The Design and Application of A Personal Printer/Scanner System

by
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Abstract

A prototype system for concurrent printing and scanning of documents has been constructed. By taking a personal computer ink-jet printer and modifying it to include a line-scan sensor, major benefits are derived.

Both conventional printers and scanners contain mechanisms for moving either documents, sensors or mirrors. Combining a printer and a scanner into a single device offers a potential reduction in cost because the printer's mechanisms then serve a double duty.

A scanner makes available to the personal computer user established commercial applications such as image digitization and facsimile. Moreover, unique document processing features are possible when a scanner is present in a printing device. With documents already containing some information, intelligent printing anotation can be performed. For example, a previously scanned and digitized picture can be printed on a new document already containing text and open space. Scaling, positioning and printing of the digitized picture to fit within the open space is acheived through scanning and analyzing the new document.

The physical and functional characteristics of the printer/scanner system are described. Principles relevant to the design, construction and application of the printer/scanner are given, and present and future applications discussed.

Thesis Supervisor: Andrew Lippman
Title: Associate Professor of Media Technology

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Chapter One

Introduction

One of the things that personal computers are best suited for is the preparation of documents. The personal computer and attendant word processing software are rapidly replacing the typewriter in offices and homes. However, documents produced by these computers are still largely devoid of quality graphics and images.

It is well known that an image can often transcend the printed word as a rapid means to communicate certain types of information. We would hardly expect any major newspaper or magazine to survive today without an abundance of graphics and images, even if they only appear as advertisements. Both consciously and unconsciously we assimilate a montage of sophisticated imagery from city and roadside environments, and the press and television. These are images created by specialists-- beyond the snapshot, the typical literate individual does not express himself pictorially. This is largely because the image making process can demand considerable time and skill, and often requires costly or complex technological implements.

Computers have been employed in automating the typesetting of newspapers, books and magazines, and have also aided in the enhancement and manipulation of images [Schrieber 78]. We now begin to see scanners appearing as peripheral devices for personal computers in office automation products . One such system, made by Datacopy Incorporated, permits the integration of images with text in a database system using: an IBM personal computer, for image processing and storage; a scanner, used to convert an image into computer readable form; and a printer, used to output computer processed images and text. An application suggesting the integration of portrait photographs of employees with associated textual data in personnel database records is offered [Datacopy 85]. By reducing the amount of effort usually required in the aquisition and manipulation of images, the personal computer user has a new means of effective expression.

This thesis is about a personal document creation system configured in an unusual way. The printer/scanner system incorporates two existing image processing technologies by implanting a line-scan camera into a color ink-jet printer. The camera is placed such that it views a horizontal slice across a document in the printer's paper feeder at the same place where the carriage performs printing.

Combining a printer and a scanner into a single device offers a potential reduction in cost as the paper feeder serves a double duty. The printer/scanner system not only includes all the potential features of systems with stand-alone printers and scanners, but offers the unique ability of performing document anotation.

Chapter Two

Physical Description of System

2.1 System Components

The printer/scanner hardware components consist of: an International Business Machines (IBM) Advanced Technology (AT) Personal Computer (PC); a Tektronix 4695 color ink-jet printer; a Fairchild charge coupled device (CCD) line-scan camera, lens, and camera control unit (CCU); a Dolan Jenner (Model 180) microscope illuminator, 2 fiber optic light pipes with rectangular apertures and lenses; a General Research Personal Computer Transient Recorder (PCTR) analog to digital converter card which is placed on the IBM's bus; and an aluminum pedestal testbed with folded light path designed and constructed specifically for this prototype system. Photographs of the total system are shown in Figure 2.1.

