Continuous Pattern Transfer and Arbitrable Piping Process for Ink-Jet Fabrication

Hung-Pin Shih, Chieh-Yi Huang, Chen-Chu Tsai & Kevin Cheng; Industrial Technology Research Institute; Hsinchu, Taiwan

Abstract

As a bright star of manufacture process development, the ink-jet fabrication has penetrated into the field of display and semiconductor, for example, the fabrication of color filter, the forming of metal circuit, the dispensing of liquid crystal, and further continuous manufacture of flexible display etc. Would it be ideal and expectable? The obstacle lies across is the throughput rate, or the data transfer speed compromises of printing speed. Prior researches suggested to equipping multiple ink-jet heads to speed up printing and patterning, however, it was unfavorable for some applications need high class environment, because of its huge platform occupied and high cost expense. This article designed an electrical system with twin memory arbiter to swing the image data while printing and substrate delivery. It was realized by piping the image data in a multiplexer, and then transferring the data follow with printing process and substrate delivery synchronously. In thus design, the printing head is always kept on its maximum firing speed and the jetting quality can be maintainable. Estimation of the performance improving, the save of waiting time would be 40% or above, and is also accessible for mass production needs.

Introduction

Recently, there has been growing interest in the development of the ink-jet printing technologies, which are expected see use in the fabrication of color filter [1] [2], the forming of metal circuit [3] [4], the dispensing of liquid crystal [5], and further continuous manufacture of flexible display etc. The advantages of ink-jet printing technology are straightforward which offers a well-developed process for depositing small, precise quantities of material quickly, accurately and inexpensively. And unlike other fabrication technologies, ink-jet printing does not require contact for transferring the desired pattern on the substrate, thus minimizing contamination of inks. Digital deposition may eliminate the need for a die or photo mask, as used in traditional photolithographic, thus allowing the printer to modify the pattern quickly and inexpensively.

Additionally, ink-jet printing technologies use an additive fabrication process, which reduces the waste of material, also it can be bated the costs of product. Practical manufacturing systems are required the integration of precision mechanism, application-specific ink, inkjet head driving controller and high stability ink-jet print heads. An important consideration in designing the equipment is determining the resolution [6]. Generally speaking, there is a trade-off between printing resolution and processed data throughput where the latter is precedence for the some manufacture of inkjet fabrication. How to improve the speed of production in those special ink-jet printing fabrication under an acceptable printing resolution. Maybe we can either speed up some process state that can reduce over all time of production or practice the pipeline architecture designed which improves the system throughput. For example, the novel manufacturing ink-jet fabrication in many applications consists of a loader, a vision inspection, an ink-jet printing, an ink curing and an unloader. Under the restriction of the physical condition, it is a difficult thing to shorten time for some ink-jet printing process. So we think that will be a better choice to select the practice of pipeline for use which jump over the obstacle where lies across is the throughput rate, or the data transfer speed compromises of printing speed. We will make the discussion of pipeline practice detail to provide an improved method of ink-jet printing in which the processing time is significantly reduced. The improvement of throughput rate and a concrete practice in the special ink-jet fabrication.

Piping Process for Ink-Jet Fabrication

In the present article, we expound the high throughput pipeline architecture base on an ink-jet printing system for manufacturing application which contain the substrate loader / unloader, a vision inspection, an ink-jet printing controller and an ink curing apparatus, it is depicted in Fig.1.

However, considering the system application that is required high throughput and inexpensive, whose each module must be single and independent operation, such as the CCD Vision inspection module, ink-jet print head module, and UV curing module. The ink-jet printing process base on these independent operation module which needed to be considered the machinery layout and rationalization of physical-limit condition consists of loader, image recognition, front printing, UV curing, flip, return, pick and place, reverse printing, reverse UV curing, and unloader which is shown in Fig. 2.

The image recognition is the first function station in processing flow which captures some identification mark to define the jetting location and data. The second function station is a printing module which is a leading role, according to some jetting location from image recognition, and then arranges for printing heads to firing ink onto some particular position of substrate. The third main function station is an UV curing station which focus on curing ink of printed on substrate. In some application of ink-jet marking process is needed to deposit onto both side of substrate, so we design a printing system for double side inkjet marking process which gives consideration to mass production, high throughput and elasticity of production process.

