Design of Automatic Online Alignment for Multi

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Design of Automatic Online Alignment for Multi-Color Flat Screen Printing

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Abstract: Flat screen printing is a popular economical technique for introducing color and design onto a fabric in a small batch production. It achieves multi-color design by printing a set of patterns color by color. Quality of multi-color print is depended upon pattern registration that is often done offline by observation and manual adjustment prior to the run. This paper presents a design of an automatic online alignment for multicolor printing on a single flat screen printing machine that one pattern is printed at a time for the entire batch. Alignment is made by adjusting a printing screen before it comes into contact with a fabric that is fixed on a pallet sitting on a platform. Since a pallet is loaded and unloaded for every printing, alignment is required for each of them. The movements of the screen both 2D translation and about vertical axis rotation are computer controlled via a frame on which it is mounted. Machine vision and image processing technique are applied to determine the orientations and positions of a printed pattern and of a printing screen. Their relative orientation and position are converted to be commands for proper adjustment of the screen. This automatic alignment is implemented on LabVIEW program and tested. Its demonstration is also presented in this paper.

Keywords: flat screen printing, alignment, multi-color printing, LabVIEW.

1 INTRODUCTION

Screen printing is a popular printing process to produce text and image on a piece of sheet material such as paper, plastic, fabric, etc. The system involves a technique where a blade squeezes the print paste containing coloring matters and thickening agents through the mesh openings in pattern screen onto the media. The printed media subsequently undergoes drying and fixation steps using steam and requires further washed-off process to remove the remaining thickening agents and unfixed colors. There are two type of screen printing, i.e. flat screen printing and rotary screen printing. The former produces image on a printed media by transferring the ink through a block screen which has designed pattern on it (Dawson et al. 2008). The later, instead of placing a traditional block screen on top of the printed media, uses a rolling screen that can rotate in a fixed position. This method is commonly used for large production batches. (Zoomer. 2002).

In textile industry, these two methods are very popular to print multi-color images on fabric due to their superior quality. However, the systems have limitation in term of the number of colors that can be accommodated since each color needs one screen in one run. This means several screens should be mounted onto the machine in order to print a multi-color image in one process. The number of screen is at least the same with the number of colors that need to be printed. As a result, in order to accommodate more colors, a huge system is needed. For Small and Medium Enterprises (SMEs), which has the limitation of cost investment and working space, those kinds of machine are not feasible. Moreover, even though the machines may run automatically, the pattern alignment or pattern registration is achieved by manual observation and adjustment. In practice, it consumes more time and resources. Therefore, a single flat automatic screen printing which can align the screen online in the process is needed to fulfill the SMEs requirement.

Presented in this paper is a mechanism design of automatic alignment for multi-color flat screen printing machine that will allow the screen alignment conducted online in the process.

2 MULTI-COLOR SCREEN PRINTING PROCESS

In screen printing, design is imposed on a screen of silk or other fine mesh, with blank areas coated with an impermeable substance, and ink is forced through the mesh onto the substrate, for instance, cloth and T-shirt. Figure 1 illustrates the process of this method. For multi color, the designed pattern is separated into a set of contours based on its color and the screens are

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then made accordingly. Figure 2 shows the example of screen preparation for multi color printing.

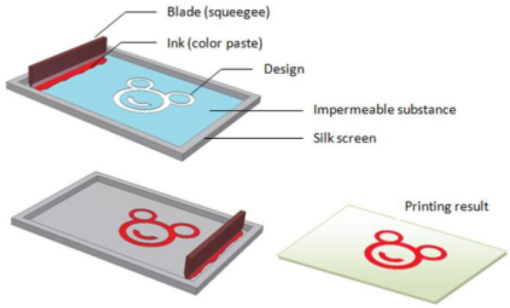

Figure 1. Screen printing process.

