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Online Registration of Watermarks from Continuous Web Paper

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Abstract. Machine vision has substantial potential, allowing us to implement reliable and flexible solutions for various tasks such as inspection, surface quality analysis, object detection, etc. In this paper we present a real-time system for automatic detection and registration of watermarks from continuous web paper. This is an important issue in papermaking since the manufacturers require the watermark to be placed in the exact position on each sheet. Our registration method consists of a succession of straightforward morphological operations followed by signature analysis. Our results illustrate the possibility of applying the proposed method to a commercial inspection system.

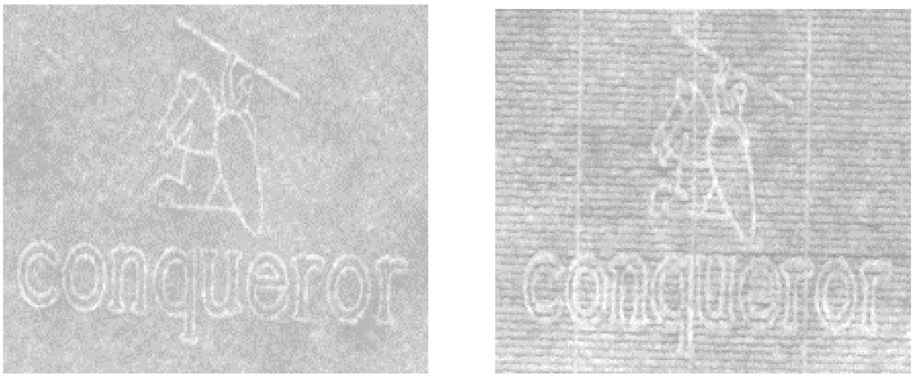
Keywords: Watermark, Morphology, Registration, Signature Analysis

1 Introduction

Due to new technological achievements, machine vision has made it possible to implement reliable solutions for industrial applications. In the paper manufacturing process various inspection tasks such as detection of spots, creases, holes in the paper, contamination analysis or paper formation analysis have now been successfully automated. Another important feature for some paper mills is the quality analysis and classification of watermarks from continuous web paper.

The watermarks are used for security and quality purposes. They usually take the form of brand names, brook bonds or logos (figure 1). The watermark formation process consists of impressing the paper by a rotary cylinder (called dandy) engraved with watermark patterns on its surface. Depending on the fabrication process, two types of paper are commercially available, woven paper and paper with laid (horizontal) and chain (vertical) lines (these lines determine a complex background and make the segmentation process even more complicated) (figure 1b). For the sake of simplicity the paper without laid and chain lines will be hereafter referred as plain paper (figure 1a) and the paper with laid and chain lines referred to laid paper (figure 1b).

At present, no automated solution for quality analysis of the watermark exists. Instead, the watermark image is captured using a high-speed camera and displayed on video monitor. The image is examined occasionally by a human operator but this solution is far from accurate.



(a) Plain paper watermark (b) Laid paper watermark

Fig. 1. Typical watermark images

This paper presents an approach for automatic detection and registration of paper watermarks. This is the first step towards an integrated system for quality inspection of various watermarks. A precise registration of the watermark is also very important since it allows:

- control of the position of the watermark on each cut sheet.
- constant spacing between two consecutive watermarks by controlling the speed of the dandy.

Currently, available registration methods are based on detecting registration marks placed on either side of the paper web during the impression of the watermarks (figure 2).

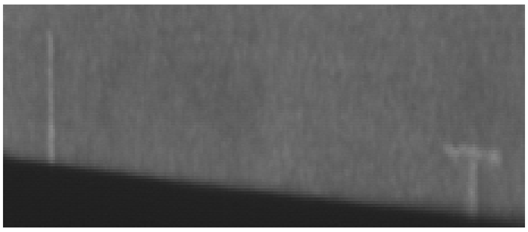


Fig 2 Registration marks placed on the edge of the paper web

Although this method has been used with some degree of success it is expensive because the paper is not efficiently used (the sides containing the registration marks are later removed). To overcome the deficiency above mentioned we propose a fast software registration technique based on the mathematical morphology approach developed in [1] and signature analysis.

This paper is organised as follows. Section 2 presents the image acquisition characteristics. Section 3 describes the real-time registration implementation while test results and the performance of the system are detailed in Section 4. Section 5 provides the conclusions and the possible next steps of this project.