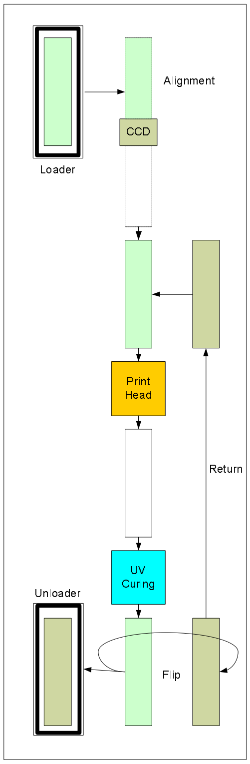

Fig 1 An ink-jet print fabrication system

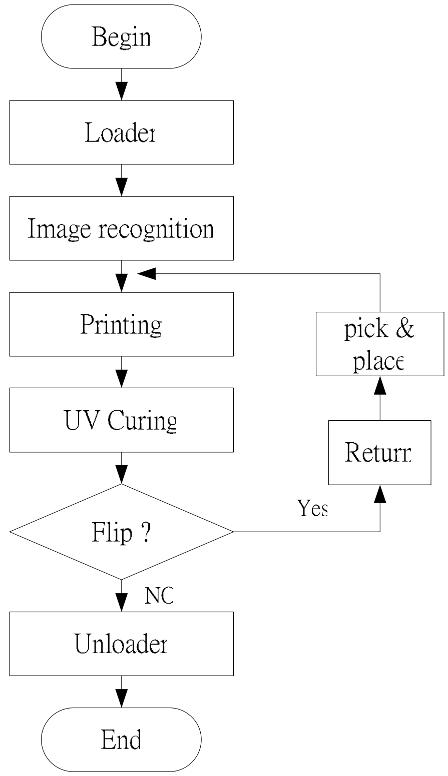

Fig. 2 Ink-jet printing process

In the printing processing system, the jetting high throughput is just what we expected. So that, we try scheduling pipeline design and analysis the system as fig 1. We studied the effect of production in various degrees of pipelining. Another way, join some delay buffer in process flow on the proper opportunity, to produce the improvement result of the speeding. At the same time the pipeline architecture design is needed to consider the conflict of the procedure, for instance, printing simultaneously both side of substrate that is not allowed in the printing system.

For the various degree of pipelining how to influence, there are 10 states in original flow as printing both side of substrate which contains loading/unloading substrate, CCD image capture, printing on substrate and UV curing, etc. A definition for the period of a state is an unit period, the all printing process period is 10 times of unit time without pipelining. With pipelining schedule design , how fast is throughput of printing system ? Assume the throughput of system is 1.0 without pipelining and any additional delay state.

Table 1 The comparison sheet of throughput efficiency

Deg. / Delay	1	2	3	4	5
0 state	1	1.67	2.5	3.33	5
1 state	0.91	1.67	2.5	3.33	5
4 states	0.71	1.43	2	2.5	---

As degree of pipeline is 4 without any additional delay state which is shown in Fig 3. The system throughput performance that print a double-side substrate every interval 3 states. It seems it is a good result and more degrees better in Table 1, but high throughput performance complicated matters considerably for mechanism design and printing data processing, and therefore the more degrees of pipelining maybe not an essentials which need to be balance between high speed and complicated design. In overall view, mechanism design can be accepted to deal with 4 substrates at the same time. Then make discussion on some different conditions.

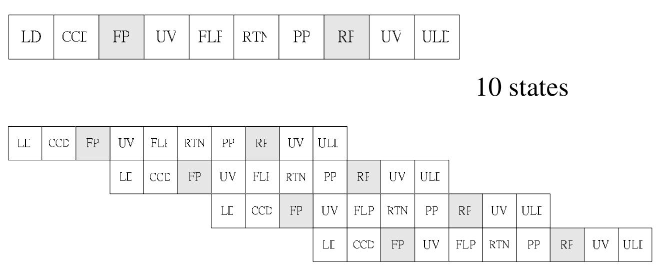

Fig 3. Degrees of pipelining = 4, with 0 delay state

Base on the degree of pipelining is 4, then it will lead to the effect of others and come out to join some delay states. We find that it can maintain the throughput of interval of 3 states when insert a delay state between CCD and FP in the original process flow. Just this throughput of interval of 3 states is not same as last one where the unit state period is different. The more states in process can distribute shorter unit state period that pushes the overall throughput to high. Thus the most longest state of process is divided several states which can make every state consuming time to shorten and improve the produce throughput. The Fig 4 shows the pipeline process with one delay state with faster state period.

