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Abstract. Fabric's smoothness is a key factor in determining the quality of finished textile products and has great influence on the functionality of industrial textiles and high-end textile products. With popularization of the zero defect industrial concept, identifying and measuring defective material in the early stage of production is of great interest to the industry. In the current market, many systems are able to achieve automatic monitoring and control of fabric, paper, and nonwoven material during the entire production process, however online measurement of hairiness is still an open topic and highly desirable for industrial applications. We propose a computer vision approach to compute epipole by using variable homography, which can be used to measure emergent fiber length on textile fabrics. The main challenges addressed in this paper are the application of variable homography on textile monitoring and measurement, as well as the accuracy of the estimated calculation. We propose that a fibrous structure can be considered as a two-layer structure, and then we show how variable homography combined with epipolar geometry can estimate the length of the fiber defects. Simulations are carried out to show the effectiveness of this method. The true length of selected fibers is measured precisely using a digital optical microscope, and then the same fibers are tested by our method. Our experimental results suggest that smoothness monitored by variable homography is an accurate and robust method of quality control for important industrial fabrics. © 2012 SPIE and IS&T. [DOI: 10.1117/1.JEI.21.2.021103]

1 Introduction

The smoothness of fabrics is essential to the quality and functionality of finished industrial textiles and high-requirement textile products, such as spacesuits, aircraft interior fabrics, and conveyor belts. The glass fiber fabric considered in this paper can be coated with polytetrafluoroethylene (PTFE), for example, prior to its use as a conveyor belt. For high specification articles, fabric substrates such as glass fiber or Kevlar should meet high requirements for heat resistance. Since PTFE is an expensive material with a lengthy coating process, the base fabrics must be of first-rate quality, with no weaving faults or broken fibers that may project through the coated surface.¹ In addition, special functional nonwoven fabrics and wiper/paper also need flat surfaces. Surface finishing of nonwoven material is aimed at removing the fuzziness. For paper, optical properties depend on roughness, which affects the printing and coating quality. Therefore, detection and measurement of hairiness has become of great interest,² and 3D online measurement is presently in high demand.

Methods for automatic textile defects detection are based on statistical, spectral, or model-based approaches and can be achieved through web inspection of textured materials.^{3,4} However, currently available fabric inspection systems are mainly using vision systems to automatically detect defects, but not necessarily measurement.⁵ For instance, Campbell et al.⁶ used a camera to capture images of fabric at specific locations on the conveyor belt, such as on the edge of a roll. The defects at such specific locations are more easily highlighted by the illumination system allowing efficient edge detection, threshold, and filtering techniques to detect defects.

Smoothness measurements are usually taken off-line in a laboratory environment by using 3D optical microscopy, profilometry, stereovision systems, or confocal laser scanning microscopy. One can then obtain a variety of surface data or 3D mapping of the surface.^{7,8} However, in fiber hairiness testing, the scale of the fine fiber or broken filament is extremely small compared to the field of view. The fiber defect's length may vary from tens of micrometers to

about one centimeter, which usually exceeds the maximum scanning range of the microscope. In this situation, conventional testing equipment often cannot automatically capture the surface map of a fabric and therefore cannot be applied to online textile surface inspection. In this work, we used a VHX 600 digital optical microscope to manually measure defect dimensions in order to compare the reliability of our method.

In order to measure the height of the fiber online, we made an investigation of possible 3D measurement methods. Stereovision is a well known method to measure the distance or make 3D reconstructions of objects. The major weakness of stereovision for our textile application is the difficulty in precisely calibrating the system. Analyzed surface is about 1 cm², and at this scale, an operator-made calibration would be delicate and long. An interesting alternative could be planar stereovision, where a simple triangulation is sufficient to determine the height of emergent fibers. But in our case, right and left images are obtained by a single camera, which takes two successive images of the textile fabric moving in translation. In this situation, the overlap area size in both images is variable (and depends on the speed of the textile fabric conveyor), and therefore triangulation cannot be used to compute the depth.

In this paper, we propose an original approach to measure textile defects elevation. We will use the principle of variable homography and apply it to 3D measurement. With this method, the advantages are as follows: (1) the overlap area size in both images can be variable; (2) a simple planar calibration is sufficient to calibrate the system.

At first, we recall the fundamentals of variable homography and explain the relation between variable homography and epipolar geometry. A second section is devoted to simulations in order to prove the interest of this method. The last section concerns the experimental validations of this method compared to traditional optical quality controls.

