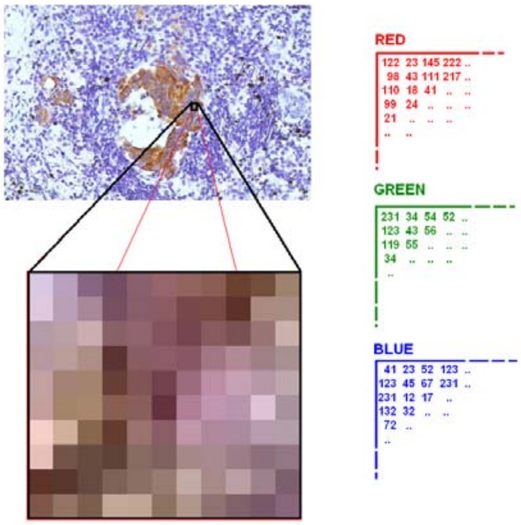


Figure 1. Digital image composition: each pixel of the image is composed by three RGB components

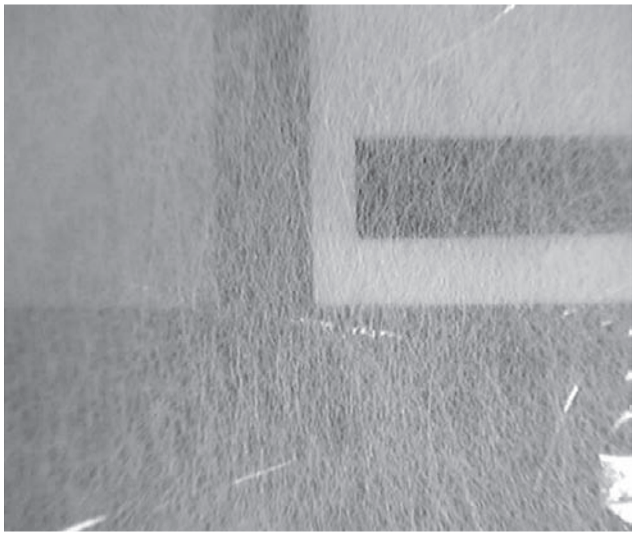


Figure 2. Frame grabbed during a canvas restoration process

These cameras are placed over the drying up platform using mini-tripods. This vision system is small, flexible and easy to set up. The user need only put the cameras on those view points which focus on the paper zones to be monitored during the flattening process; after that, the user simply runs the software application in order to start the monitoring process.

2. The image acquisition process

Digital processing requires digital images to be obtained in the form of electrical signals. The most common sensor is the charge coupled device or CCD, which consists of a large number of photosensitive elements (Davies, 1997). These photosensitive elements collect charge proportionally to illumination. The number of sensitive elements determines the image resolution. Each one represents one pixel and the digital image is a matrix of the image dimension. Each element of the matrix represents the luminance of the pixel it represents, and this luminance is represented by a number from 0 to 255. In case of colour images, the matrix is triple, since each element represents the luminance of one of the RGB colours (red, green and blue). Colour is represented by these three numbers (see figure 2).

Several image sequences were captured from the flattening paper processes, using a colour web camera (Logitech QuickCam Pro). The web camera was located perpendicularly to the paper surface, under semi-controlled lighting conditions. Images were captured with a resolution of 640×480 pixels in jpeg format.

The image analysis algorithms, described in this paper, were implemented on a Windows application developed by using *Visual C++.NET* code (MicroSoft®). *Visual C++.NET* enables developers to create powerful applications using the C++ language. The first problem solved in this software application was the implementation of a driver to acquire images from the web cameras based on the widespread "VideoForWindows" standard.

A frame taken during a canvas restoration process can be seen in figure 3, showing the corner of the paper sheet. Figure 3 shows the main paper sheet on the right and a control sheet on the left).

3. The image analysis process

Image processing is not a one-step process. Several steps must be performed one after another until data of interest from an observed image (Gonzalez and Woods, 1992) can be extracted. Image processing begins with the capture of an image with a suitable, but not necessarily optical, acquisition system. Depending on the application, an appropriate image system should be chosen, as well as the illumination system and its relative positioning. The first step of digital processing is known as image pre-processing. If the sensor has non linear characteristics, these need to be corrected. Likewise, brightness and contrast of the image may require improvement.

