Dynamic Print Mode Control for Inkjet Printing [1] [2]

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One Pass Printing

- Inkjet printers use print-modes to control the quality and the speed of printing.
- One-pass printing:
  - Each horizontal move of the print-head prints the whole swath.
  - Fastest printing mode.
  - Can result in print quality defects.
  - Not robust to defects and non-uniformities in the nozzles.

Original Image

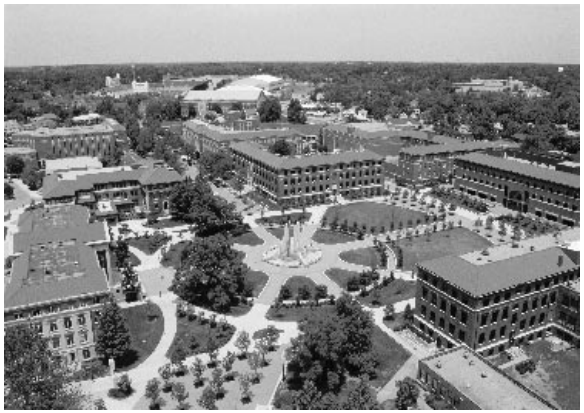
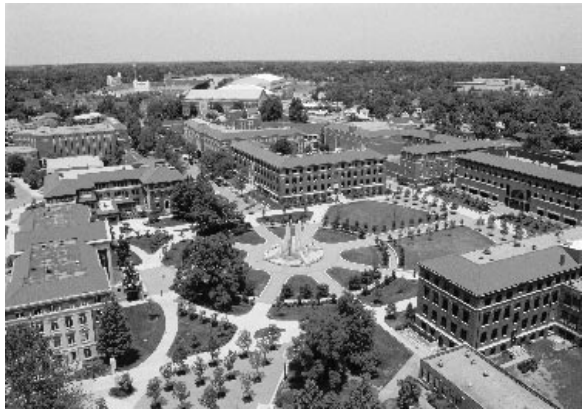


Image printed in one pass

Multi Pass Printing

- Multi-pass printing:
  - Each pixel is covered by more than one pass of the print-head.
  - Slow.
  - Higher print quality.

Original Image



Print Mask

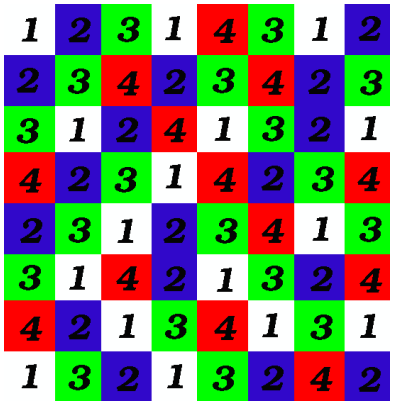
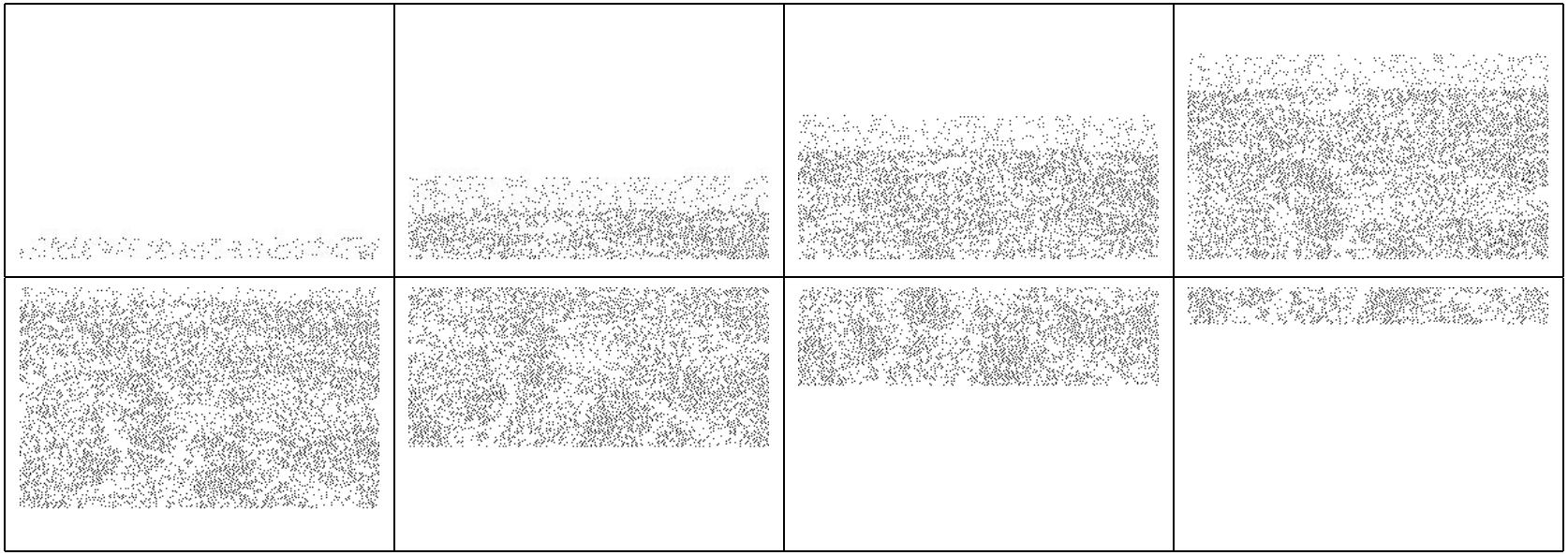


