A Quantitative Self Alignment Method in Incremental Printing: Coalescent Bar Alignment*

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Abstract

The repeatability error creeps in every corner of mechanical design as mechanical design becomes diverse and complicated. Inkjet printing has inherent repeatability error problem due to its nature of seamless incremental image synthesis of partial images.

Without the calibration for the repeatability error, realization of high print quality or enhancement of other printing performance could be impaired. Printer designers have met this recurrent problem even before the inception of inkjet print device and contrived various solutions as their own intelectual proprietary. Also, it is a trend to perform necessary calibration without painstaking human intervention. To come up with another useful and proprietary solution has become an important ingredient in inkjet printer design. This paper presents such a solution developed at Digital Printing Division of Samsung Electronics Company.

1 Introduction

Inkjet printer forms a complete image on the recording medium by synthesizing many pieces of partial images using mechanical reciprocal scanning movement of inkjet nozzles. The way the inkjet printer is forming a whole image is often coined as incremental printing. The rationale of using incremental printing is mainly due to the limited resource of ink jetting device, which simply cannot make a whole picture simultaneously by its limited inkjet head size and limited gamut of colors.

Looking over the full process of forming a partial image onto the recording medium, the individual delivery method of a partial image often takes different form one way or another. For example, inks in use might be distributed over seperate ink cartridges, or the mechanical scanning motion for delivering a partial image might not be the same for the sake of throughput or for the sake of smoothing out the undesirable side effects arising from mechanical tolerances. Hardly, all the partial images are transferred at the same time either, which could affect the color realization. Differences among methods of delivering partial images are everywhere; the irregular ink jet cartridge installation position, variation of media depth, and so on.

Based on the misalignment characteristics measured through the repeatability error measurement phase, the next compensation phase exerts the right control effort to stich incremental images seamlessly. There are various potential control inputs for compensating stitching error. For example, depending on the repeatability error, the control input could mean the selection of nozzle, shifting print start position, or the selection of right delay time for firing ink droplet.

Then the problem of self alignment can be summarized as follows:

"Given the repeatability error, the problem is to find out the right control input and the right control effort to bring incremental images towards the perfect fit."

Traditionally, in order to find out the right amount of repeatability error compensation, ink jet printer users are asked to select the best fit out of numerous trial and error patterns. The patent [7, 6, 8], from Hewlett Packard and the patent [9] from Cannon are the good examples of finding the best match. Each pair of pattern is associated with slightly different amount of control effort. Numerous pairs of trial and error image patterns are generated by two different methods; for example, one of a pair of patterns may be printed out while inkjet device is moving towards the left side frame on the first run and the other pattern shapes form while moving towards the right side frame on the second run.

Some clever test patterns exposing horizontal and vertical repeatability errors simultaneously are proposed by Xerox [4] and Lexmark [3].

* Pending patent.

These approaches requiring large number of trial and error patterns, are suitable for global compensation of repeatability error.

Self alignment can be accomplished without recording medium [1, 5, 2]. Some of them does not even use the ink droplet. Through the survey of current inkjet printing technology about self alignment, the use of test pattern that exposes repeatability error seems to be in trend at the moment. This is especially true in the inexpênsive consumer inkjet related product line up, as other methods requiring precision optic sensors are likely to add cost and development lead-time. Even worse, those self alignment methods that do not make use of ink droplet are skeptical about whether to reflect the ink droplet flying characteristics in their repeatability error measuring instrumentation.

Thus the devised self alignment is presented focusing on how to generate the test pattern which exposes the repeatability error of interest and how to compensate the repeatability error based on the quantitative measurement of repeatability error.

2 Coalescent Bar Alignment

This method measures the difference in lengths of the reference pattern and the test pattern. The test pattern is equally divided into two halves of the reference pattern where the printing method for the second half of pattern causing the misalignment differs from the printing method for the first half test pattern. If there is any repeatability error between two different printing methods, the overall length of the coalescent bar as a result of combining two bars in series shows either reduction or elongation in length compared to the reference pattern.

Often, it is likely to complicate the design of high precision edge detector based only on the gray level of an image. Here, the role of the reference pattern is noteworthy. If a simple edge detector that determines the edge based only on a certain gray level of an image for its simple nature of implementation, some error in measuring the absolute length of pattern is induced due to ambiguous gray level of the edge in the noisy environment.