2 Production environment

The principal elements of the integrated system are:

- a SONY (ILX510) solid-state linear CCD camera. This a sensor developed for high resolution applications, with 5150 effective pixels of size 7μm pitch
- a high frequency fluorescent bulb used in backlighting configuration along with an acrylic rod to focus the light on the paper. This creates a light strip which helps reduce the gradient illumination
- a PC based system containing a frame grabber and running the registration software on Windows NT 4.0

Any design solution that addresses the watermark registration must take into account the following constraints imposed by the industrial requirements:

- the maximum speed of the web is 250 meters/minute. Usually the web speed is between 100 and 200 meters/minute with a maximal error of 5%
- the spacing between watermarks is constant and it is 297 mm (i.e. the length of an A4 page). For a web speed of 150 meters/minute the required processing time per individual watermark is about 120 ms
- each watermark must be registered
- the chain lines are perpendicular on the backlighting strip
- required registration tolerance is 0.1 mm (approx.)
- the colour and the thickness of the paper may vary

3 Automatic registration of the watermarks

Due to various sources of noise (i.e. illumination gradient) and relatively low contrast of the watermarks simple thresholding techniques will not provide a reliable solution to their registration. Furthermore, global thresholding techniques will fail when applied to laid paper watermarks since the laid lines and the watermark have the same intensity.

Our proposed method for watermark registration is based on the theoretical results presented in [1]. There, two approaches for watermark segmentation were evaluated: one based on mathematical morphology and the other on the Fourier transform. While both techniques performed relatively well, the morphological approach proved to be better suited for real-time registration of watermarks. After the segmentation is complete, a common method to find the registration point is to compute the convex hull and then to find its centroid. Apart from being computationally inefficient, the convex hull is extremely sensitive to noise. A single isolated pixel present in the segmented image could completely alter the registration result. To overcome this problem a very precise segmentation is needed. In this case, the segmentation operation is very difficult to automate in the required time.

Finding the registration point does not necessarily require a complete segmentation of the watermark. Furthermore, in our application only the *y* co-ordinate has to be determined since the *x* co-ordinate is always known due to the fabrication process of the watermarks. Taking into account that the watermark images show a specific vertical profile, we have extended the morphological approach detailed in [1] by adding a signature analysis technique. This registration method is simpler, less computationally intensive and more robust than the based on segmentation approach described above. It can be divided into two main steps:

- registration of a single watermark
- start-up procedure

3.1 Registration of a single watermark

The proposed method for real-time watermark registration consists of a succession of simple morphological operations followed by the generation and analysis of a vertical signature. The processing steps are outlined in the figure 3 and detailed below:

Step 1 Vertical filtering

This additional step is only required for the analysis of the laid paper watermarks. Since the chain lines have very little effect on the vertical signature during this preprocessing step, only the influence of the laid lines is diminished with the help of a vertical erosion operator. Another suggested solution could be to apply the opening operation instead of erosion with the advantage of recovering the brighter parts of the watermark that have been eroded. It was found that the use of erosion allows a unitary approach to both plain and laid paper watermarks (the predefined values used in step 4 are the same). The erosion operation was implemented using a recursive algorithm developed in [2] with the size of the vertical structuring element varying from 3 up to 11 (depending on the resolution of the camera and on the web speed). It turned out that a structuring element of size 3 provides the best compromise between the blurring of laid lines and the preservation of vertical signature. Longer structuring elements offer a better removal of the laid lines but they also affect the vertical signature taken in Step 5 (the sharpness of the peaks) due to the presence of longer vertical segments in the binary image obtained after the reconstruction by dilation step. It is worth mentioning here that the blurring effect created by the movement of the paper beneath the camera simplifies the filtering operation.

Step 2 Morphological top-hat

The application of the morphological top-hat reduces the effects of uneven illumination while preserving the thin features of the image. It also shifts the histogram back to the origin therefore simplifying the histogram analysis in step 3. The morphological top-hat is the slowest operation involved in the registration algorithm. It was implemented using a 7x7 square structuring element which provided both speed and efficiency.