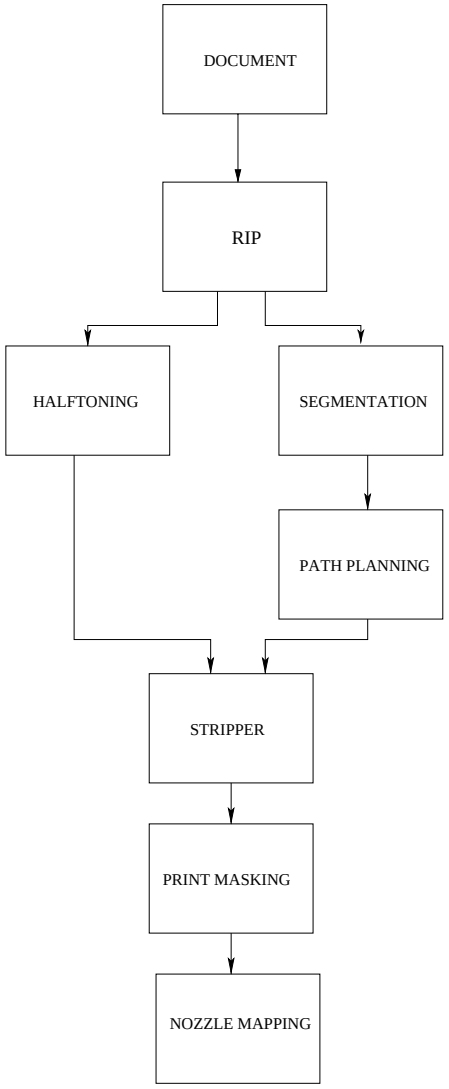
Image printed in multi pass

Multi Pass Printing



- Typical printers use a single print-mode for entire document or they cannot switch the print mode in the middle of the swath.
- Dynamic print-mode control can change the print-mode between any arbitrary regions that require different quality.
- Regions may have **arbitrary** shapes. Small regions of multi pass pixels may exist inside one pass regions.

Dynamic Print Mode System



- RIP: Converts document to 600 dpi 8-bit deep raster image without anti-aliasing.
- Binary Halftoning: Converts 8-bit grayscale image to 8-bit binary image.
- Segmentation: Segments the document into regions that require different print-modes.
- Path Plan: Plans the path that the print-head will take.
- Stripper: Extracts the binary image corresponding to the path of the print-head.
- Print-mask: Determines which pixels will be printed and which will be skipped on each pass.
- Nozzle-map: Converts the masked strips to hardware-ready signals.

Segmentation

- Segmentation labels each pixel with its required print-mode.
- Each pixel is labeled as one of the following:
  - NP - No print: Pixels which are not printed (ie. white space).
  - 1P - 1 Pass: Pixels that are printed in one pass print-mode.
  - 4P - 4 Pass: Pixels that are printed in four pass print-mode.

- Pixels are segmented using their 8 bit value.

