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Automated dyeing of free-form leather patch edges: a Machine Vision based system

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Abstract

Many fashioned leather goods are characterized by seamless but visible edges, finished by means of time-consuming iterative processes involving edge grinding and subsequent dyeing. In the last years great efforts have been made by scientific and technical community to automate many leather manufacturing processes; therefore, the need to carry out manually the edge dyeing procedure represents a bottleneck for the entire leather finishing process. As a consequence the development of an automated dyeing procedure is advisable. The main purpose of the present work is to describe a Machine Vision based system for automatically dyeing leather patch edges. Such a system comprises two main parts: a Machine Vision (MV) system devoted to leathers edge detection and a CNC painting pantograph (2 axis Cartesian robot) whose painting tool is moved according to the output of the MV apparatus. The developed system, tested on a prototype dyeing machine, proved to be effective in delivering high quality edge finishing.

1 Introduction

Fashioned leather goods such as handbags, leatherwear, luxury briefcases, travel bags, purses, wallets and leather diaries are usually branded by seamless but visible dyed edges whose visual appearance represents a key issue in terms of quality grading; a high-quality leather product has to be characterized by homogeneously coloured and shaped edges with uniform ink thickness as depicted in Fig. 1.

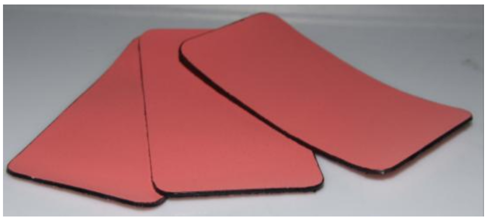


Fig. 1 Leather patches featuring black dyed edges.

Usually, edge dyeing of leather patches is manually performed using particular grinding-polishing-dyeing machines involving time-consuming iterative finishing processes.

The recent trend towards unsupervised machining centers, equipped with properly developed controllers, encourages companies working in the field of leather finishing to provide themselves with tools for automatic edge leather dyeing.

In the last years great efforts have been made by scientific and technical community to automate many leather manufacturing processes by using Machine Vision (MV) systems, especially for leather inspection and classification, for nesting, cutting and gluing processes. A machine-vision-based approach for grading leather hides for footwear industry is proposed in [1]; tools for automatically inspecting leather surfaces have been proposed so far in [2 – 7] with the aim of detecting scars, mite nests, warts, open fissures, healed scars, holes, pin holes, and fat folds. Such features are investigated, by using statistical or other computing techniques (e.g. neural networks (NNs), fuzzy systems (FSs) and support vector machines (SVMs)) [8, 9].

LASER and water jet cutting machines are widely employed [10]; generally speaking, such machines comprise a table where the leather is arranged and a cutting station provided with the cutting device. Both systems may be, substantially, defined as CNC machines which process 2D leather CAD sketches providing the proper cut path. These systems overcome the limitations of classical leather cut, usually performed by means of pneumatic presses which set on metallic dies manually positioned by the operators. Some systems have also been devised in order to help manual edge dyeing; such systems distribute the ink on a cylinder so as to provide, steadily, the right proportion of ink while the operator properly move the leather patch.

Unfortunately, even when systems like the one mentioned above are used, edge dyeing procedure is, still today, manually performed by human operators; a skilled operator will pay close attention to grinding and dyeing performance particularly when a new combination of tool, material and colors are being tried. However, since dyeing process may be repetitive and time-consuming, the quality of obtained product highly depends, not only on operator expertise, but also by ensuing fatigue and inattentiveness. Therefore, the need to carry out manually the edge dyeing procedure represents a bottleneck for the entire leather finishing process.

As a consequence, the development of an automated process for free-form leather edge dyeing would be extremely useful since it could allow a considerable reduction of processing time and higher quality edge finishing.

The main objective of the present work is to provide a system for automatically dyeing leather patches' edges.

Such a system comprises two main parts: a Machine Vision (MV) system devoted to patches' edges detection and a CNC painting pantograph (2 axis Cartesian robot) whose painting tool is moved according to the output of the MV apparatus. Some of the advantages of the devised system are: it is a more reliable process when compared with manual process; it is automatically performed (operators only have to place the leather goods on the plane, thus avoiding problems that arise as a result of using manual operations); it can result in lower labour costs an

2 Machine Architecture

The devised automatic dyeing machine comprises the following main parts:

1) a CNC painting pantograph (2 axis Cartesian robot) whose painting tool, which has been appositely devised for the specific application, is moved according to the output of the MV apparatus (see Fig. 2).