2 Theory and Principle

The theory we use to measure surface regularity is based on the work of Zhang and Greenspan,⁹ who introduce a variable homography method to compensate parallax effects during mosaic image reconstruction for planar stereovision systems. We have extended this work to propose an original method to compute the height of emergent fibers in textile fabric. This method is interesting when the distance between both cameras is unknown, and when 3D calibration is not easy to process, which is the case for this application. In this part, we first introduce the theory of imaging principle and variable homography, and then demonstrate its extension to 3D measurement by using a single camera.

2.1 Imaging Principle

We consider the projection of a point onto the image plane, considering a 3D orthonormal coordinate system centered on the optical center of the lens. If P_A and P_B are two points with the same X, Y coordinates but located at different depths, a relation between their projections can be obtained. To demonstrate, we suppose that the intrinsic matrix of the camera is known. Figure 1 illustrates the projection of P_A and P_B on the camera plane. Equation (1) [resp. (2)] gives the relationship between P_A (resp. P_B) and its projection P_{RA} (resp. P_{RB}).

Fig. 1 Imaging principle.

$$P_{RA} = w_{RA} \cdot \begin{pmatrix} u_A \\ v_A \\ 1 \end{pmatrix} = \begin{pmatrix} f & 0 & u_0 \\ 0 & f & v_0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} X_A \\ Y_A \\ Z_A \end{pmatrix}. \quad (1)$$

$$P_{RB} = w_{RB} \cdot \begin{pmatrix} u_B \\ v_B \\ 1 \end{pmatrix} = \begin{pmatrix} f & 0 & u_0 \\ 0 & f & v_0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} X_B \\ Y_B \\ Z_B \end{pmatrix}. \quad (2)$$

We note: u_0, v_0 : principle points of the camera, f : focal = $w_{RA} = w_{RB}$ = distance from optical center to camera plane in pixel.

Assuming that $X_A = X_B, Y_A = Y_B$, and defining k as being the depth ratio between planes A and B ($k = Z_A/Z_B$), with Eqs. (1) and (2) one can obtain relation between P_{RA} and P_{RB} [(Eq. 3)].

$$P_{RB} = \begin{pmatrix} u_{RB} \\ v_{RB} \\ 1 \end{pmatrix} = \begin{pmatrix} k & 0 & (1-k)u_0 \\ 0 & k & (1-k)v_0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} u_{RA} \\ v_{RA} \\ 1 \end{pmatrix} = K \cdot P_{RA}. \quad (3)$$

Variable homography, described in the following paragraph, is based on Eq. (3). By knowing the projection of P_A and P_B in the same camera, we still cannot calculate the distance between two layers. Therefore, we are looking for a relation of the projected points from the same layer in two images.

2.2 Variable Homography

Homography is an important transformation matrix in image registration. It can be used to calculate the transformation of different planes in an image or the transformation of the same plane in different images. Hartley and Zisserman¹⁰ define homography as “an invertible transformation from the real projective plane to the projective plane that maps straight lines to straight lines.” Homography is a 3×3 matrix defined as:

$$s \cdot P_R = s \begin{pmatrix} u_R \\ v_R \\ 1 \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{pmatrix} \begin{pmatrix} u_L \\ v_L \\ 1 \end{pmatrix} = H \cdot P_L, \quad (4)$$

where P_R is a specific point from the right camera image and P_L its corresponding point from the left camera image, and s is a

scale factor. Homography (H) is usable for points located in a same plane.

Since homography is a plane to plane relation, this transformation will automatically fail for a 3D scene with multiple planes. For planar stereovision, Zhang and Greenspan⁹ propose to link homographies of parallel planes, with variable homography. Figure 2 presents a geometric configuration with variable homography. Equation (3) can be extended to the left camera with points P_{LB} and P_{LA} .

From this figure, we have:

$$P_{RA} = H_A P_{LA} \quad \text{and} \quad P_{RB} = H_B P_{LB}. \quad (5)$$

If plane A and plane B are parallel, with Eqs. (3)–(5), Zhang and Greenspan determined that homographies H_A and H_B are related to each other by:

$$H_B = K H_A K^{-1} \quad (6)$$

This equation gives H_B without calibration points in plane B, but only by knowing H_A , cameras intrinsic matrices and the ratio k . Equation (6) is also applicable even if plane A and plane B are not parallel to the cameras planes.