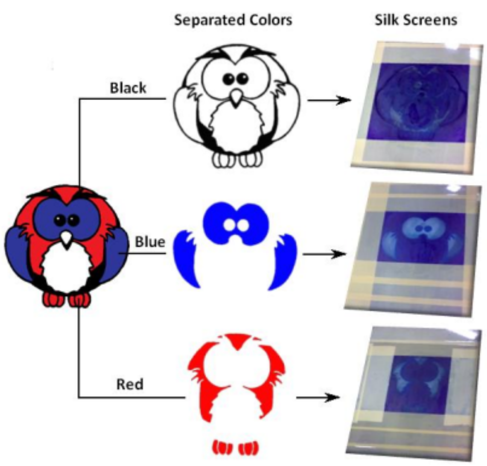

Figure 2. Screen preparation for multi color printing.

After the screens have been prepared, the first color is then printed on the material continuously until the intended number of one batch is achieved. Prior to printing the next color, the screen should be changed and positioned in such a way so that the subsequent color will align with the previous one. The alignment process is made by adjusting the printing screen before it comes into contact with the printed material that is fixed on a pallet sitting on a platform. This is often done offline based on operator visual observation and manual adjustment. Once the screen is considerably aligned, the second color is ready to print. These procedures are performed until all colors of the design are accomplished.

There are some parameters need to be considered in order a perfect image can be created on the substrate. These parameters include the hardness of squeegee, method of holding, amount of pressure, wire diameter of the screen, mesh count, the flatness, the tension of the mesh, etc. (Owczareket al. 1990). In addition, for multi color screen printing, the quality of product is also characterized by how good the alignment process is so that there will be no overlapped color on printed image. Hence, screen alignment plays very important role in ensuring the optimum quality of printing result. This will be the focus of the discussion in the next section.

3 SYSTEM DESIGN

Aligning two objects is about to make them into condition where those two objects have same orientation and position relative to the desired condition. In multi color screen printing process, it means to place and orientate the screen relative to the printed material in order to achieve the same image as designed. This can be done by registering position and orientation of each color in the design relative to a chosen reference. By positioning the screens based on these registration data, the alignment process can be performed. This approach will be adopted in this research by using the first color as reference for all other colors. Hence, when the first color has been printed on to the material, its position and orientation are acquired and used as reference for screen adjustment of the next colors.

The alignment process consists of three main movements; rotation, translation in X axis, and translation in Y axis as shown in figure 3. Mathematically, it depends on the function of $f(\alpha, T_X, T_Y)$; where α is rotational angle, T_X is translation in X axis and T_Y is translation in Y axis. Hence, the relative position and orientation of the pattern in first color and the pattern in n color has to be known appropriately.

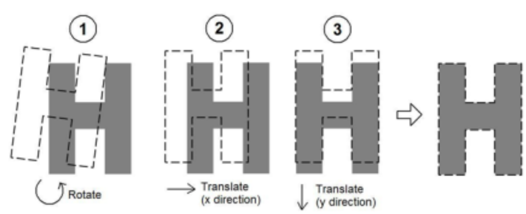

Figure 3. Three steps of screen alignments.

The orientation of each color can be defined by identifying two points that represent the color entity. In this research, the center gravities of two contours are used. By connecting those points, a straight line

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can be created. Color orientation can be calculated by measuring the angle of the line from the horizontal, while color position can be obtained from its midpoint. Figure 4 illustrates the representations of color orientation and its position. The orientation of the first object (blue color) is represented by α_1 while the orientation of second object (green color) is represented by α_2. After those two lines have been created, the relative angle between two images which are representing the orientation of all images in the design pattern can be determined and it is called as a reference angle. The reference angle can be calculated by using this equation;

$$\alpha_R = \alpha_1 - \alpha_2 \quad (1)$$

The relative position of two colors can be determined by calculating the distance between the two representative points by using these following equations:

$$\Delta X = X_{MP_B} - X_{MP_A} \quad (2)$$

$$\Delta Y = Y_{MP_B} - Y_{MP_A} \quad (3)$$

By using first color as reference, the relative position and orientation of all colors in the design can be identified. The screen alignment in the printing process will be based on these representations.