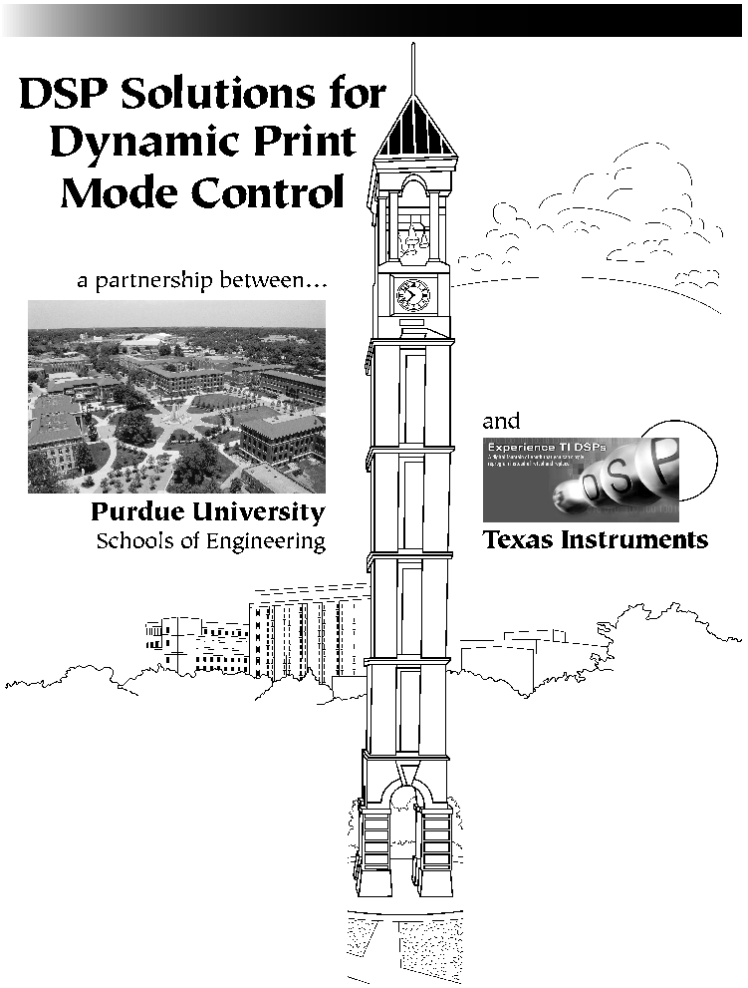
  Gray level 0 $\Leftrightarrow$ No print (NP)

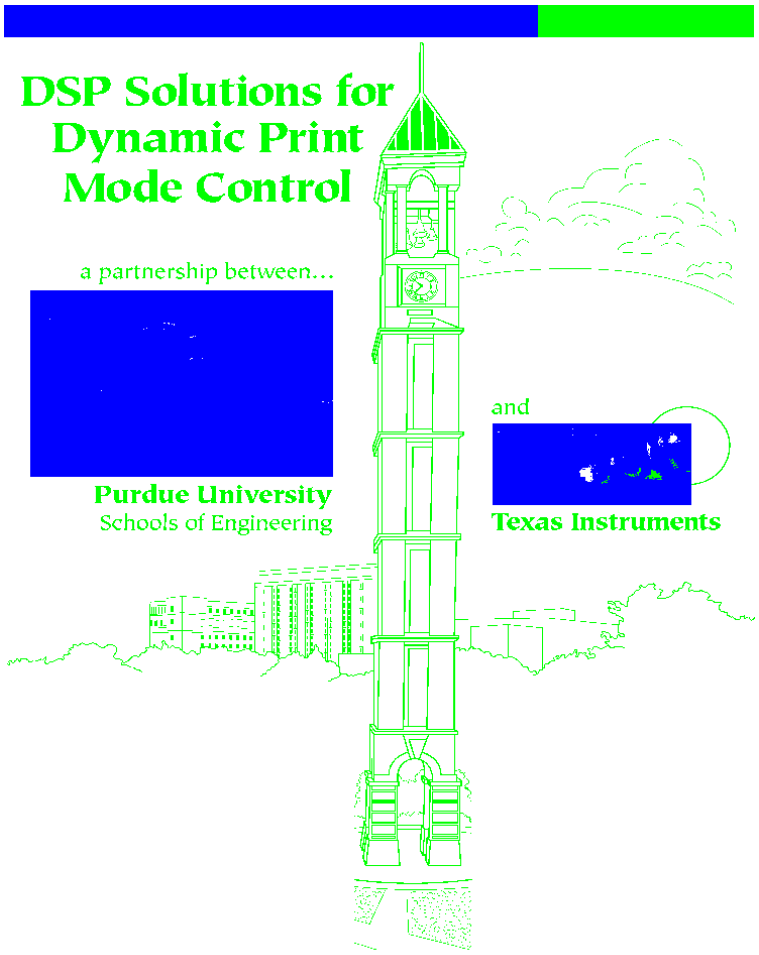
  Gray level 255 $\Leftrightarrow$ 1 pass (1P)

  Other gray levels $\Leftrightarrow$ 4 pass (4P)

- Print mode of each pixel is chosen independently of the other pixels.