In the original paper, Zhang and Greenspan⁹ use their method to compensate the effect of parallax in mosaic images. They compute optimal values of k on overlapping regions in order to facilitate the merging of objects lying at different depths. Their objective is to find the best scale factor k to ensure an efficient merging and thus to avoid abrupt changes in computed mosaics. In the next paragraph, we extend this approach to obtain a 3D measurement of emergent fibers in textile with a single camera.

2.3 Extension of the Method to Height Measurement with a Single Camera

When the analyzed fabric is placed on a conveyor belt running along the X -axis, left and right images can be grabbed with two shoots by using a single camera. This situation is equivalent to the one presented on Fig. 2 and variable homography previously explained can be applied in these acquisition conditions.

Our goal is to measure the height (h_{defect}) of the emergent fiber, which is the difference between Z_A and Z_B (see Fig. 2).

To measure this height $Z_A - Z_B$, a simple triangulation could be sufficient if the distance between cameras is known. But here, even if the conveyor speed is adjusted to 10 cm/s, eventual tension or friction phenomena of the

Fig. 2 Camera configuration for variable homography set-up.

fabric produce variable fabric displacements between two acquisitions. Therefore, triangulation is not suitable to compute the height $Z_A - Z_B$.

To measure the emergent fiber in this case, we propose an alternative method by using variable homography. This method is well adapted to measure emergent fibers on fabrics, where the background is considered as being plane A, and the top of emergent fibers is supposed to be on plane B as shown in Fig. 2. The homography H_A is calculated with matching points located on the background of the textile fabric. Then the corresponding emergent fibers, seen as points P_{RB} and P_{LB} , can be used to solve Eq. (7) to determine k .

$$P_{RB} - K \cdot H_A \cdot K^{-1} \cdot P_{LB} = 0. \quad (7)$$

If Z_A is known, the height of emergent fiber h_{defect} depends only on k .

$$h_{\text{defect}} = Z_A - Z_B = Z_A - \frac{Z_A}{k}. \quad (8)$$

Z_A is constant if the camera plane is parallel with plane A and can be easily determined as well as intrinsic camera parameters during the initial calibration process.

A difficulty remains in the resolution of Eq. (7). In fact, this matrix relation is a system of three equations which can be reduced to two equations after standard normalization is applied for homography computation. If the matching of P_{LB} and P_{RB} is exact (ideal conditions), both equations are

Fig. 3 Relation between variable homography and epipolar line.

equivalent and their solution leads to two identical solutions for k .

But in experimental conditions where P_{RB} and P_{LB} are never exactly matched, two different values of k are found. Therefore we propose an alternative to compute k by combining variable homography with epipolar geometry.

2.4 Use of Variable Homography to Compute Epipoles

Variable homography can be linked to epipolar geometry. Indeed, in Fig. (3), P_{LB} is projected onto right camera plane using Eq. (6) with different values of k . The corresponding projections $P_{RB}(k)$ are then located on epipolar line. The interest is to compute epipolar line as a parametric function of k , and in experimental conditions, solve Eq. (7) and find k without ambiguity.

We can get the best corresponding point P_{RB} of P_{LB} located near the epipolar line by a correlative method. In experimental conditions, where P_{RB} is never exactly on the epipolar line, we retain k minimizing the distance between $P_{RB}(k)$ and P_{RB} (Fig. 4), as usually done in stereovision.

The combination of variable homography and epipolar geometry leads to find the best value of k . Z_A has been previously determined and therefore h_{defect} can be computed.

2.5 Experimental Set-up

We have to measure hairiness defects between one and five millimeters. The distance between the camera and the fabric is about 7 cm. In our prototype we use an IDS uEye 1240 SE monochrome camera built with a 1/2 CMOS sensor with a 1280×1024 resolution, which can deliver images at 25 frames per second in free run mode. The exposure time of each frame is 0.5 ms and the speed of fabric is about 10 cm/s. We have fixed the delay between two acquisitions at 60 ms, which ensures an overlap of minimum 40% between both images.

The camera is mounted with a 25 mm lens and an additional 10 mm ring extension to focus on the surface with a proper Z_A . With our prototype described in Fig. 5, we analyze an area of approximately 1 cm². We have chosen a laser line light to illuminate the fiber defect in order to detect it with segmentation based on a simple threshold technique.

This laser line is placed about 2.5 mm over the fabric and produces a grazing incidence beam on the fabric, which is

Fig. 4 Zoomed right and left images to determine the minimum distance between P_{RB} and epipolar line.