A whole chain of processing steps is necessary to analyze and identify objects. First, adequate filtering procedures must be applied in order to distinguish objects of interest from other objects and the background. The basic tools for this task are averaging, edge detection, the analysis of simple neighbourhoods and complex patterns known in image processing as "texture".

Then, the objects have to be separated from the background. Separating an object from the background involves the identification of the pixels which represent it. This means that regions of constant features and discontinuities must be identified by segmentation. This can be an easy task if an object is well distinguished from the background by some local features.

Once the geometrical shape of the object is known, morphological operators can be used to analyze and modify the shape of objects or extract further information such as the mean grey value, area, perimeter, and other parameters of the form of the object. These parameters can be used to classify objects.

In order to track the deformations detected in the canvases, we have implemented several pattern recognition techniques. The used techniques can be sorted in two different groups: direct pattern matching and border matching techniques.

3.1. Direct pattern matching

The first proposed solution can be called direct pattern matching and consists of capturing a small square fraction of a frame called the pattern, (that particular area is chosen by the user) and then trying to find another similar size region in the following frames with high pixel to pixel similarity (see figure 4). This process can be performed with the untouched or Sobel-processed frames. This method is fairly reliable, although it is highly sensitive to light variations, bright spots, and other visual interferences.

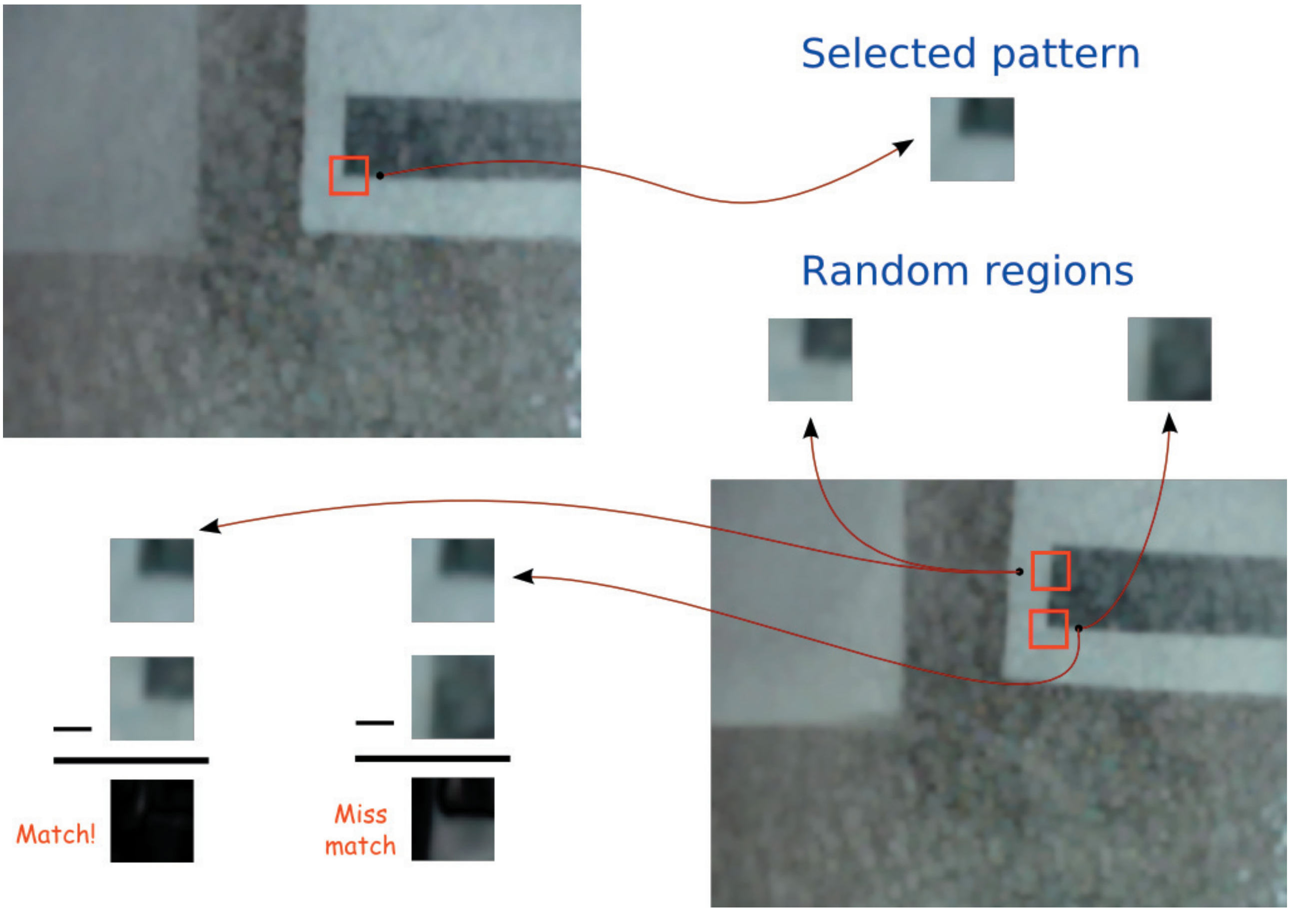


Figure 3. Selected pattern from the top image and matched results from two random regions extracted from the bottom image. Note the low resolution, due to the use of a low-cost camera

Figure 4. (a) First image in the image sequence; (b) Another image in the image sequence; (c) Borders extracted with Canny (in this case the green and red borders are selected to estimate the object movement after the borders selection process)

3.2. Border tracking