Segmentation Result





NP - No Print $\Leftrightarrow$ White

1P - One Pass $\Leftrightarrow$ Green

4P - Four Pass $\Leftrightarrow$ Blue

Path Planning

- The path of the print-head must be planned before printing, so that each pixel can be printed using the desired print-mode.
- The path must cover:
  - Each 1P pixel at least once,
  - Each 4P pixel exactly four times.

Basic Head Motions

Code	HeadMotion	Parameters
1PLR	1 pass left to right	Start: First 1P or 4P pixel in the swath Stop: Last 1P or 4P pixel in the swath
1PRL	1 pass right to left	Start: First 1P or 4P pixel in the swath Last: Last 1P or 4P pixel in the swath
4PLR	4 pass left to right	Start: First 4P pixel in the swath Stop: Last 4P pixel in the swath
4PRL	4 pass right to left	Start: First 4P pixel in the swath Stop: Last 4P pixel in the swath
NPLR	No print left to right	
NPRL	No print right to left	
PA	Paper advance by N/4	

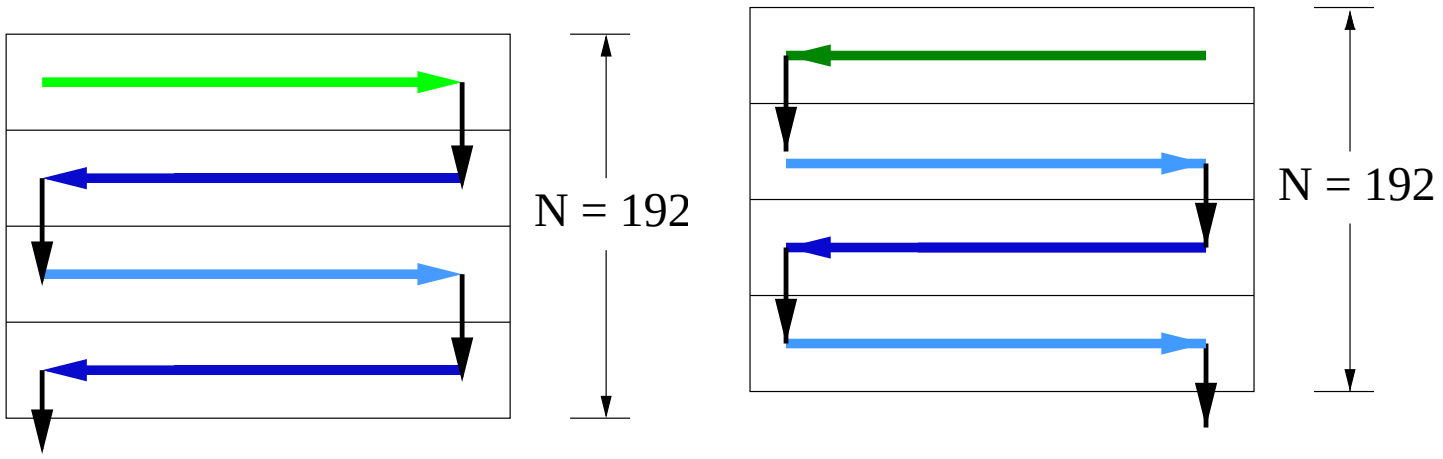
Path Planning

- We initialize path plan in one of the two possible manners.

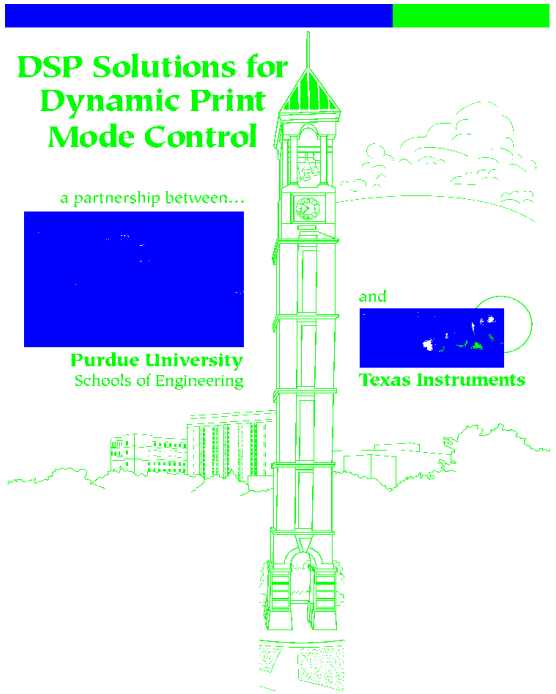
```
If (HeadPosition == left) {
  New Motions = {1PLR,PA,4PRL,PA,4PLR,PA,4PRL,PA}
}
If (HeadPosition == right) {
  New Motions = {1PRL,PA,4PLR,PA,4PRL,PA,4PLR,PA}
}
```