Fig. 5 Experimental proto-type and actual set-up for measurement validation.

used to compute Z_A and k without needing any other light system. Therefore, during acquisitions, the area of the fabric has to be protected against external illumination devices or ambient lighting. The power of the laser light leads to easy detection of the emergent fiber on an area of several pixels because of the diameter of the detected fiber. P_{RB} and P_{LB} are computed by taking the gravity centers of each spot light in right and left images. The Gaussian distribution of the laser beam slightly illuminates the background of fabric and then, a Harris corners detector can be applied to compute H_A .

Figure 6 outlines the main steps of the experimental process. First, like all the existing vision measurement systems, a standard calibration is done to determine the intrinsic parameters of our camera. During this stage, a mini-chessboard (1×1 mm) and a calibrated object (stair seen on Fig. 7) are used to determine the reference distance Z_A . This distance represents the distance between the optical center and textile fabric. Between two acquisitions separated of 60 ms, fabric textile is displaced about five millimeters. In step 5,

a standard corners or key points detector (as Harris and Stephens¹¹ or SIFT¹²) associated with the RANSAC algorithm¹³ is used to compute homography (H_A), which links left and right images for all points of the fabric's surface. In step 6, standard image processing functions are used to detect the bright spots in the left image, and their corresponding points in the right image are automatically found by using a correlation method. The bright spots are those fibers illuminated by the laser line and represent the fibers emerging from the fabric surface. From these correlations, in step 7, we compute the corresponding height (h_{defect}) of these fibers as described previously. In step 8, we copy the left image in right image for the next iteration. The algorithm returns to step 3 and wait 60 ms comprising the computation time of steps 4 to 8. This prototype allows us to validate the measurement method and proves, with the evaluation of computation time (<44 ms), that the process can be executed in real-time in consideration of displacement parameters presented previously (60 ms between two snaps).

Fig. 6 Main steps of the fiber defect measurement method and computation times evaluation using the optimized image processing library (OpenCV Windows, Intel® core™ i3).

Fig. 7 3D pattern (on left), an example of measurement (mm) by VHS (in the middle) and by VHX 600 (on right).

3 Simulation of Experiment Conditions

In this section, several simulations are performed, taking into account real conditions for the application of the textile industry. First, we simulate the accuracy of the measurement when a bad match occurs between P_{LB} and P_{RB} . Then one describes the influence of a non flat surface on the computation of H_A . We also simulate the presence of eventual vibrations, which may occur during the scroll of the fabric on the conveyor belt. Finally, we simulate the

precision of the measurement when the calibration plane is not exactly parallel with the image camera plane.

3.1 Simulation of Non-Exact Correlation

This section describes the way to perform simulations to validate the method and estimate the accuracy of the measurements. We focus our attention on errors induced by non-exact correlations between the right and left images. Even if the correlation is known to be precise, the laser line causes some saturated areas, and a small shift could sometimes be observed between the defect found by the correlation and a visual estimation. This method exploits the parallax due to the height of the fiber defect. Following the direction of the corresponding error, the measurement on h_{defect} will be affected differently. Figure 8 shows two images obtained from left and right cameras with the translation following X and Y -axis, respectively. The bright line in both images is the detected emergent fiber on glass fiber fabric displayed in different positions, and the red cross represents the corresponding area obtained by correlation. In Fig. 9, we display the computed measurement for the shift of simulated displacement along the epipolar line.

Parameters for the simulations are the same as for the prototype described previously, and the Z_A reference distance is fixed at 7 cm.

Simulations for 1 and 5 mm object heights are presented in Fig. 9. When a corresponding point in the right image is

Fig. 8 Simulation of pixel displacement. (a) Left image: a fiber defect is detected. (b) Right image: the red cross represents the corresponding area obtained by correlation, while the arrow represents the displacement direction used for simulations.

Fig. 9 Simulated height estimations for defects of 1 mm (a) and 5 mm (b), when corresponding points in the left and right images are mismatched (from 1 to 5 pixels).

Fig. 10 Irregular structure of the fabric and different Z_A .

shifted from -5 to $+5$ pixels, a linear variation of the computed height arises. This is an expected result arising from the projective camera model.

The linear variation will affect the error made in real applications when the range of measured height is different. For example, with a 1 mm height, a 1 pixel error for two matching points will produce a relative error of 5%. Conversely, the same 1 pixel displacement for an object of 5 mm height will produce a relative error of approximately 1%. For experimental measurements, the determination of matching correlations is of great influence on the final precision, especially for low elevation fibers.