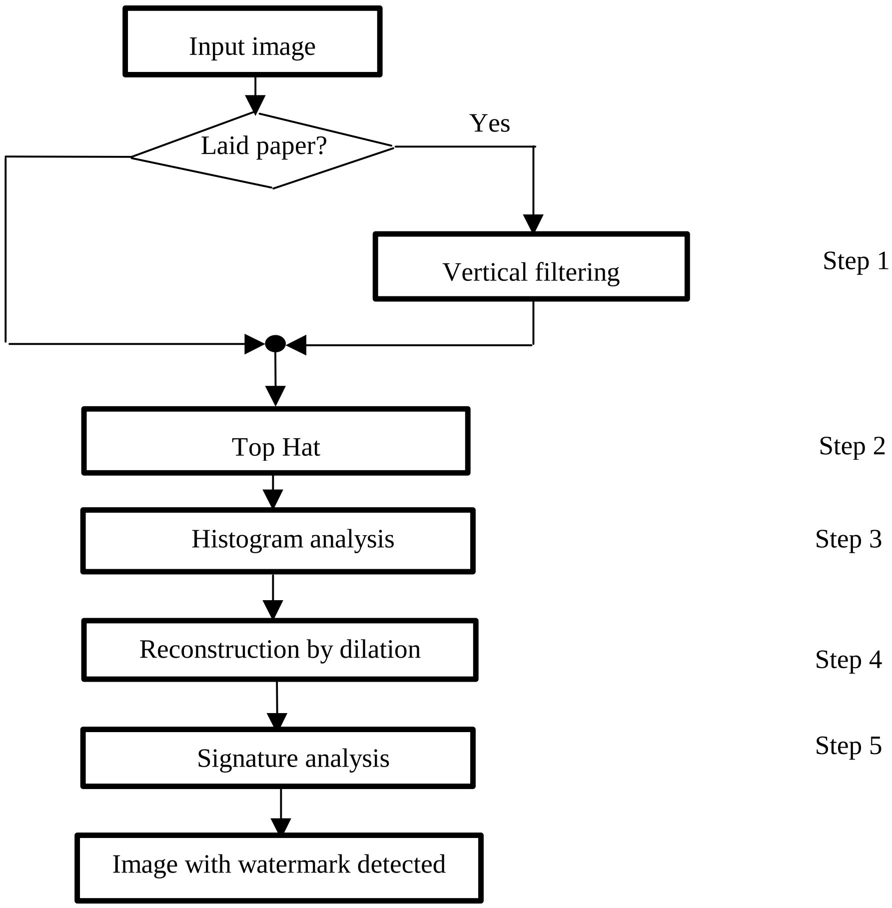
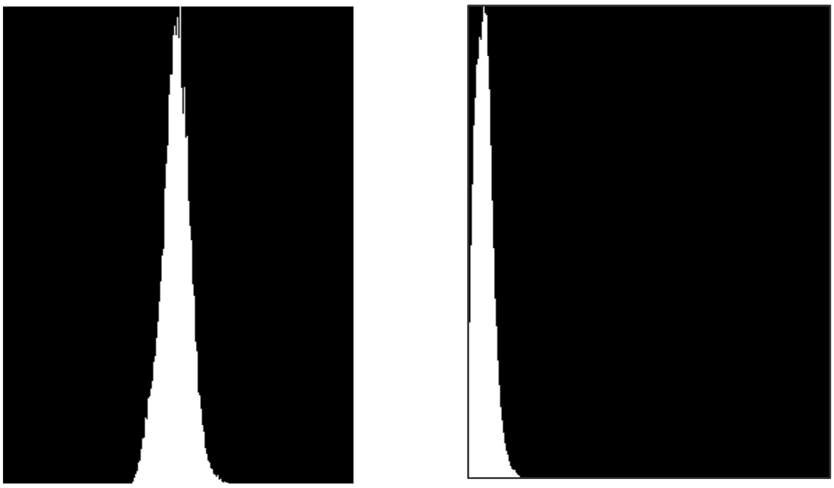


Fig 3 Watermark detection flowchart

Step 3 Histogram analysis

This is the most important step since it has a profound impact on the system's robustness. Here two threshold values are estimated based on histogram analysis. The low threshold value, *t1*, is used to generate the mask image while the high threshold value, *t2,* is used to obtain the marker image). The histogram analysis technique is based on the following assumtions:

- the histogram is shifted back to the origin and the noise has a gaussian distribution (figure 4)
- the average value of the watermark pixels is greater than the average of the background pixels.
- the number of pixels belonging to the watermark is relativelly small compared to the total number of pixels of the image



(a) Histogram of the original image

(b) Histogram of the image obtained after top-hat operator

Fig.4 Typical watermark histograms

The threshold values *t1*and *t2* are estimated using both, the histogram and the cumulatuive histogram. Taking into account the first two assumtions, an empirical method to obtain the mask threshold *t1* is to allocate it a value that is twice the grey level scale corresponded to the histogram peak. The marker threshold *t2* is determined by analysing the cumulative histogram (figure 5)

Let N be the total number of pixels in the image, N_{t1} the total number of pixels with a grey level below *t1* (mask threshold) and N_{t2} the total number of pixels with a grey level below *t2* (marker image). Therefore, $N_{mask}= N – N_{t1}$ represents the number of pixels in the mask image and $N_{marker}= N – N_{t2}$ represents the number of pixels in the marker image.