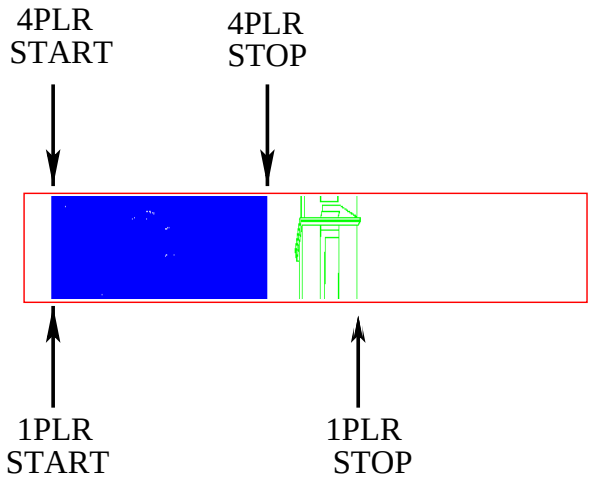
- Each sequence advances the paper by one full print head height.

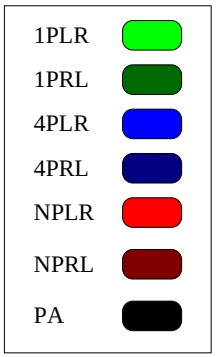
If PrintHead == Left If PrintHead == right



Finding Paths

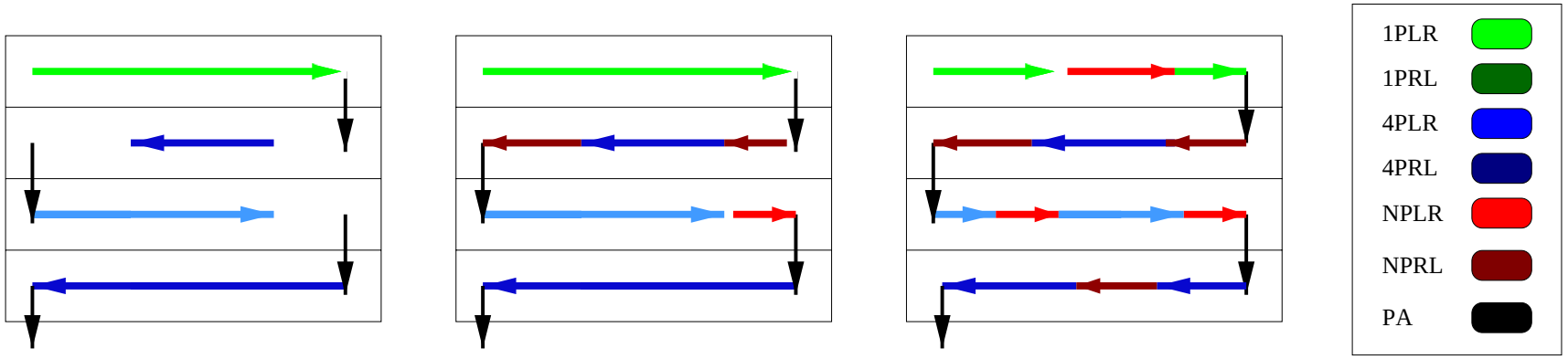






- For each head motion:
  - Compute start and stop positions
  - Determine if head motion is empty
- For 1P motions consider both 1P and 4P pixels
- For 4P motions consider only 4P motions
- Delete empty head motions

Connection and Optimization of Head Motions



(a) (b) (c)

(a) After deletion paths may not be connected to each other.

(b) Reconnect the paths by inserting by no prints, eg. NPLR or NPRL.

(c) Split the paths and insert no prints, eg. NPLR or NPRL to the white regions of the document.