Tracking the extracted borders using a Canny filter (Canny, 1986) on the first image was also considered. In this case, the borders detected in a frame are compared to the borders detected in the following frames using a string comparison algorithm. Once compared, the system can tell which borders from a frame are identifiable with the borders found in another frame, thus being able to measure movements (see figure 5). This technique is more reliable than the previous, and it is less sensitive to light conditions. However, this approach requires more computation time.

Due to the fact that the border we want to track must be strong (*F*), long (*L*) and as less similar to the others as possible (*S*) we face a multi-objective function with ratios that we have to calculate for it to perform well (1).

$$M = A * F + B * L + C * S \qquad (1)$$

The ratios have been calculated experimentally using a trial-and-error technique showing us that the degree of similarity depends on the strings themselves making it difficult for us to obtain an optimum value for *C*. By using more than one border there is no further need to choose those strings less similar to other ones. Instead, we only need to choose long and strong borders (we can ignore the last factor from the previous formula).

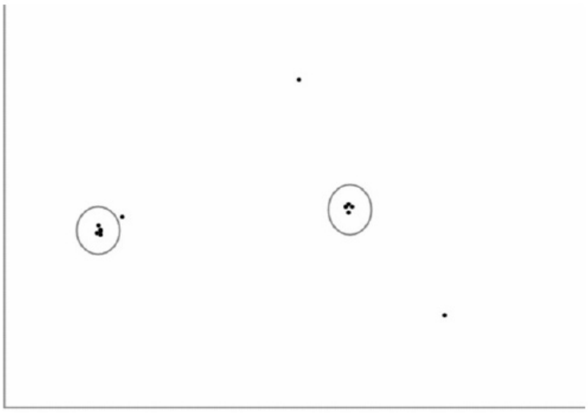


Figure 5: Point clouds showing border movements

When comparing a set of borders F_0 with another one F_1, wrong matches can take place but this is not a problem at all because, when representing the movement for all matching borders in an XY plane, we get some points clouds that show the movement of entire objects, where it is easy to remove isolated points as shown in figure 6.

We can see some clouds of points (surrounded by two circles) in the previous figure showing the movement of two different objects and some isolated points produced by miss-matches.

There is one last problem we have to deal when using this method: the selection of the best points for movement estimation. We have chosen a distance threshold (*H*) to define the points belonging to the same cloud, and so select one point for every cloud of points.

Every single point from the set (*J*), composed of all the extracted points is defined according to expression (2):

$$P(J_h) = \sum_{i=0}^{N} V(J_i) : d(J_h, J_i) < H \qquad (2)$$

Where (*d*) represents the Euclidean distance and (*V*) is a function that tells us the strength of the border that was created by the point J_i. Then we select from the original set (*J*) only the points J_h that fulfil the following expression (3):