The marker threshold $t2 = t1 + c$ is initially applied to the image with the constant c having a predefined value (c=4). The ratio between the number of marker pixels and the number of mask pixels is then checked to ensure that we have reduced the noise sufficiently while retaining as much of the watermark as possible. If the ratio is too large then the marker image has too much noise and therefore *t2* is increased by incrementing the constant *c*. If the ratio is too small then the watermark is poorly preserved and *t2* is decreased by decrementing *c*. Based on experimental results, we found that the ratio should be in the range

$$0.4 < \frac{N_{marker}}{N_{mask}} < 0.6 \quad (1)$$

The gap between the higher and the lower threshold level is usually between 3 and 5 grey levels. This method is very fast and has been successfully verified on several test images. It failed only twice out of 23 testing cases due to insufficient contrast of the watermark. A more robust implementation would have been possible if the size of the image was assumed constant and known. However, the watermark images have a strong vertical profile (i.e. the 2 peaks are strong). Therefore the threshold values *t1* and *t2* are not necessarily to be very precisely determined.

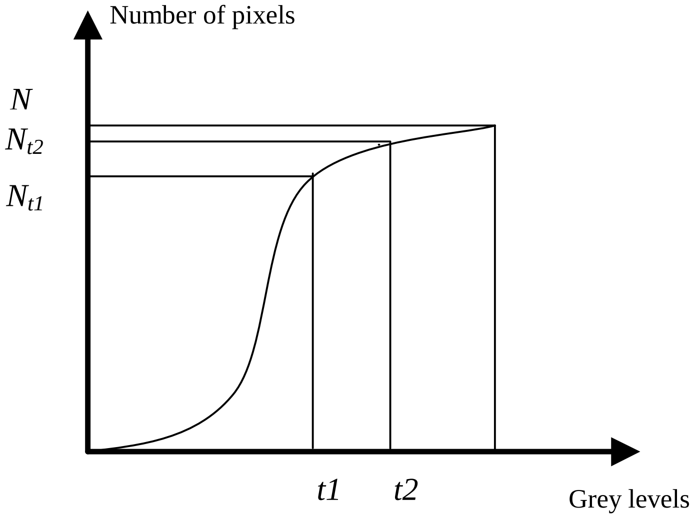


Fig 5 Using cumulative histogram in determining the marker threshold

Perhaps a simpler and robust threshold technique would consist in selecting the threshold level that outputs a percentage of object pixels closed to the ideal watermark. This method described in [3] has the disadvantage of being based on the assumptions that the size of the image known *a-priori* (this is rarely the case) and we have the ideal watermark to work from (this is difficult to estimate). Moreover this method cannot be used for start-up procedure (section 3.1) since the image may not contain a watermark.

Step 4 Reconstruction by dilation

In the reconstruction by dilation operation, the mask image is recovered by successive dilations of the marker image using fast reconstruction algorithms as detailed in

[4]. This technique is a preferable alternative to simple thresholding operation especially in the case of images corrupted by noise.

Step 5 Vertical signature analysis

This step consists of taking the vertical projection of the binary image resulting from step 4. The signature analysis plays an important role in binary vision since it can easily be computed in real time [5]. Consider *I*, the *M*x*N* size image obtained after the reconstruction by dilation step (figure 7 b). The vertical signature is a vector *V* of size *N* computed according with the following equation:

$$V[y] = \sum_{x=0}^{x<M} I(x, y) \qquad \text{where } y \in [0 \ldots N-1] \tag{2}$$

The analysis of the signature shape reveals two prominent peaks (see figure 7c) corresponding to the top and the bottom co-ordinates of the watermark text ("conqueror" for watermark shown in figure 7a). By identifying these peaks we are able to determine the vertical location in the paper sheet. Because only the text part of the watermark contains useful information for registration the speed of the system can be increased by analysing only this region. Furthermore, the size of the watermark can be estimated from this measurement which could prove useful for verification and classification purposes.