Here comes the role of the reference pattern that rescues from this kind of problem. Since, the same amount of error resides both in the lengths of the reference pattern and the calibration pattern, it is possible to get rid of this imperfection of the imprecise edge detector by measuring the difference of lengths. Rephrased, it is an advantage of this algorithm to use a simple imprecise edge detector by help of the reference pattern.

Figure 1 is an example of how test pattern is generated for the horizontal bi-directional print alignment. The first half of the pattern is printed towards the left side and the second half of the test pattern is printed towards the right side. The actual length of coalescent bar will be slightly different from that of the reference pattern. This difference is then regarded as the horizontal repeatability error caused by the bi-directional printing mode.

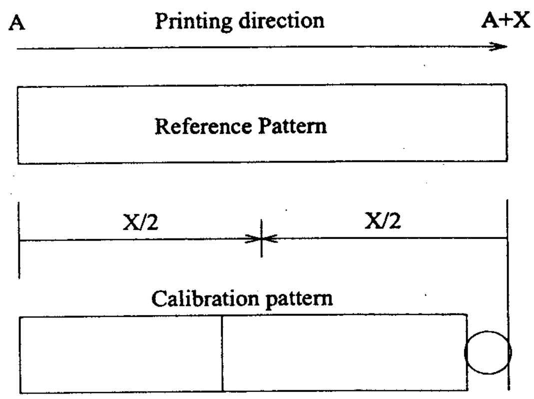

Figure 1: Coalescent bar exposing horizontal misalignment due to bi-directional print

Similarly, the test pattern for exposing vertical repeatability error caused by use of two different ink cartridges could be obtained through rotating the shape of figure 1 by 90 degrees.

Now that, the test pattern to expose the repeatability error of interest is ready, with an example of horizontal bi-directional alignment, the remaining principal elements of coalescent bar algorithm are described as follows:

Step 1. Print the reference pattern as in figure 1 in one method.

Step 2. Print the coalescent bar as in figure 1 using two different methods, where the difference in this case is in the printing direction.

Step 3. Compute the repeatability error as the difference in lengths between the reference pattern and the calibration pattern.

Step 4. Find out controllable inputs for adjusting the ink droplet landing position.

Step 6. Translate the repeatability error into conrol effort for the selected cotrollable input.

3 Results

The platform to test the proposed algorithms have been implemented on the inkjet printer engine and

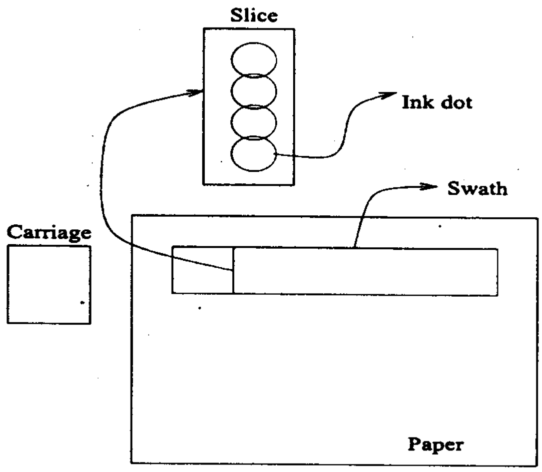

Figure 2: Visualization of swath, slice, and ink dot abstract

the inkjet head both developed by Samsung Electronics Co.

For simplicity of experimentation, the print start position register where the least significant controllable unit is 1/600" is chosen as the controllable input for the correction of horizontal misalignment.

An incremental band image is represented by the swath data comprised by series of slice data as in figure 2. A slice of swath data represents a column of the incremental band image and has ink dots as its constituents. And the test pattern shapes onto the print medium by transferring series of slice data to ink firing blcok in timely fashion.

The height of test pattern usually does not exceed the height of a swath data in order to exclude the artifacts from paper feeding movement. The printing speed is another factor that complicates self alignment even further. Because the carrier speed affects the flying characteristics of ink droplet, there is a slight difference between the desired ink droplet landing position and the actual ink droplet landing position. Therefore, alignment process may be necessary for each speed used in various printing modes for high image quality.

The voltage level of sensor output ranges from 0 to 255 where 0 represents black and 255 represents white. And the gray level of 100 is selected as the decision boundary for black and white region at this test. That is, gray level less than 100 is regarded as black.