3.2 Simulation of Noise on Z_A

H_A is computed with corresponding points located on the background of the textile fabric. But textile surfaces are not flat, due to the weaving. Therefore those points used to compute homography H_A are not well aligned in a plane, as represented in Fig. 10. In experimental conditions, this introduces inaccuracies on H_A calculation and consequently on the position of the reference plane A. With our glass fiber fabric, the maximum convex value is about 0.5 mm. RANSAC algorithm, used to compute H_A , helps to keep the best aligned points, but the exact Z_A distance of this plane to the

coordinates system is unknown, and this plane is not necessarily parallel with the image camera planes.

In Fig. 11, we present the simulation obtained for an emergent fiber of 2 mm. We add a white noise on Z coordinates of calibration points used to compute H_A . This noise is generated with maximum amplitude of 0.5 mm. Z_A is fixed at 7 cm and the simulated emergent fiber of 2 mm height is aligned with the left camera optical axis. We have resumed the 3000 trials on a histogram presented on Fig. 11. This figure shows that error is kept below $\pm 5\%$.

3.3 Simulation of Vibrations of the Fabric Plane

In our application, both acquisitions are done with a single camera when the fabric is moving on the conveyor belt. In this section, we propose to study the influence of eventual vibrations of the fabric. The consequence of these vibrations is that between two camera snaps; the distance from the camera to the fabric plane varies. Figure 12 gives the simulation set-up used to compute the influence of vibration amplitude $d = \pm 2.5$ mm on a fiber measurement of 2 mm with $Z_A = 7$ cm.

Results of simulations (Fig. 13) show that the relative error measurement on a fiber height of 2 mm is lower than 1% when the vertical displacement is comprised between ± 2.5 mm. This good result can be explained by the fact that both values Z_A and Z_B are used to compute h_{defect} and are also both affected by the displacement (right camera on Fig. 12). Therefore, if we compare the ratio of $(Z_A + d)/(Z_B + d)$ to Z_A/Z_B , the error induced by the vibration has no significant impact.

3.4 Simulation of a Fabric Plane not Parallel to Camera Image Planes

Another case may happen during real production, when the fabric is not strictly parallel to the image plane. In this case, the principle of variable homography remains valid. With our algorithm, the computed value of k is always correct, but is not constant on the whole image because Z_A and Z_B depend on X_A and Y_A . If we compute the height (h_{defect}) with Eq. (8) with a constant value for Z_A , as done in the ideal conditions, the 3D measurement is affected by the tilt between the fabric

Fig. 11 Simulation of a 2 mm fiber height measurement when calibration points to compute H_A are not exactly in plane A.

Fig. 12 Simulation set-up for the influence study of vibrations of the fabric.

Fig. 13 Simulation of a 2 mm defect on a fabric with a vertical displacement of the fabric from -2.5 mm to $+2.5$ mm between the acquisitions.

Fig. 14 Simulation set-up for the influence study with a tilt angle α .

plane and the camera image planes. We propose to evaluate the influence of this non-parallelism. In Fig. 14, we represent the condition of simulations in which the fabric is tilted with a small angle α . In Fig. 15, we see that with an expected result of 2 mm, the computed height forms a parabola shape with a tilt angle from -3 deg to $+3$ deg.

In real conditions, these extreme values represent a high tilt due to the tension of the conveyor system. In fact, a tilt can also be observed if the camera position is

Fig. 15 Simulation of a 2 mm defect on a fabric with a tilt angle α from -3 deg to $+3$ deg.

deteriorated. These results show that with a tilt angle, the measured results are always higher than the true value, which is an expected result corresponding to the geometry of the system. The error stays below 10%, and is therefore eligible in our application. However, one should take care to avoid any tilt in the experimental set-up in order to keep the global accuracy of the measurement in an acceptable range.

3.5 Conclusion on Simulation Results

Most of the simulations presented in this part have been done by placing the emergent fiber at the same distance from both cameras. During real conditions, the emergent fiber can be located anywhere on the fabric, and simulations done in these conditions confirm that the global accuracy remains in the same range order. In conclusion, the simulation results show that despite the different experimental situations that could occur in our application, the global accuracy is about 10%, which conforms to industrial specifications. This measurement accuracy is confirmed in our experimental results presented in the next section.

4 Experimental Results

In this section, we validate the method by using a 3D calibrated pattern. Then VHS (Variable Homography System) measurements on glass fiber fabric, which is our target application, and other textiles are presented and compared with the results obtained with a VHX 600 Keyence microscope.