3.2 Start-up procedure

The purpose of the start-up procedure is to extract and register the first watermark once the system has been initialised. Having the first watermark registered and assuming that the watermarks are evenly spaced we can jump forward to the next watermark. This eliminates the need of analysis the regions that do not contain watermarks and therefore increases the speed of the system.

Since a simple sum of grey level pixels along the horizontal lines gives unreliable results we have adopted a method based on sliding window analysis. A small window is extracted from the row image and analysed by applying the same algorithm presented in section 3.1. If the vertical window does not reveal any significant peaks then the window advances. The process stops when two significant peaks have been detected.

4 Testing and Results

The proposed registration method has been tested on both plain and laid paper samples with diverse watermarks (figures 7, 8). The images were captured by a CCD line scan camera at a speed of 120 meters/minute in similar conditions with those in the production line. The watermark registration algorithm was implemented on a personal computer Pentium Pro 233 MHz with 64 MB RAM and running Windows NT 4.0.

As the system has reached stability (the web speed is constant) the start-up procedure locates the first watermark by searching the desired vertical profile. Once the first watermark is registered we can predict the position of the next watermark since they are separated by a known distance (e.g. A4 length). Occasionally the watermarks are not evenly spaced due to paper joints or cuts. This is taken into account by varying the size of the sliding window during the start-up procedure. The worst case start-up procedure took 661 ms, which happens to be when the first watermark has the lowest position on the row. The height of the sliding window has very little effect on the start-up time since a full A4 length has to be scanned.

The registration time for 6 watermarks at a speed of 120 meters/min and using a 60 pixels moving window including the start-up procedure is approximately 1.13 seconds. Assuming the worst case for the start-up procedure, the processing time per individual watermark is approximately 160 ms. Faster results can be obtained by using a smaller sliding window. However, sizes between 40 and 60 appear to provide the best compromise between robustness (i.e. uneven distances between watermarks) and speed.

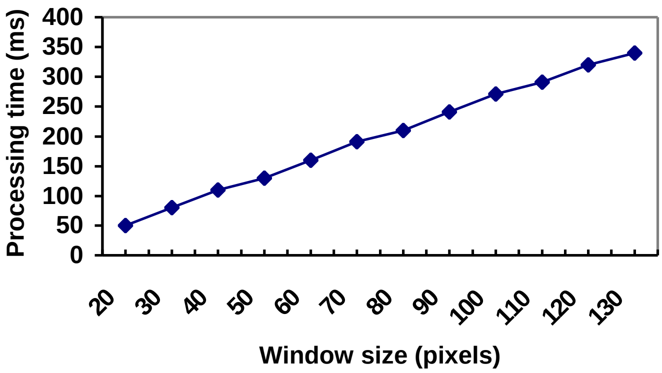


Fig 6 Processing time per watermark as a function of the size of the sliding window

The relationship between the size of the sliding window and the registration time is depicted in figure 6. The use of smaller window size increases the possibility of miss-registration due to insufficient information while a window with a large size may capture more then one watermark thus confusing the registration.

5. Conclusions

In this paper, a robust method for real-time registration of both, plain and laid paper watermarks has been proposed. It is based on simple morphological operation followed by the vertical profile analysis. Experimental results have proven the effectiveness of our technique even when the quality of the images is poor. The main advantage of this system is that it eliminates the need for the registration region placed on the sides of the paper web. This region represents approximately 3% of the total amount of paper produced.

To ensure the maximum performance of the system further testing has to be carried out on a large database of watermark images. Further research will also be focused on the real-time registration of complex watermarks.