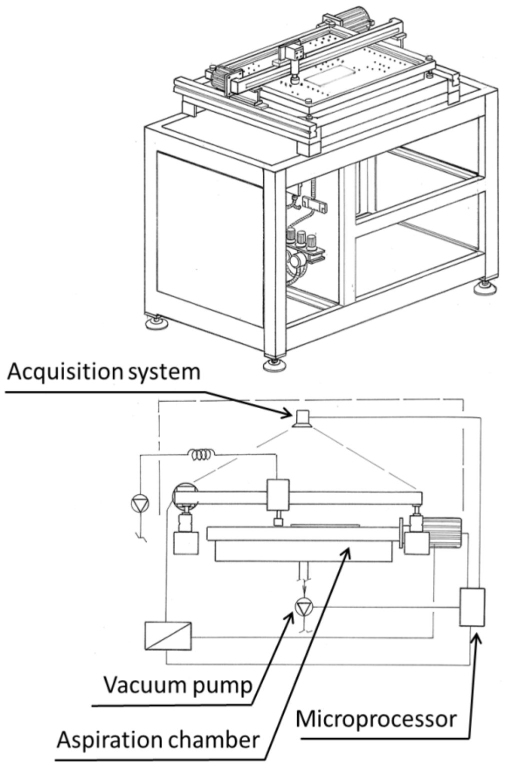


Fig. 2 Machine architecture.

2) a Machine Vision (MV) system consisting of both illumination and high resolution acquisition devices (camera), which allows to acquire images of a number of leather patches disposed on the pantograph working plane. Such images are processed by means of image processing-based algorithms in order to detect the patches' edges to be dyed.

2.1 CNC painting pantograph

The main aim of the CNC painting pantograph is to dye leather patches once patch edges are detected by the MV system. This system is composed by a frame supporting a working plane where the patches are disposed and hold in position by means of an appositely designed vacuum system. In detail, an aspiration chamber is attached to the lower side of the working plane. De-pressure is assured by a vacuum pump controlled by a microprocessor (see Fig. 2).

The plane (size 400 mm x 300 mm) has been built by means of a Rapid Prototyping machine, namely by Dimension FDM (see Fig. 3); the holes are necessary to let the aspiration air flow to hold in position the leather patches.

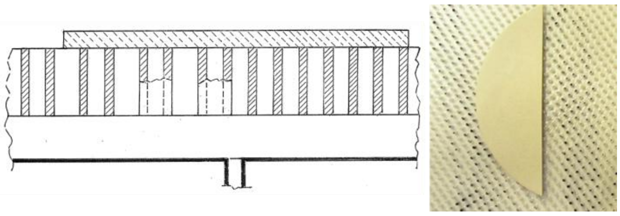


Fig. 3 Working plane.

The working plane is painted with a fluorescent ink as shown in Fig. 4; when opportunely illuminated, for instance by means of a U.V. light, the ink produces a diffuse and uniform light, in visible range, across its entire surface. This illumination system allows to highlight the differences between leather patches (objects of interest in digital images) and support plane (background).

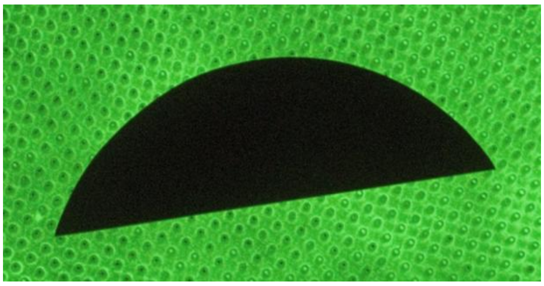


Fig. 4 Leather patch lying on the fluorescent working plane.

Attached to the plane external frame, a two axes CNC pantograph allows the movement of the painting tool by means of two stepper motors (see Fig. 5).