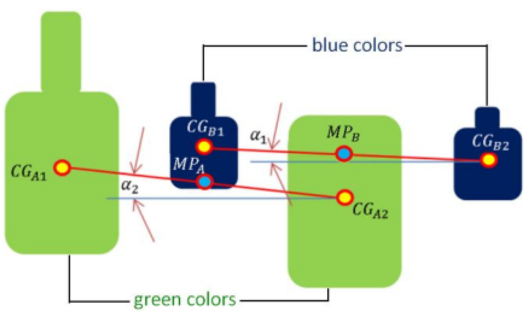

Figure 4. Indices to represent the color orientation and its position.

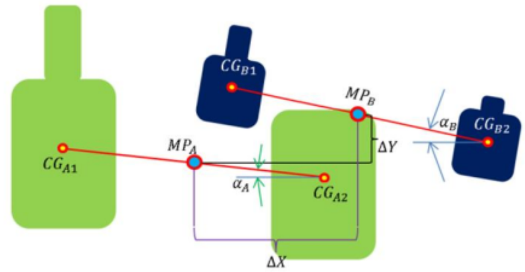

Figure 5. Example of color orientation and position that need to be aligned

In the process of multi color printing, alignment is not needed for the first color. It is needed to print the subsequent colors, due to the screen may not be installed in the same orientation and position. Figure 5 shows about real condition that may occur after printing process. On the first printed image (green object), the information about those all indices have to be obtained by calculating the angle of α_A and the position of midpoint MP_A. After changing the screen, the orientation and the position of the screen have to be known in order the pattern on the screen can be printed properly. By repeating the previous process, the orientation (α_B) and the position (MP_B) of the screen can be determined. Equation 1 up to equation 3 can be used to calculate the relative orientation and position of those objects. By comparing the relative orientation on printed image and reference image of designed pattern, the value of rotation can be determined. Similarly, by comparing the relative distance of designed pattern on the printed image and on the reference image, the value of translation in X axis and Y axis can be calculated.

3.1 Mechanism Design

The schematic diagram of multi color screen printing mechanism is presented in figure 6. In this mechanism, the alignment module is very crucial determining the printing quality. It comprises 3 degrees of freedom i.e. 1 degree in rotation (to achieve the orientation) and 2 degrees in translation (to achieve the position). The screen is easily mounted to and dismounted from the module in order to accommodate easy replacement and the movements are driven by three stepper actuators. Ballscrews are used to transform the motor rotation into translation motion.

The alignment process is done by aligning the orientation first, before aligning the position. The value of rotation angle can be determined directly by comparing the orientation of the color with the

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reference. It is important to note that the value of translation differences could not be calculated directly since rotating a plane on an axis will result in displacement of points having distance from the axis. Hence, the new position should be calculated first prior to the calculation of the difference. When the zero point (Z axis) is used as center of rotation, the new position of point (X,Y) is:

$$X^1 = (X_0 Cos\alpha - Y_0 Sin\alpha) \quad (4)$$

$$Y^1 = (Y_0 Cos\alpha + X_0 Sin\alpha) \quad (5)$$

As the center of rotation of the alignment system developed in this research is not at the middle of the screen but at the top-center (see figure 7) due to the structure of the machine, these equations should be modified as follows:

$$X^1 = (X_{Rot} Cos\alpha - Y_{Rot} Sin\alpha) + J \quad (6)$$

$$Y^1 = (Y_{Rot} Cos\alpha + X_{Rot} Sin\alpha) + K \quad (7)$$

Where,

$$X_{Rot} = X_0 - J \quad (8)$$

$$Y_{Rot} = Y_0 - K \quad (9)$$

and J is coordinate of center of rotation in X axis while K is center of rotation in Y axis. By comparing between new distance in X-Y axis after rotation in printed image and distance in X-Y in reference pattern, the translation value can be determined.