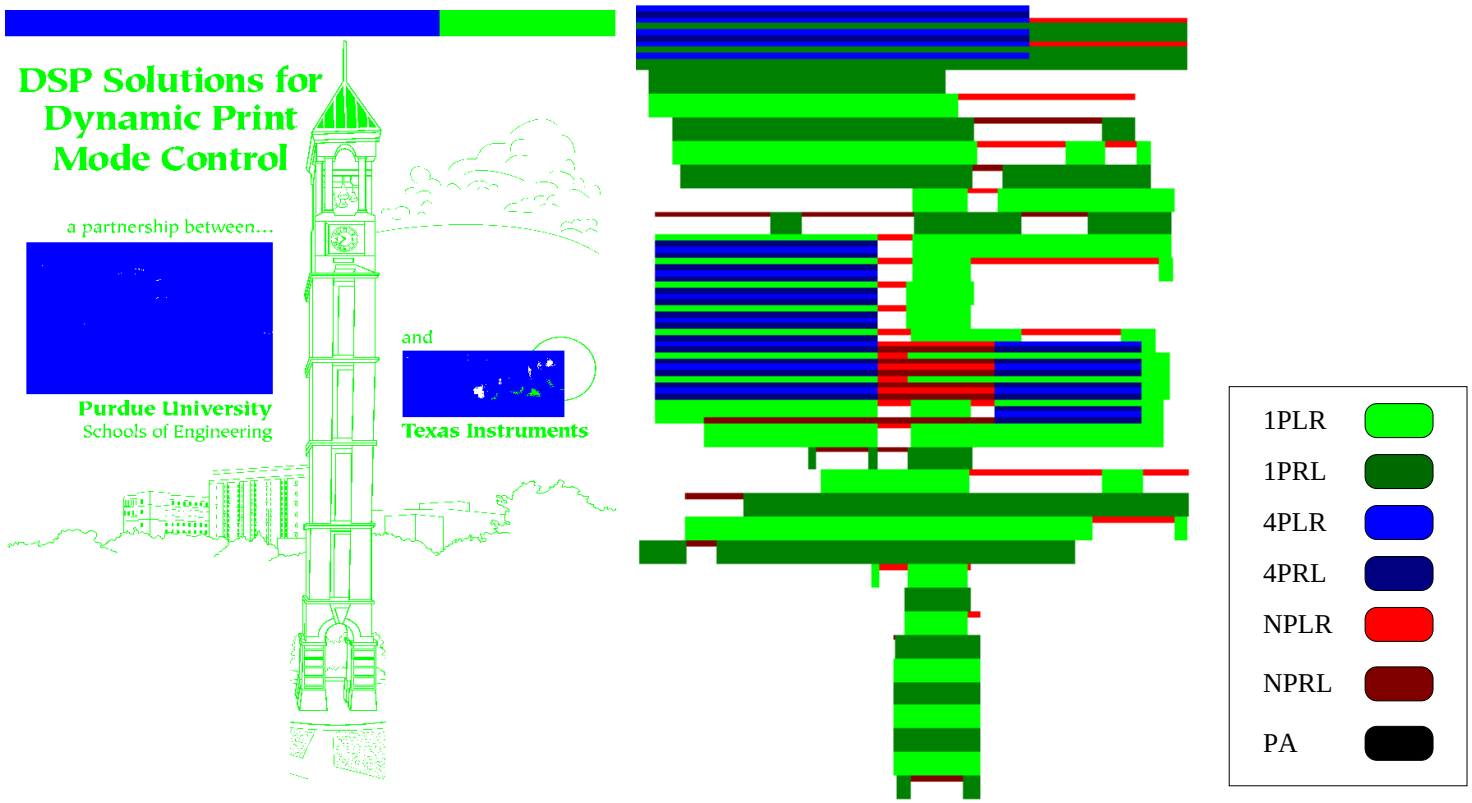
Repeat Process

- The new head motions are concatenated to the existing head motions

$$\text{HeadMotions} \leftarrow \text{cat}\,(\text{HeadMotions}, \text{NewHeadMotions})$$

- The process is restarted until the end of the page is reached.

Path Planning Result



- The color corresponding to later motions overwrites earlier motions.

Halftoning and Stripping

- Floyd and Steinberg error diffusion algorithm is used to convert the 300 dpi 8 bit raster document into 300 dpi binary raster document.
- Halftone, path plan and segmentation results are sent to "stripper". It extracts the halftone and segmentation data required by each print-head motion, and stores it to data structures.
- The output of the "stripper" is sent to the print-masker.