$$J_h = \max_{\forall J_i \in J} P(J_i) : d(J_h, J_i) < H \qquad (3)$$

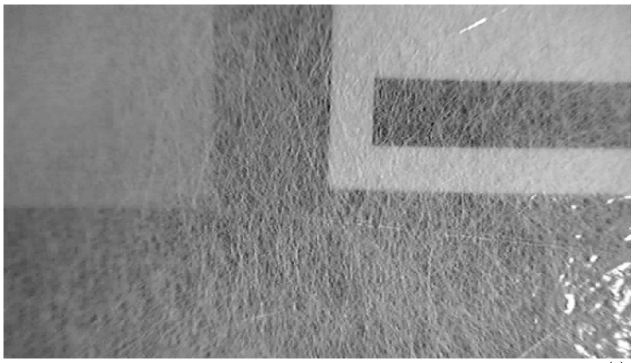
After the optimization process defined by the equation (3) a subset of points (*J'*) is obtained by the points J_h which accomplish the equation (3). Nevertheless more than one point could be selected in one cloud; therefore a final selection process is carried out. Finally every point accepted J_h must be kept only if it is alone in its cloud (4):

$$J_h : \forall J_i \in J', \quad d(J_h, J_i) < H \qquad (4)$$

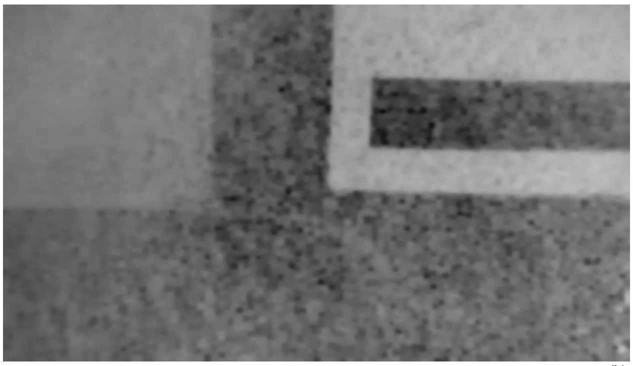
Every point which fulfils this selection process is treated as an object movement in the image.

3.3. Sheet thresholding

When using this technique we try to perform a threshold process in order to separate the sheet from the background and to estimate the resulting borders. This technique is quite simple but it has not been implemented due to the fact that we can not ensure that the background colour will be different enough from the colour of the paper sheet, especially in the uncontrolled light conditions in which the monitoring process will take place. When using this technique with a paper sheet and a background having similar colour, many errors arise.



(a)



(b)

Figure 6. (a) Original image; (b) processed image after applying a 5X5 kernel dilate filter followed by gaussian blurring

RESULTS AND DISCUSSION

1. Main problems found

1.1. The semitransparent film

The semitransparent film that covers the paper sheet during the drying process was a highly problematic factor, due to the fact that its transparency is not uniform throughout its entire surface. The large fibres on the film surface make the paper beneath look whiter in some areas. This colour variation cannot always be estimated and consequently the artificial vision system cannot completely correct it.

We have implemented several techniques to deal with this problem, from band-pass FIR filters, processing filters with Boxcar and Hamming windows to frequency analysis of the images. However, a 5x5 kernel dilate filter followed by a Gaussian blurring produced the best results (see figure 7). The complete removal of the white fibres was impossible, but a fairly good erasing solution was achieved.

1.2. The computational step

Most computer applications use a single processing thread, which is why the graphical interface remains blocked temporally when a long computational step is required. A temporal locking usually annoys the user due to the fact that the program needs a couple of seconds to perform the tasks “ordered” by the user. That problem gets worse as the computational step required gets longer because the applications halt during a long period of time.