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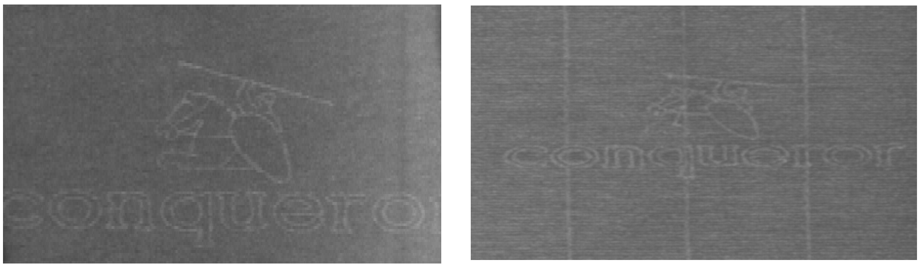
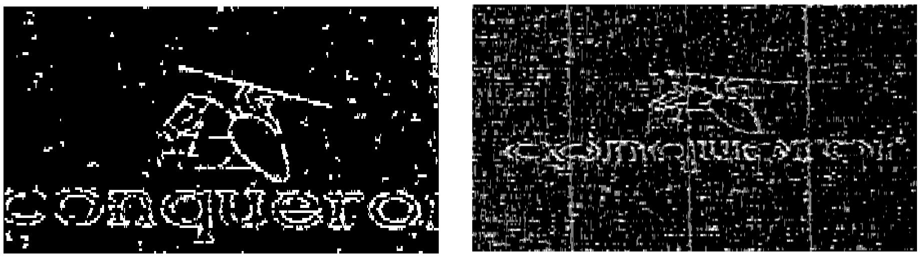
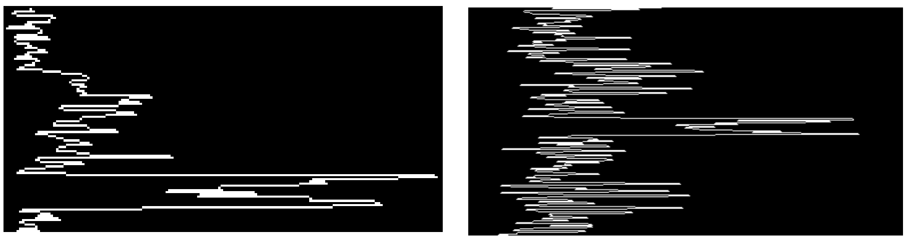


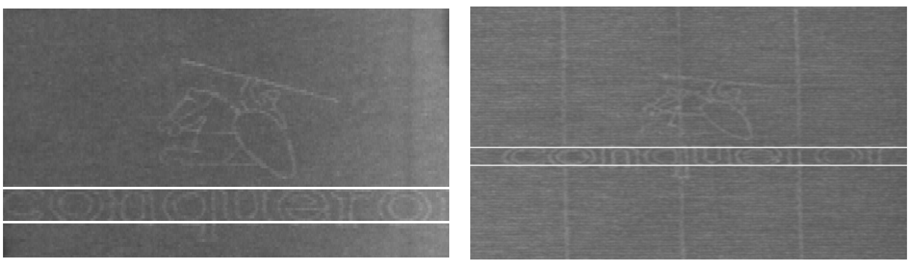
(a) Original images



(b) Reconstruction by dilation



(c) Vertical signature



(d) Two most prominent peaks generated by the vertical signature (c) are isolated

Fig 7. Watermark registration sequence for plain paper (left column) and laid paper (right column)