Print Masking

- Print-masking decides which pixels will be printed in the current pass.
- 1PRL and 1PLR print both 1P and 4P pixels
- In 1PLR or 1PRL:
  - 1P pixels must be printed
  - 4P pixels which are not masked out must be printed.
- In 4PRL or 4PLR:
  - 1P pixels must be skipped.
  - 4P pixels which are not masked out must be printed.

Print Masking

- Each pixel has a pass number depending their row number in the swath. A pixel in row i has:

$$PixelPassNumber = \lfloor (191 - i)/48 \rfloor.$$

- In any pass, pixels in the last quarter of the print head have their first passes and the ones in the last first quarter have their fourth pass.
- If the entry in the print mask is not equal to PixelPassNumber of a pixel, it will be masked out in 4PLR and 4PRL paths.

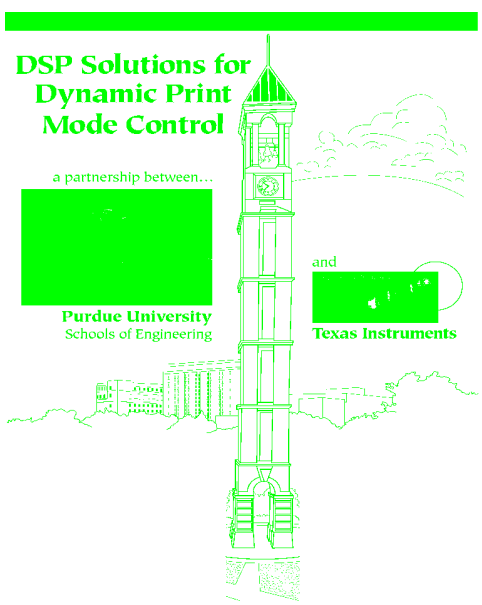
$$\text{Print if } Mask[x\%8][y\%8] == PixelPassNumber$$

Printing System

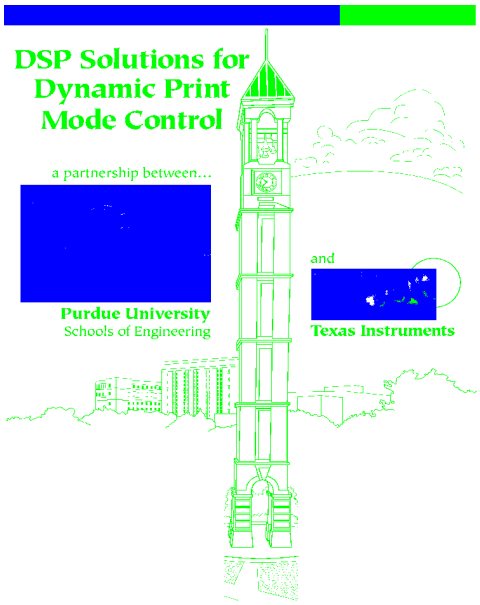
- Dynamic print mode control was implemented using:
  - Lexmark Z-52 printer mechanism
  - Texas Instruments Tiger-II DSP board based on C6211 VLIW DSP for real-time carriage/paper motion control and nozzle firing.
- The functioning system was demonstrated at Comdex 2000 in Las Vegas.
- Entire system was designed and implemented in less then 6 months.