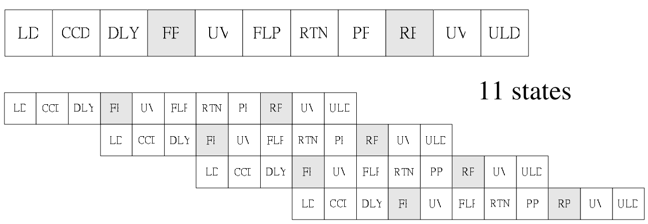

Fig 4. Degrees of pipeline= 4, with 1 delay state

If we insert 4 delay states in the process flow which is inserted in 3 delay states between CCD and FP and insert another delay state between RET and PP. Thus the practice make slow down for produce throughput, in addition to limit the degrees of pipelining to under 4 level. The Fig 5 shows the scheduling in our system which the degrees of pipelining is 4 with 4 delay states. In the method of delay insertion which may have an opportunity to simplify and design or improve the speed of production. However, it maybe lead to the fact and produce the decline of the throughput. It's very cautious with delay insertion for pipeline scheduling design.

Anyhow the degree of pipelining is more the better in some mechanism limit conditions, and the delay state insertion is a method of efficiency of improving production that can be appropriate. The Fig 6 shows the relation of throughput and degrees of pipelining with delay for double-side substrate printing.

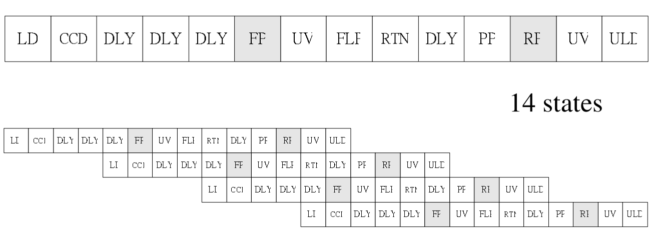

Fig 5. Degrees of pipelining= 4, with 4 delay state

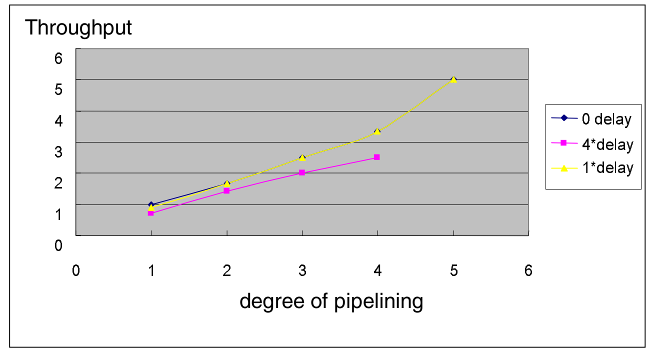

Fig 6.The relation of throughput and degrees of pipelining with delay for double-side substrate printing

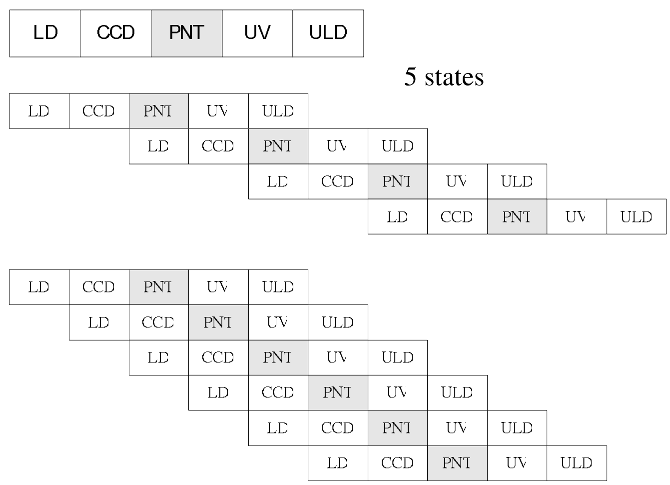

Fig 7 Comparing the pipelining operations with degree=4 or 6 for single-side substrate printing

In the single-side substrate printing process which has the same trend for throughput when changes the degrees of pipelining. The pipelining schedule is shown in Fig. 7.

The Fig. 8 depicts the relation of throughput and degrees of pipelining .The most fastest case which finished printing process and output in each state. The same reason that a good choose with a feasible mode of execution which the degrees of pipelining must be 4 .