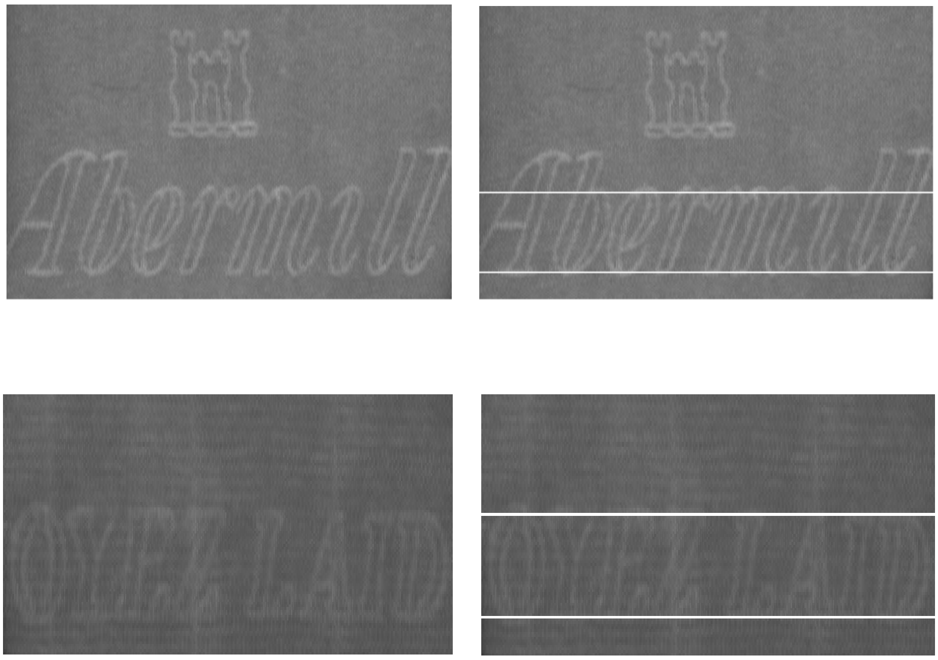


Fig 8 Application of registration to sample watermarks

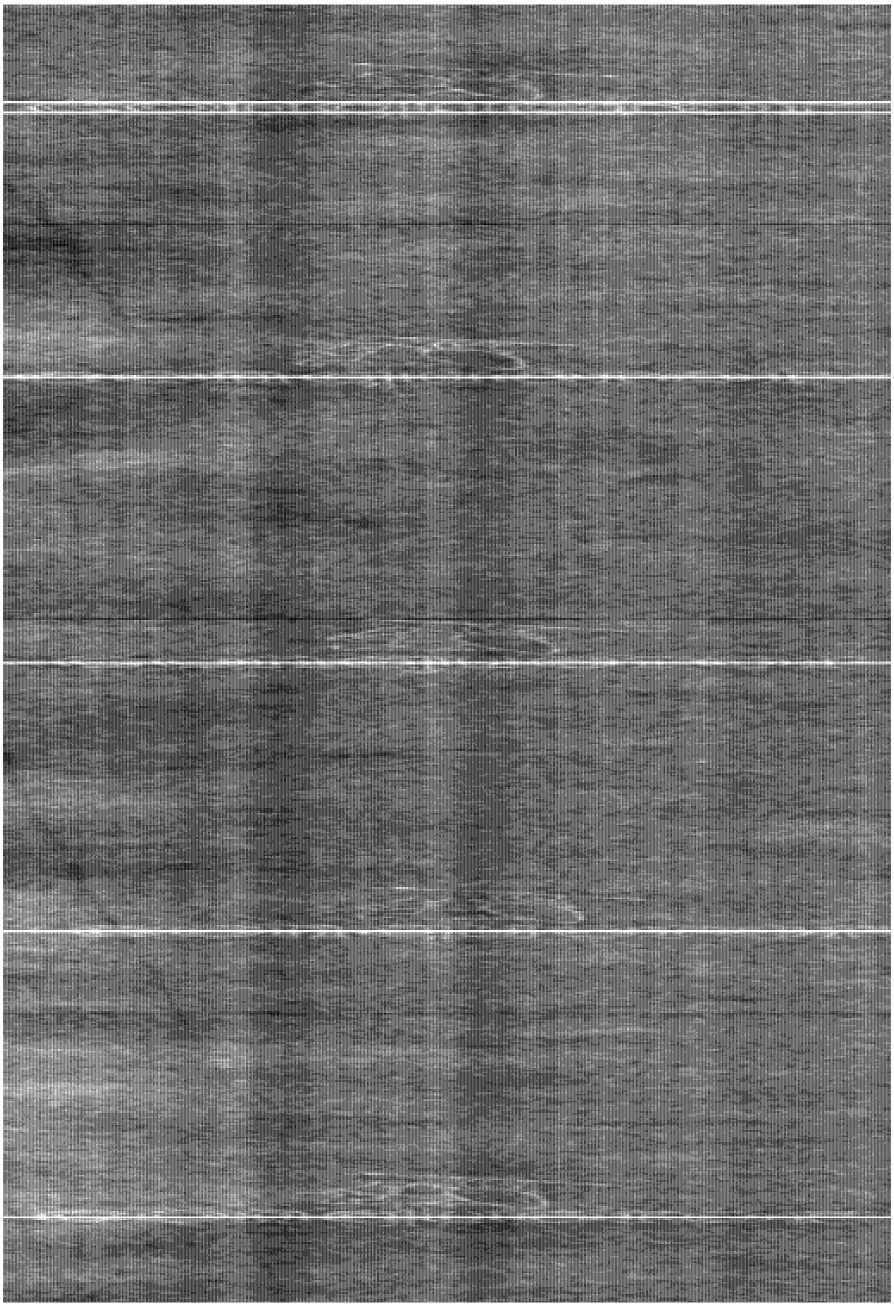


Fig 9 Real-time registration of plain paper watermark. The images were taken at 120m/min. The double white lines indicate the first watermark detected. The single line indicates the registration co-ordinate