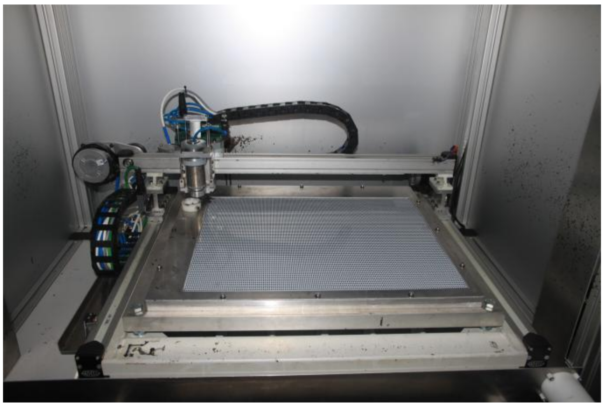


Fig. 5 Two axes pantograph.

The painting tool has undergone a large series of modifications, since its design is crucial in order to obtain the desired dyeing. In its final version it is made of a conic tip housed by a tank containing a quantity of water-based ink. Due to the high viscosity of the ink, a compressed air circuit has been used with the aim of providing, during painting phase, an adjustable pressure to the tank, thus allowing tip soaking (Fig. 6).

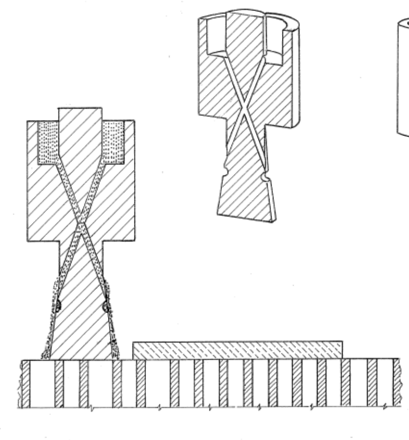


Fig. 6 Conic tip architecture.

The two X-shaped ink ducts assure that the entire tip surface is properly fed during the dyeing process and no ink accumulation occurs. In Fig. 7 the painting tool is shown in its final form. In order to provide a proper edge finishing the tip must run close to the patch edge without actually touching it. The acceptable distance between the tip and the patch has been experimentally determined and resulted to be comprised between 0.1 and 0.4 mm (0.1 mm is the optimum value). A lower distance leads the painting tool to ink leather patch upper surface; a greater distance does not allow to properly ink edges.

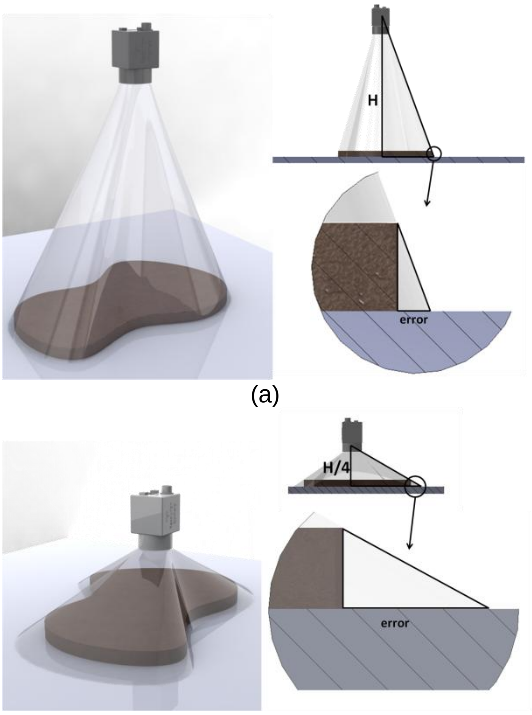
Fig. 7 Painting tool.

2.2 Machine Vision system

The MV system is required to automatically identify a series of leather patches placed on a plane. Due to the optimum distance value mentioned above between the painting tool tip and the patch edge, a spatial resolution of at least 0.1 mm/pixel was initially sought for the MV system.

Image acquisition is performed by means of a high resolution commercial camera which is placed above the plane at a distance of approximately 1500 mm. This distance is necessary to minimize the error induced by the fact that, due to central projection, upper or lower patch edges cannot be distinguished during acquisition.

In Fig. 8 are shown 2 different camera positions. In particular, the camera shown in Fig. 8a is placed above the plane at a distance equal to ¼ of the camera shown in Fig. 8b. As can be seen the greater is the distance the lower is the edge detection error due to the projection of the upper edge on the working plane.



(a)

(b)

Fig. 8 Projection error related to camera position distance from image plane.