4.1 Validation of the Method

A calibrated 3D pattern has been built in order to validate the VHS method. This object is stairs with 5 steps of 1 mm (see Fig. 7). The pattern is placed on a chessboard to facilitate the homography computation H_A . We use one camera and translate the set-up of about 2 millimeters along X and/or Y axes for each measurement. On the middle image of Fig. 7, an example of results obtained at each step on the stairs is given. The right image shows an example of 3D reconstruction with the VHX 600 microscope. Table 1 compares results where 20 measurements for each step have been done on the same acquisition.

These results are in adequacy with the previously presented simulations. A maximum error of about 10% is observed on these experimental results with our VHS

Table 1 Measurements comparison between VHS and VHX 600 (20 trials have been done for each step on the 3D pattern).

Height expected	VHS measurements		VHX 600 measurements	
	Average of measurements	Standard deviation	Average of measurements	Standard deviation
1 mm	1.03 mm	0.06 mm	1.01 mm	0.2 mm
2 mm	2.07 mm	0.06 mm	2.01 mm	0.2 mm
3 mm	2.96 mm	0.04 mm	3.01 mm	0.2 mm
4 mm	3.99 mm	0.04 mm	4.02 mm	0.2 mm
5 mm	5.11 mm	0.08 mm	5.03 mm	0.2 mm

measurements, and they are close to those obtained with the VHX 600. Therefore, our method is validated and can then be tested on real emergent fibers.

4.2 Glass Fiber Fabric Defects Measurement

In this section, a representative result is obtained on actual glass fiber fabric. On this test specimen, one fiber is extruding from the surface of the fabric.

Figure 16 is a comparison of the results between our VHS and VHX600 digital microscope with the same corresponding area. This figure is a single representative example of comparison; other comparisons are summarized and commented in the next part. The fiber is well illuminated by

the laser line in image (a). This allows easy detection of the top of the emergent fiber and its matching with the right VHS image.

Our system measures a defect height of 980 μm , compared to 870 μm measured with the VHX 600 microscope. The relative error between these measurements is in the order of 10% and confirms the precision estimated by previous simulations and tests on calibrated objects. Note that the VHX 600 microscope cannot give an absolute measurement, and the results are also affected by dimensional uncertainty. However, the similar results obtained with these two methods lead to comfort us in the interest of our method.

Fig. 16 Zoomed view of a glass fabric defect (a) Left image and result obtained from VHS (b) Image and result obtained from VHX 600 digital microscope.

Fig. 17 Comparison results of VHS and VHX 600 with different materials (the values represent the average measurement obtained on 20 tests and vertical bars highlight the standard deviation).

4.3 Other Textile Fabric Fibers Measurement

To examine the usability and accuracy of VHS, we have done 20 tests on different materials. Figure 17 indicates defect elevations measured from the VHS and VHX 600 systems for different materials, such as glass fiber fabrics with different shapes of defects (emergent and loop), paper/wiper, felt, and nonwoven materials.

With glass fiber fabric, the results are close to the previously obtained results whatever the shape of the defect. With other materials, a notable difference can be observed. A reason for this difference can be related to the nature of the fabrics. For example, the texture of wiper fabrics is granular and disturbs the selection of the dominant plane A . We conclude that our method is well-adapted to materials such as glass fibers, where the background surface is relatively flat and easily detectable. The acquisition conditions being the same as for Sec. 4.1, the average measurement errors are estimated to be of similar order.

5 Conclusions and Future Work

We have presented an original method for 3D measurements. We have demonstrated that the combination of variable homography with epipolar geometry can lead to an alternate method for 3D measurements. This method is especially interesting when the stereovision acquisition is done by a single camera and when the 3D calibration is not easy to perform. Simulations have been performed to prove the validity and estimate the robustness of this method. These simulations have taken into account real industrial conditions such as vibrations or nonalignment of the image sensor and the sample being examined. Experimental evidence confirms that precise depth measurement in the 1 mm to 5 mm range is achieved. The results from our VHS have been confirmed by laboratory equipment—VHX 600 optical microscope, and also with several trials performed on different materials. We have also shown with the benchmarks computed with OpenCV library, that our variable homography setup can operate on-line in real-time. The interest lies in an easy planar calibration adapted for real-time applications. Experimental results presented in this paper show that the aim to measure emergent glass fabric fibers is achieved with an estimated accuracy of 10%. Considering real production conditions, when it is often not necessary to precisely measure the defect while detecting it, the manufacturer can calibrate the system according to its requirements or ISO standards.

Our future work will focus on enhancing our prototype for on-line and real-time defect detection and measurement.

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