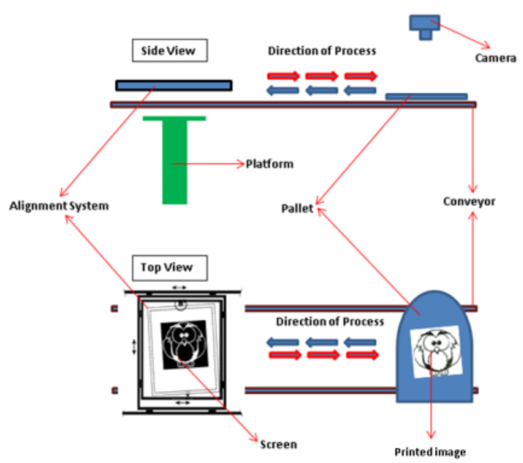

Figure 6. Schematic diagram of multi color screen printing mechanism

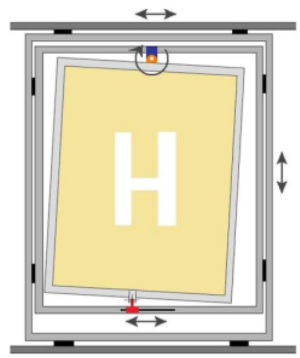

Figure 7. Alignment system

3.2 Camera

In order to collect information needed for automatic alignment, a single camera is placed above the loading station (as shown in figure 8) and used to capture the image of designed pattern which has been printed on the fabric. To get a better resolution of the image, the position of the camera should be taken into account. The camera has to be placed in optimum height from the image in order to get the focus image and the maximum coverage area (figure 9).

The image which is captured by the camera will be the input for image processing unit to come up with the information about the relative orientation and position of the printed image. Here, image processing seeks to modify and prepare the pixel value of a digitized image to produce a form that is more suitable for next operation in the same model (Awcocket al. 1996). Based on the image captured by the camera, Canny edge detection is then used to identify the edge of each color. The center of gravity of the contour will be determined to calculate the indices to represent the orientation and position of the printed image.

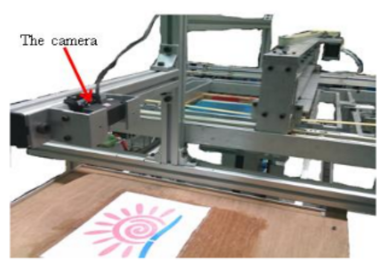

Figure 8. The position of the camera

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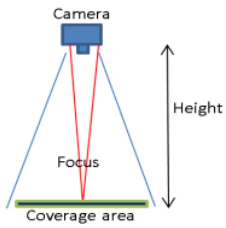

Figure 9. Optimum position on capturing image

3.3 Control Module

In order to build a controller for the automatic screen alignment module, several software and hardware are utilized (figure 10). The software is divided into two big groups of programs i.e. manual mode to control the alignment system manually and automatic mode to control the system automatically. Both are developed in the LabVIEW 7.0 environment (figure 11). In manual mode, which is placed in the lower half on the main front panel, operator is allowed to use computer interface to adjust the screen position and orientation manually by pressing the direction buttons. The automatic alignment program of the system is integrated with the operation mode which is placed in the upper half of the main front panel.

In the production mode, all the parameters which have been set before will be used automatically in the process. By pressing start button, the program will control the machine to run the process from beginning until completed. The automatic alignment process takes place prior to the subsequent color is printed onto the previous one by utilizing the information from captured images.

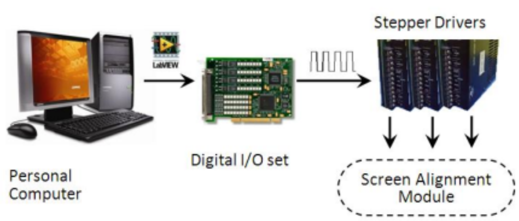

Figure 10. Hardware setup for screen alignment controller

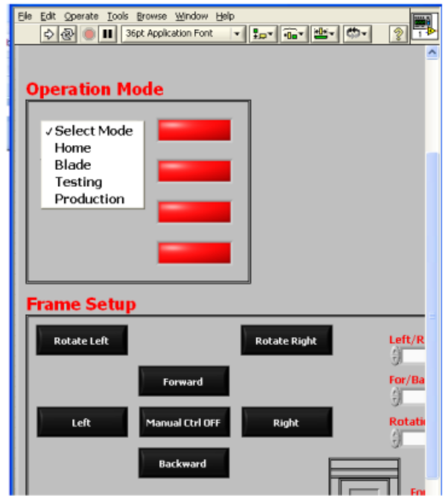

Figure 11. Main front panel

4 VALIDATION AND IMPLEMENTATION

4.1 Validation

In order to validate the system, some experiments in automatic alignment have been conducted. The purpose of the experiments is to know how well the responses of the system in aligning the screens. Predefined misalignments in rotation (angle) and translation (X and Y) were used to check the system accuracy. Three misalignment conditions were investigated i.e. (1) rotation only, (2) translation only and (3) combination between translation and rotation. The procedure of the experiment is as follows:

1. Set the screen on initial position without any rotation or translation
2. Print the pattern on a piece of fabric
3. Capture the printed image using the camera
4. Run the image processing to get all indices
5. Rotate and/or move the screen in known angle and/or displacements
6. Print the pattern on a new piece of fabric
7. Capture the new printed image using the camera
8. Run the image processing to get all new indices
9. Run the automatic alignment program to move the screen back to its initial position by using all obtained indices as the input(as illustrated in Figure 12)
10. Calculate the difference between final position and the initial position to get the error.

By varying the predefined initial misalignments of the screen, the data in table 1 to table 3 could be obtained.

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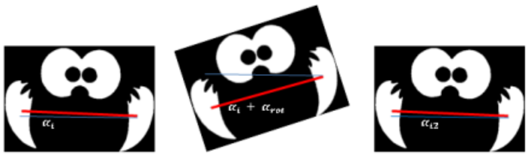

(A) (B) (C)

Figure 12. Experiment process for rotation test. (A) Initial condition, (B) after rotation, (C) after automatic alignment

Table 1. Result of automatic alignment experiment in rotation

Screen 1				Screen 2			
Initial image orientation (α_i, *degree*)	Angle after rotation (α_1, *degree*)	Angle after auto alignment (α_2, *degree*)	Error (α_i- α_2, *degree*)	Initial image orientation (α_i, *degree*)	Angle after rotation (α_1, *degree*)	Angle after auto alignment (α_2, *degree*)	Error (α_i- α_2, *degree*)
1.528	1.98	1.528	0	1.534	2.036	1.534	0
1.534	2.02	1.534	0	1.782	2.545	1.528	0.254
1.534	1.023	1.279	0.255	1.273	0.83	1.279	-0.006
1.534	0.767	1.534	0	1.279	0.256	1.273	0.006

Table 2. Result of automatic alignment experiment in translation

Screen 1								Screen 2							
Initial midpoint MP position -*mm*		MP after translation -*mm*		MP after auto alignment -*mm*		**Error** - *mm*		Initial midpoint MP position -*mm*		MP after translation-*mm*		MP after auto alignment -*mm*		**Error** - *mm*	
X_i	Y_i	X_1	Y_1	X_2	Y_2	$X_i - X_2$	$Y_i - Y_2$	X_i	Y_i	X_1	Y_1	X_2	Y_2	$X_i - X_2$	$Y_i - Y_2$
112.175	104.65	111.475	103.95	112.175	104.3	0	0.35	113.4	102.725	113.05	102.725	113.225	102.375	**0.175**	**0.35**
113.225	105.525	112.175	107.625	113.575	104.825	-0.35	0.7	113.575	103.6	115.85	106.575	113.4	102.725	**0.175**	**0.875**
111.825	104.475	112.175	104.475	111.825	103.775	0	0.7	115.675	105.35	115.15	105.175	115.85	105.7	**-0.175**	**-0.35**
111.475	103.95	110.425	103.075	112	104.475	-0.525	-0.525	113.4	103.075	113.75	103.775	113.575	103.075	**-0.175**	**0**

Table 3. Result of automatic alignment experiment in translation and rotation

no	Initial midpoint MP position - *mm*		Initial orientation (α_i, *degree*)	Midpoint after auto alignment - *mm*		Angle after auto alignment (α_2, *degree*)	Error		
	X	Y		X	Y		X (mm)	Y (mm)	Angle (°)
1	111.723	104.524	0.767	112.248	105.224	0.771	-0.525	-0.7	0.004
2	112.521	105.246	0.764	113.046	105.596	1.023	-0.525	-0.35	0.259
3	112.745	106.432	1.023	113.795	106.782	1.023	-1.05	-0.35	0
4	111.316	104.534	0.767	111.841	105.059	1.023	-0.525	-0.525	0.256