Using the maximum allowable resolution of the camera, the spatial resolution resulted to be approximately 0.2 mm/pixel that is sufficiently close to optimum value of 0.1 mm. The camera is connected to a PC by means of an USB 2.0 port and the images are managed by using a Graphical User Interface (GUI) appositely developed in Matlab® environment.

The entire system is enclosed into a sealed cabin as shown in Fig. 9, in order to provide a totally light controlled acquisition environment.

Fig. 9 Dyeing machine external cabin.

3 Method

Beyond the development of an effective painting tool (described in section 2.1), the main tasks confronted in the present work are related to the extremely high accuracy required in the detection of leather edges in order to obtain a high quality dyeing. Detection accuracy is affected by camera lenses distortion; moreover the possibility of processing a number of leather patches with a single image acquisition must be assured. Therefore, the devised system includes 1) a camera calibration method capable of compensating the optical distortions caused by camera lenses, 2) an edge detection algorithm able to detect leather borders and 3) a “path algorithm” to guide the painting tool movement.

3.1 Camera Calibration

As widely known [11], camera calibration, often referred to as camera resectioning, is the process of finding the true parameters of the camera that produced a given image.

Accurate camera calibration and orientation procedures are a necessary prerequisite for the extraction of precise and reliable metric information from images. Usually a camera is considered calibrated if the principal distance, principal point offset and lens distortion parameters are known.

The main issues to be faced are:

- to compensate the effects of lens-induced image distortions;
- to establish a bi-univocal correspondence between the image coordinate system and the Cartesian pantograph one.

3.1.1 Compensation of distortion

With reference to the first issue, distortion compensation may be carried out by means of a flat calibration pattern [13]. Such a pattern is randomly moved near the working plane so as to be acquired by the camera. Practically, a set of 20 images of the calibration pattern in different positions is acquired.

As described in Section 3.1.2 the last acquired image is obtained positioning the pattern perfectly lying on the working plane and with its edges coincident with the CNC axis.

Let P_i be a generic 3D point (of the pattern) whose coordinates are described by a vector $P_i = [x_{ci}, y_{ci}, z_{ci}]$ in the camera reference frame as shown in Fig. 10.

As widely known, the projection of point P_i onto the image plane π, taking into account lens distortion (both tangential and radial ones), is described by a vector X_d:

$$X_d = \Im_r(X_n)\cdot X_n + \Im_t(X_n) \qquad (1)$$

Where, in the simplest case of a 2th order radial distortion:

$$\begin{aligned} X_n &= [x_{ci}/z_{ci}, y_{ci}/z_{ci}]^T \\ \Im_r &= 1 + k_{c,1}\cdot(X_{n,1}^2 + X_{n,2}^2) \\ \Im_t &= \begin{bmatrix} 2k_{c,3}\cdot X_{n,1}\cdot X_{n,2} + k_{c,4}(3X_{n,1}^2 + X_{n,2}^2) \\ k_{c,3}(X_{n,1}^2 + 3X_{n,2}^2) + 2k_{c,4}\cdot X_{n,1}\cdot X_{n,2} \end{bmatrix} \end{aligned} \qquad (2)$$

Vector k_c contains both radial ($k_{c,1}$ in this case) and tangential ($k_{c,3}, k_{c,4}$) distortion coefficients.

As a consequence, it is possible to state a correlation between each pattern point projection on the image plane X_d (referred to the camera) and its final coordinates in pixel X_p with respect to the image plane coordinate system:

$$\begin{aligned} X_{p,1} &= f_{c,1}\cdot\left(X_{d,1} + \alpha_c X_{d,2}\right) + c_1 \\ X_{p,2} &= f_{c,2}\cdot X_{d,1} + c_2 \end{aligned} \qquad (3)$$

Defining KK as the camera matrix [12-13]:

$$KK = \begin{bmatrix} f_{c,1} & \alpha_c\cdot f_{c,1} & c_1 \\ 0 & f_{c,2} & c_2 \\ 0 & 0 & 1 \end{bmatrix} \qquad (4)$$

(where $f_{c,1}$ and $f_{c,2}$ are the focal distance - a unique value in mm - expressed in units of horizontal and vertical pixels; c_1 and c_2 are the coordinates of the image principal point; the coefficient α_c encodes the angle between x and y sensor axes) it is possible to rewrite eq. 3 in the following matricial form:

$$\begin{bmatrix} X_{p,1} \\ X_{p,2} \\ 1 \end{bmatrix} = KK \begin{bmatrix} X_{d,1} \\ X_{d,2} \\ 1 \end{bmatrix} \qquad (5)$$

Since calibration pattern is characterized by known geometric entities (for instance in the present work the pattern is a checkerboard with 29x17 checkers with 20 mm edge length), calibration procedure, accomplished according to [13], allows the estimation of f_c, k_c, c and α_c (so called “intrinsic calibration parameters”).