Even though the measured length may be different from the absolute length at the arbitrary gray level of 100 chosen here as the edge boundary, the idea of *coalescent bar algorithm* is to measure the difference in lengths between the reference pattern and the test pattern so that the errors induced in the edges of both patterns may cancel each other and the resultant difference in lengths remains as the valid repeatability error measure.

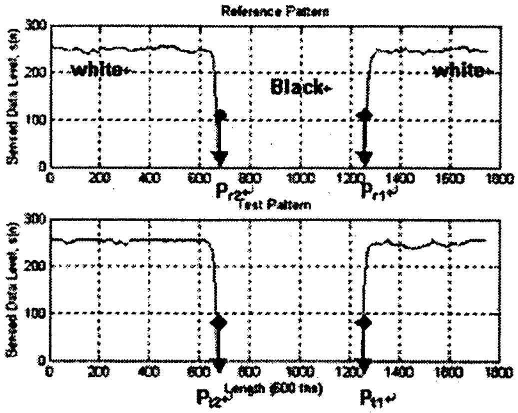

Figure 3: Sensed gray levels of the test pattern

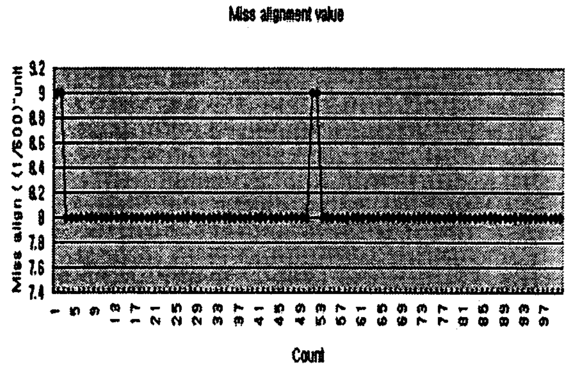

Figure 4: 100 trials of misalignment measurement

Sampled every 1/600" interval, figure 3 shows the relationship between the sensed gray level and positional informations. The length of the reference pattern is calculated from $P_{r1} - P_{r2}$ and the length of test pattern, from $P_{t1} - P_{t2}$.

Figure 4 and table 1 show the results of 100 trials of measuring repeatability error.

Based on the identification of the repeatbility error of 8 or 9 600th of an inch, the control effort of 8 is added to the original contents of print start position registser. And figure 5 shows two enlarged pictures before and after applying the *coalescent bar self align-*

μ	σ	Minimum	Maximum
8.04	0.2	8.0	9.0

Table 1: Misalignment measurement statitics in 1/600" unit for mono bi-directional printing

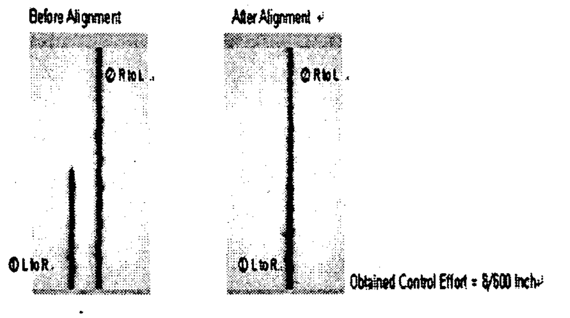

Figure 5: Self alignment result before and after compensation

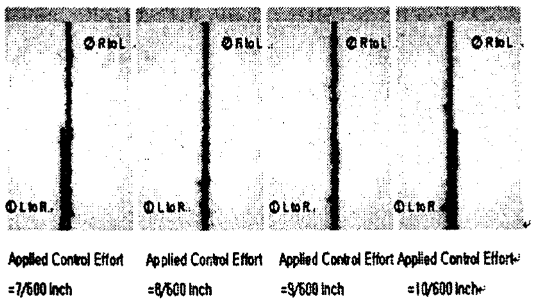

Figure 6: Compensation results caused by various amount of control effort

ment algorithm.

Figure 6 shows various results of applying several different amounts of control effort. Clearly, the use of compensation value of 8 calculated from the *coalescent bar algorithm* shows the best alignment result.

4 Conclusion

Self alignment technology is indispensable trend in the consumer incremental printing products. The principal elements for correcting repeatability error have been identified. And the proposed self alignment algorithm, *coalescent bar algorithm*, eluding prevailing intellectual property has been proposed, implemented, and tested. The self alignment results turned out to be successful for their practical application in the future production of incremental image printing products. And the results obtained through this research are believed to serve as the baselines for future innovation.

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