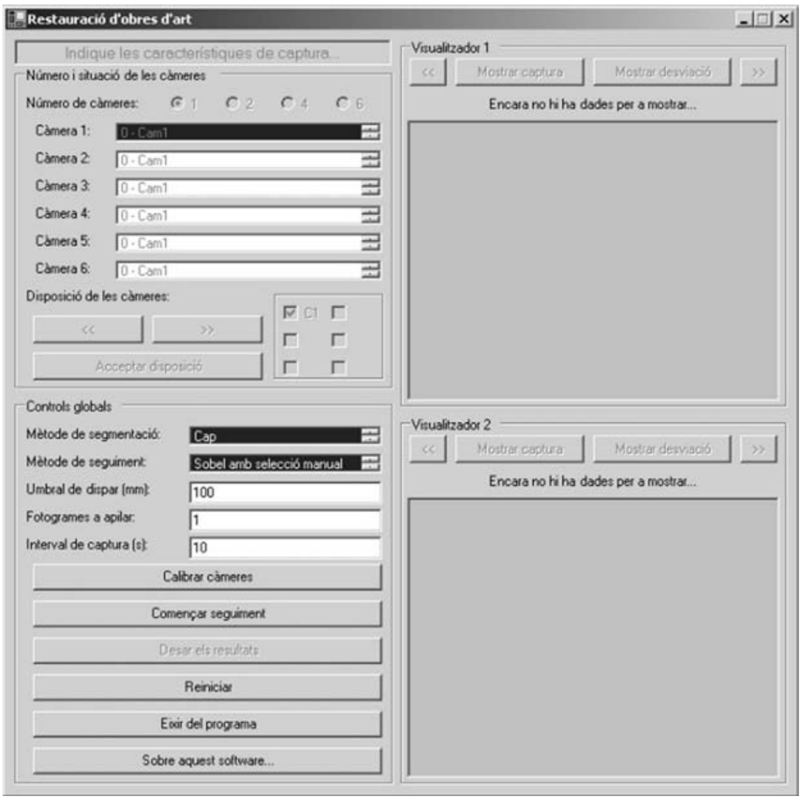


Figure 7: The friendly, Windows-based man-machine interface

We solved the previous problem by creating an additional main independent processing thread used to perform CPU heavy tasks; the main thread takes care of the user, the second one performs all additional tasks and can be stopped or killed when required.

2. Results

A Windows application with a friendly man-machine interface was implemented to apply the proper configuration of the vision system and to run/stop the continuous process of monitoring the paper flattening process (see figure 8). During this monitoring process, the measured shape changes were stored in a tabbed text, Excel-importable file. In this way the results produced by the vision system can be imported and analysed from Excel easily.

2.1. Direct pattern matching

The direct pattern matching technique (whether combined with filters or not) is a very simple method but it has proved to be quite useful in tracking the sheet boundaries. It is very sensitive to light variations, and bright spots can also be a problem if they appear in the pattern region. However, we have achieved very good results with this method in real-life working conditions.

2.2. Border tracking

This technique was by far the most complex one implemented in this research work. This technique is nearly invariant to light conditions but still sensitive to bright spots appearing anywhere in the frame. It is a very reliable technique because it is able to detect any kind of movement, but it uses a lot more CPU computational power than any other algorithm.

However, in practice it turned out to be an almost useless method: the semitransparent film modifies the appearance of the paper sheet in such a way that it makes it impossible to detect the correct borders using a Canny detector. It works perfectly when no interference is present in the image.

2.3. Sheet thresholding

This method was not implemented, due to the difficulty in finding a threshold level reliable enough for accurate paper separation from the background, under any condition as, in fact, the paper colour can vary.

CONCLUSIONS

The performance of these methods was assessed by comparing the results provided by the algorithms with a human operator. A high percentage of the pixels were properly tracked. The errors are due to the presence of noise due to the texture of the transparent film.

Summarizing, some image analysis algorithms were applied to the image sequences test set, and the results suggested that the system is reliable enough. In order to reduce the problem generated by the transparent film, using new image filter algorithms could be taken into account for future work.

These techniques can be used to track paper behaviour during the paper flattening process. Therefore this image analysis process could be used to asses the effects of common pressure techniques or even to control of the paper flattening process.

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Versión española

TÍTULO: ***Comprendiendo el alisado del papel (II). Un sistema visual para la evaluación de los procesos de presión en el alisado del papel en la conservación***

RESUMEN: *Según lo mencionado en la primera parte del artículo, el alisado del papel es un tratamiento muy común en la conservación de papel. La alteración del tamaño original de la hoja de papel alisada es uno de los efectos colaterales más importantes, y sobre el que menos se ha investigado. Este artículo describe un sistema visual diseñado a medida basado en cámaras fotográficas de bajo coste para la supervisión en tiempo real de las variaciones del tamaño de hojas de papel secas. El sistema es de bajo coste, y se puede usar en las condiciones de trabajo en que se desarrollan algunos de los procesos de alisado del papel.*

PALABRAS CLAVE: *Conservación, Restauración, Alisado del papel, Sistema de control, Visión artificial, seguimiento visual*