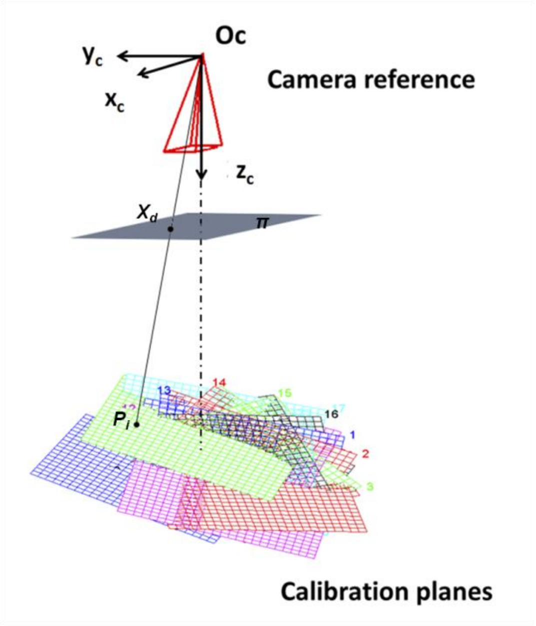


Fig. 10 Camera reference and calibration planes.

Practically, camera calibration has been performed using Camera Calibration Toolbox for Matlab, which heavily relies on previous work by Zhang [14].

Obviously, calibration procedure is affected by uncertainties on the assessment of such parameters. In order to calibrate with a sufficient accuracy an extensive experimental campaign was carried out to determine the suitable characteristics of calibration pattern. According to the results, such a pattern was built to respect the following specifications:

- maximum flatness error equal to 0.5 mm;
- maximum error in absolute position of a single checker corner equal to 0.1 mm.

3.1.2 Bi-univocal correspondence between image plane and CNC machine reference system

Once camera parameters are known, a bi-univocal correspondence between the image coordinate system in pixel (X_p) and the Cartesian pantograph one (X_φ) can be derived in order to allow the painting tool movement along patch edges.

This may be straightforwardly obtained by means of a further calibration step by using the last acquired image. Placing the calibration pattern perfectly lying on the working plane and with its edges coincident with the CNC axis, it is possible to evaluate the extrinsic camera parameters (i.e. the position, in 3D space, of the camera coordinate system with respect to the calibration pattern), expressed by a rotation matrix R and a translation vector T. The knowledge of both intrinsic and extrinsic parameters allows to establish the necessary bi-univocal correspondence, thereby taking into account effects produced by perspective distortions induced by absence of parallelism between image plane and CNC working plane.

In fact:

$$X_P = \left[KK \mid 0^{3x1}\right] \cdot \begin{bmatrix} R^{3x3} & T^{3x1} \\ 0^{1x3} & 1 \end{bmatrix} \cdot X_\varphi = P^{3x4} \cdot X_\varphi \qquad (6)$$

where *P* is the so called perspective projection matrix.

From eq. 6 the following scalar equations can be derived:

$$\begin{aligned} X_{p,1} &= \frac{p_{1,1} \cdot X_{\varphi,1} + p_{1,2} \cdot X_{\varphi,2} + p_{1,3} \cdot X_{\varphi,3} + p_{1,4}}{p_{3,1} \cdot X_{\varphi,1} + p_{3,2} \cdot X_{\varphi,2} + p_{3,3} \cdot X_{\varphi,3} + p_{3,4}} \\ X_{p,2} &= \frac{p_{2,1} \cdot X_{\varphi,1} + p_{2,2} \cdot X_{\varphi,2} + p_{2,3} \cdot X_{\varphi,3} + p_{2,4}}{p_{3,1} \cdot X_{\varphi,1} + p_{3,2} \cdot X_{\varphi,2} + p_{3,3} \cdot X_{\varphi,3} + p_{3,4}} \end{aligned} \qquad (7)$$

Once the coordinates X_p in the image plane are known, from eqs. 7 it is possible to obtained the corresponding coordinates X_φ in the CNC working plane considering that such a plane is characterized by $X_{\varphi,3} = 0$.