Table 4. Deviation of printed images from reference in multi color printing

Reference			Printed Image			Error		
Orientation (°)	X Position (mm)	Y Position (mm)	Orientation (°)	X Position (mm)	Y Position (mm)	Orientation (°)	X Position (mm)	Y Position (mm)
-12.64	7.166	-13.046	-12.59	7.638	-13.291	0.05	0.472	0.245
			-12.74	7.577	-13.335	0.1	0.411	0.288
			-12.75	7.743	-12.985	0.11	0.577	0.061
					Average of errors	0.08	-0.487	0.198

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4.2 Implementation

In addition to the aforesaid experimentations, the real implementation of the system to print a multi color design on a fabric was also investigated. The system should be able to handle the random screen misalignments that may occur in the process. Quantitative analysis is done by calculating the deviation from reference (see table 4), while qualitative analysis is by making printing result comparison between proposed automatic alignment system and manual alignment method (figure 13).

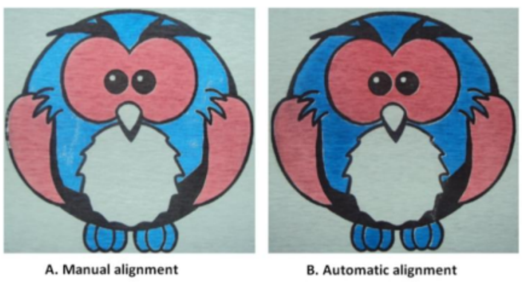

Figure 13. Result of multi color printing process by using manual and automatic alignment

5 DISCUSSION

The experiment data in table 1 to table 4 indicate that errors still occur in the aligning process. In order to see the characteristic of the errors, graphical representatives were made based on the data. Figure 14 shows the example of graphical representative of the errors based on the data of screen 1 in table 2. From these representations, the errors will be zero or very small if the return position after alignment is coincident or very close to the initial position. In this figure, the errors seem unsystematic, as no pattern can be drawn. Since there is no problem with the programs has been identified in the simulation, it is highly possible that the errors are mainly from the hardware configuration rather than from the software. It is reasonable considering that the prototype of the system is developed by using used components (including the motors and the ball screws, which are critical in alignment mechanism). From observation, when the load is high, the signal from the driver frequently could not be executed due to the motor is overloaded.

When the proposed automatic screen alignment module was employed to print multi color image, where a random misalignment might occur, the system could perform well as expected. The average errors are very small and based on visual inspection the printing quality is acceptable and comparable to the manual alignment. The performance of the system can be improved by upgrading the hardware configuration so that the unsystematic random errors can be avoided. Light structure of the alignment module should be considered in order to reduce the load of the stepping motors. The rigidity of the structure is also important to be taken into account for better result while screen preparation need to be improved for easier alignment.

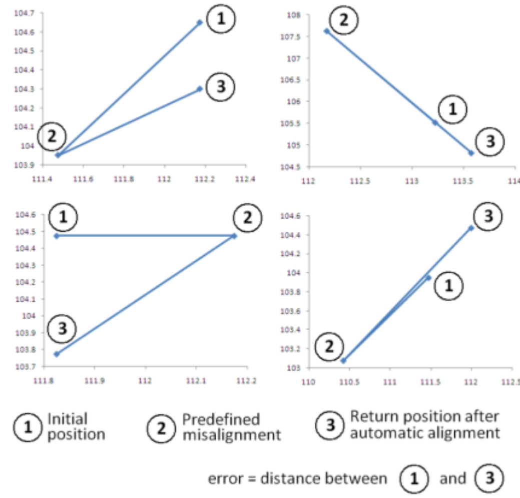

Figure 14. Graphical representation of the errors based on the data of screen 1 in table 2

6 CONCLUSIONS

Design and development of an automatic online alignment for multi-color flat screen printing process have been discussed in this paper. The system has been tested by using predefined misalignment in rotation, translation and the combination of those two as well as by using random misalignment in real printing process. Based on the data, some errors still occurs in aligning process. However, the source of the errors has been identified to be followed up. Improving the printing quality of the system may become the future research.

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