Timing Results

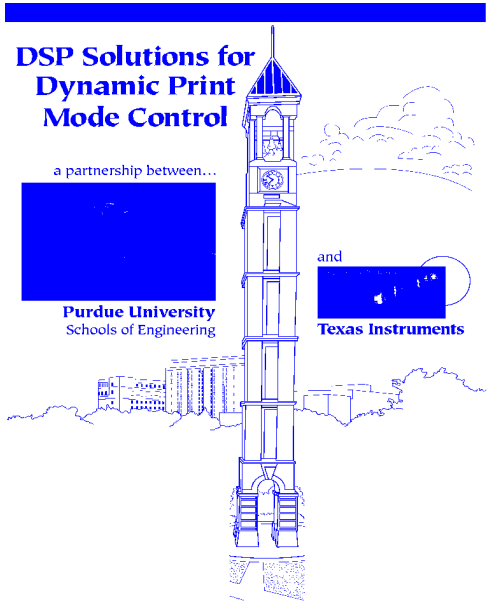
All One Pass



Dynamic Print Mode

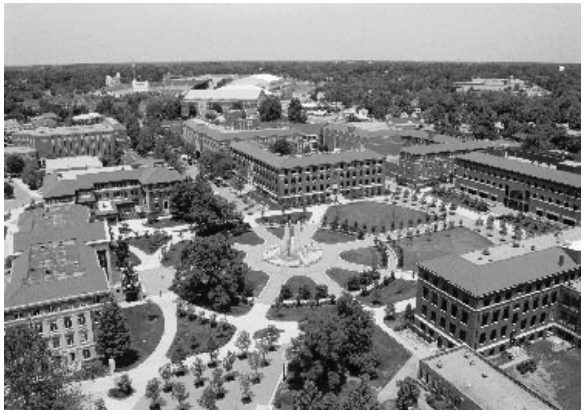


All Four Pass



	All One Pass	Dynamic Print Mode	All Four Pass
Number of Path Segments	99	146	383
Number of Swaths	33	64	132
NP Swath Length	17765	28178	51622
Total Swath Length	92499	176625	356872

Experimental Results

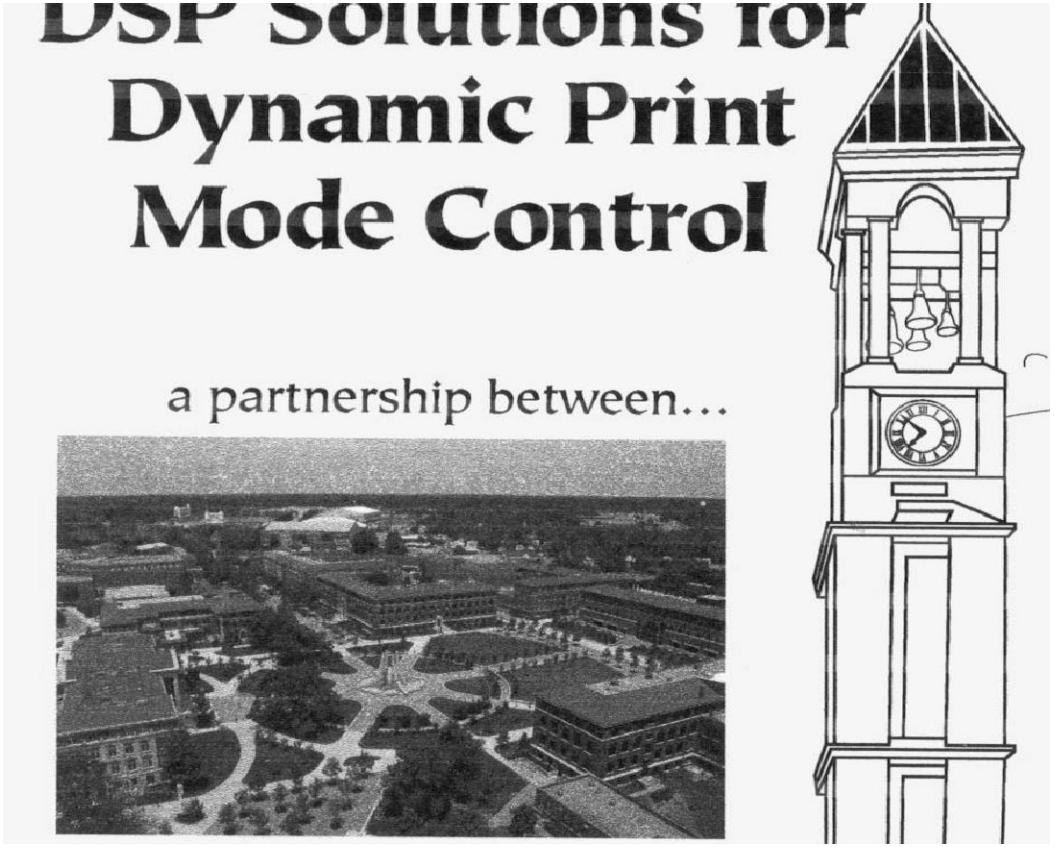


Original Image

Printed in One Pass

Printed in Four Pass

Experimental Results



- A region printed with one pass mode shows some defects due to miss-firing nozzles. However, this defects cannot be seen in four pass region.

Conclusions

- A novel printing scheme is introduced. It allows arbitrarily shaped regions in a document to be printed using different modes.
- The one pass mode results in greater print speed but has lower quality.
- The four pass mode results in greater quality but lower print speed
- Typically, the one pass mode is more suitable for text and graphics, and the four pass mode is more suitable for pictures.
- More sophisticated segmentation algorithms could be used to produce a more optimal trade-off between print quality and print speed.