3.2 Edge Detection

Once lens distortion effects are compensated and the correspondence between the above mentioned reference systems is established, it is possible to acquire a high-quality geometry image of the working plane where leather patches lye. In particular it is possible to detect leather patches edges by using a Canny edge detection method implemented in Matlab's Image Processing Toolbox.

As generally recognised [15], the Canny method finds edges by looking for local maxima of the gradient of an image. The gradient is evaluated using the derivative of a Gaussian filter (with a proper value of sigma). The method uses two thresholds to detect strong and weak edges, and includes the weak edges in the output only if they are connected to strong edges. The result of edge detection is a binary image where the edges are represented by pixel with value 1 and the background by pixel with value 0.

Edge detection strongly depends on the sigma value of the Gaussian filter and on the two threshold values. In the present work, in order to reduce the image background noise, the value of sigma has been set equal to 3 while the threshold values have been set equal to, respectively, 0.2 and 0.8. Constant threshold values proved to be suitable since the acquisition is performed in a totally light controlled environment.

The result of Canny method application to an image of 2 leather patches, disposed on the working plane, is a binary image (raster data) where edges are represented by unitary thickness outlines with pixel values equal to 1 (white pixels in Fig. 11).

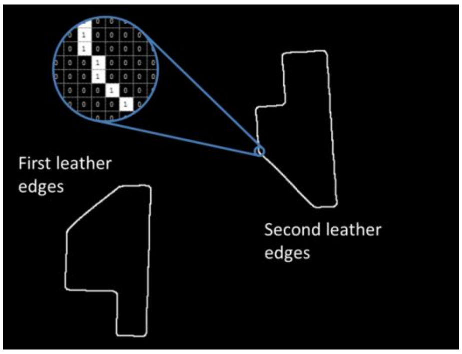


Fig. 11 Edge detection results.

3.3 Dyeing path retrieval

Since the CNC pantograph needs a series of coordinates in order to properly move the painting tool along the leather boundaries, the conversion of Canny method results into vectorial data is required.

In detail an appositely devised algorithm scans the image, row by row, starting from the upper left pixel until a white pixel is found. When this condition is satisfied, assuming that the non-zero pixel P has coordinates equal to X_p and that it belongs to a unitary thickness outline, the algorithm:

1) looks for the other two white-pixels, P' and P'', inside the 3x3 neighborhood of the pixel itself (see Fig. 11); note that, since *P* is the starting pixel and the outline has a unitary thickness, there are always two white pixels in the 3x3 neighborhood of *P*.
2) stores the coordinates X_p into a matrix S_p;
3) sets the pixel value corresponding to X_p equal to zero;
4) sets $P = P'$;
5) looks for the only white-pixel P' inside the 3x3 neighborhood of *P*;
6) iterates steps from 2 to 5 until the whole outline is "walked".

When an outline is completed, the algorithm seeks for the next leather patch by scanning the remaining image rows.

Since the above procedure is performed for each of the outline in the image, the final result is a set of matrices S_p whose rows are the ordered x-y pairs of leather contours.

These matrices are a vectorial representation of leather patches edges. Each matrix S_p is then translated into a ISO G-code together with all the information (on – off pressure, upper or lower tip position, etc.) required by the painting tool.

4 Conclusions and future work

A leather dyeing machine capable of automatically dyeing free-form patch contours has been designed and built. Extensive testing have been carried out in order to assess the reliability and the accuracy of the developed system.

The machine proves to be effective in automatically dyeing leather contours with uniform ink thickness. Edge dyeing results qualitatively better than the one performed by human operators. By experimental measures, the overall accuracy in contour extraction resulted to be approximately 0.3 mm. This value proves to be sufficient for dyeing most typologies of leather patches in most of the possible positions on the plane. However under some particular circumstances, the dyeing tool does not move sufficiently close to leather edges to assure the proper inking.

Future work will be addressed towards the accuracy increase of the MV system and/or alternative architectures of dyeing tool.

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