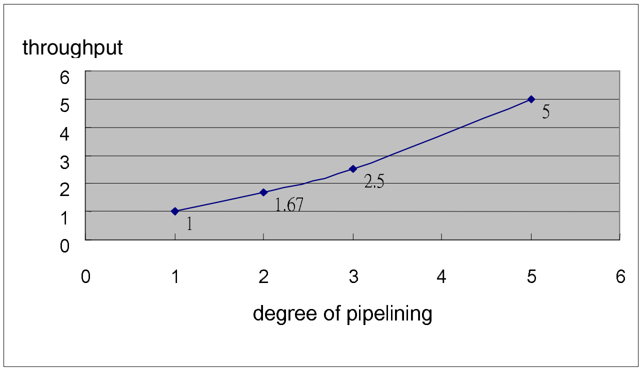

Fig. 8 The relation of throughput and degrees of pipelining for single-side substrate printing

Fig. 9 shows the memory management for inkjet printing to achieve the pipelined process. The image data are re3ceived from a computer and then stored in memory by CPU module. The DMA(Direct Memory Access) module transfer the firing data form the memory to inkjet print heads. The arbiter is used to ensure that only one, it may be CPU or DMA, accesses to the memory at any one time.

It was realized by piping the image data in a multiplexer, and then transferring the firing data follow with printing process and substrate delivery synchronously. This realization the continuous pattern transfer of utilizing the arbitrable piping process, in which memory input/output is a synchronous operation.

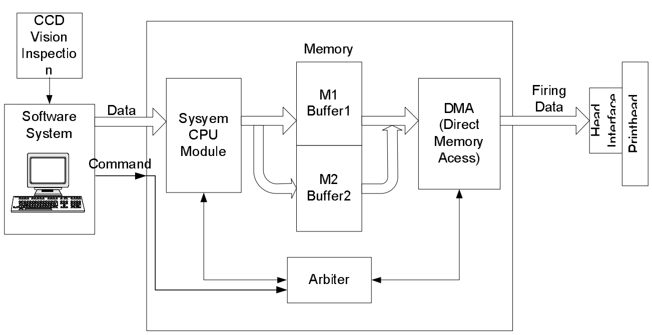

Fig. 9 Ink-jet printing electronic control system

The time of the memory arranges in an order like Fig.10, as the first substrate is being fired by print head (read M1 buffer1), it receive the second substrate of image data (write into M2 buffer2) at the same time. And as the second substrate is being fired(read M2 buffer2), it receives the image data of the third substrate(write into M1 buffer2) at same time. We circulate and reach the procedure that the memory can be written into read synchronously.

Fig. 10 Comparing the operating procedure(a) and the memory read / write(b)

Results

In this article, the throughput improvement and printing time reducing are successfully realized by the pipelined process system design. Compare the pipelined process with the no pipelined process, estimation of the performance improving, the save of waiting time would be 60% for double-side printing. And the save of waiting time would be 40% to 60% for the single-side printing.

Conclusion

As description above, to develop the ink-jet printing system for manufacturing application, the high performance and low cost must be considered. In operation procedure, had better use pipelined method that can improve the throughput. In electrical control, the memory management will be consider synchronous process, it can reduce time of printing and print head is always kept on its maximum firing speed.

References

1. Kevin Cheng et al, "A Novel Application of Ink-Jet Printing Technology on Manufacturing Color Filter for Liquid Crystal Display", NIP 17: International Conference on Digital Printing Technologies, pp.739-743, 2001.
2. Kevin Cheng et al, "Ink-Jet Printing Technology on Manufacturing Color Filter for Liquid Crystal Display Part II: Printing Quality Improvement", NIP 19: International Conference on Digital Printing Technologies, pp.309-313, 2003.
3. M. Moganti and F. Ercal, Segmentation of Printed Circuit Board Images into Basic Patterns, Computer Vision and Image Understanding 70, 1998, 74-86.
4. Chih-Hsuan Chiu, Chung-Wei Wang, Ming-Huan Yang, Chih-Jian Lin, Jane Chang, Jinn-Cherng Yang, Chun-Jung Chen & Kevin Cheng, " Image Segmentation and Trimming for Ink-Jet Fabrication of Electronic Circuits", accepted by First International Conference on Digital Fabrication Technologies, 2005.
5. Seamus E. Burns, Paul Cain, John Mils, Jizheng Wang, and Henning Sirringhaus, Inkjet Printing of polymer thin-film transistor circuit. MRS BULLETIN/NOVEMBER, 829-834, 2003.
6. Linda T. Creagh and Marlene McDonald, Design and performance of inkjet print heads for non-graphic-arts application. MRS BULLETIN/NOVEMBER, 807-810, 2003.

Author Biography

Hung-Pin Shih received the M.S. degree in biomedical engineering from Chung Yuan Christian University, Chung-Li, Taiwan in 1994. He is currently working in Display Technology Center of Industrial Technology Research Institute, Hsinchu Taiwan, as an associate Engineer. His current research areas include image processing and printing system design.