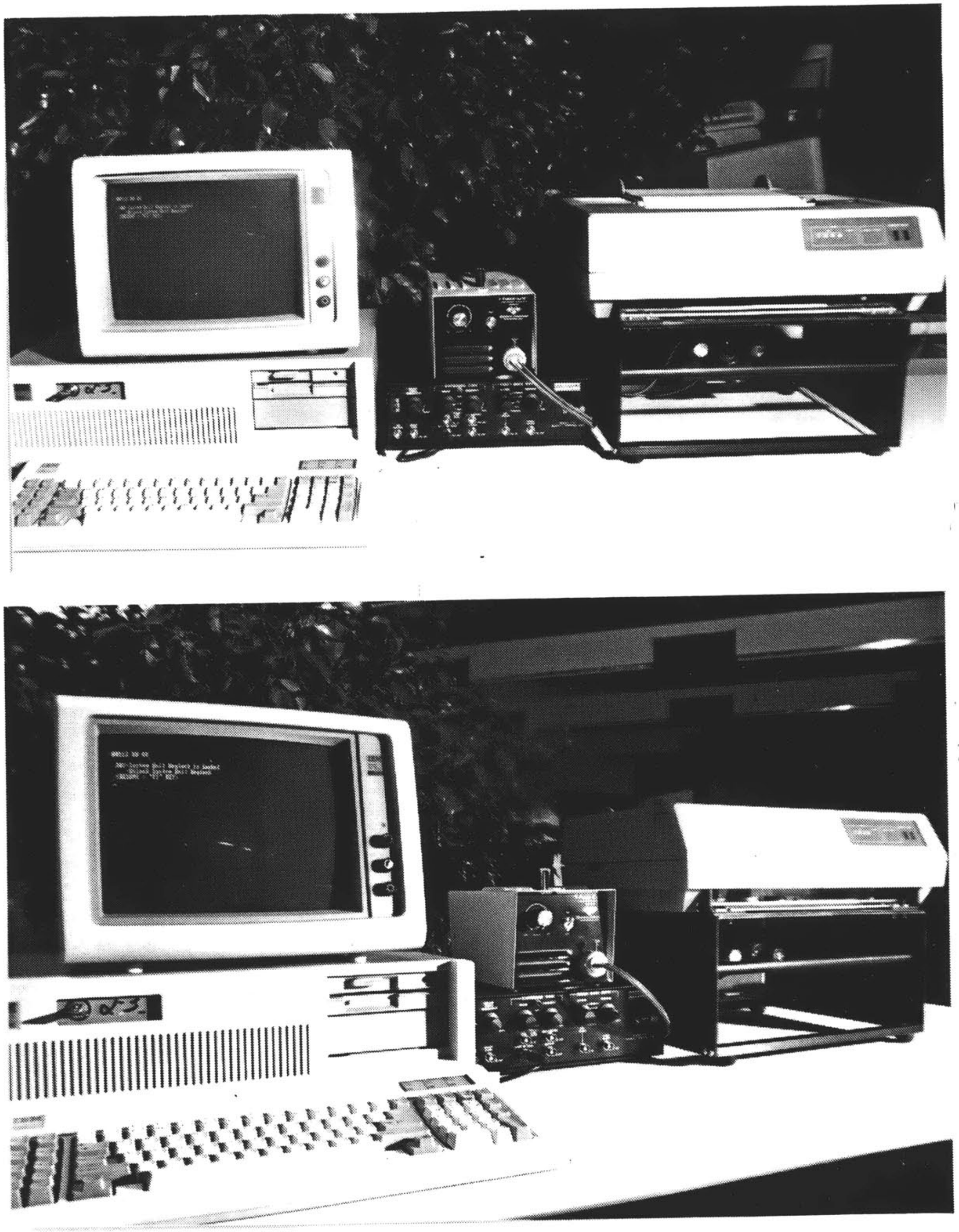


Figure 2.1 - Photographs of Printer/Scanner System.

2.2 The IBM AT PC

The IBM AT is a personal computer based on the Intel 8086 microprocessor. The System Unit has a fixed 40 megabyte disc drive and one 5 1/4 inch floppy disc drive. There is 512K bytes of RAM, a keyboard, a color monitor, a parallel interface card for controlling the printer and the PCTR analog to digital card used in digitizing the line-scan camera's video signal.

MS-DOS, Rev. 3.0, was the operating system under which software was developed. Software drivers and application code were written in both IBM assembler and Lattice C.

2.3 The Printer/Scanner Testbed

The Tektronix printer served as the base component from which designs for the printer/scanner testbed evolved. The goal is to modify the printer so that it also functions as a scanner. One design, requiring minimal optics, involves mounting both a single photo sensor and illuminator on the print carriage. In this way a document would be scanned horizontally during carriage movement and vertically by indexing the paper feed roller. Some electronics would be required to synchronize the sensor's sampling rate with carriage movement.

The most critical limitation of this approach is print carriage speed which is approximately 1 second per line. This results in excessively long document scanning times of almost 30 minutes for a 8 1/2 by 11 inch document at 200 samples per inch.

The approach we selected was to use a line-scan camera which could view the full width of a sheet of paper. This method eliminates the need for mechanical movement of the sensor and results in a horizontal scan time of about one millisecond.

The camera was mounted under the printer in a pedestal. Then through an opening in the bottom of the printer enclosure and with the aid of two front surface mirrors, a folded light path was created. This enabled the camera to see documents in the printer's feed roller. A diagram of the printer/scanner testbed is shown in Figure 2.2.

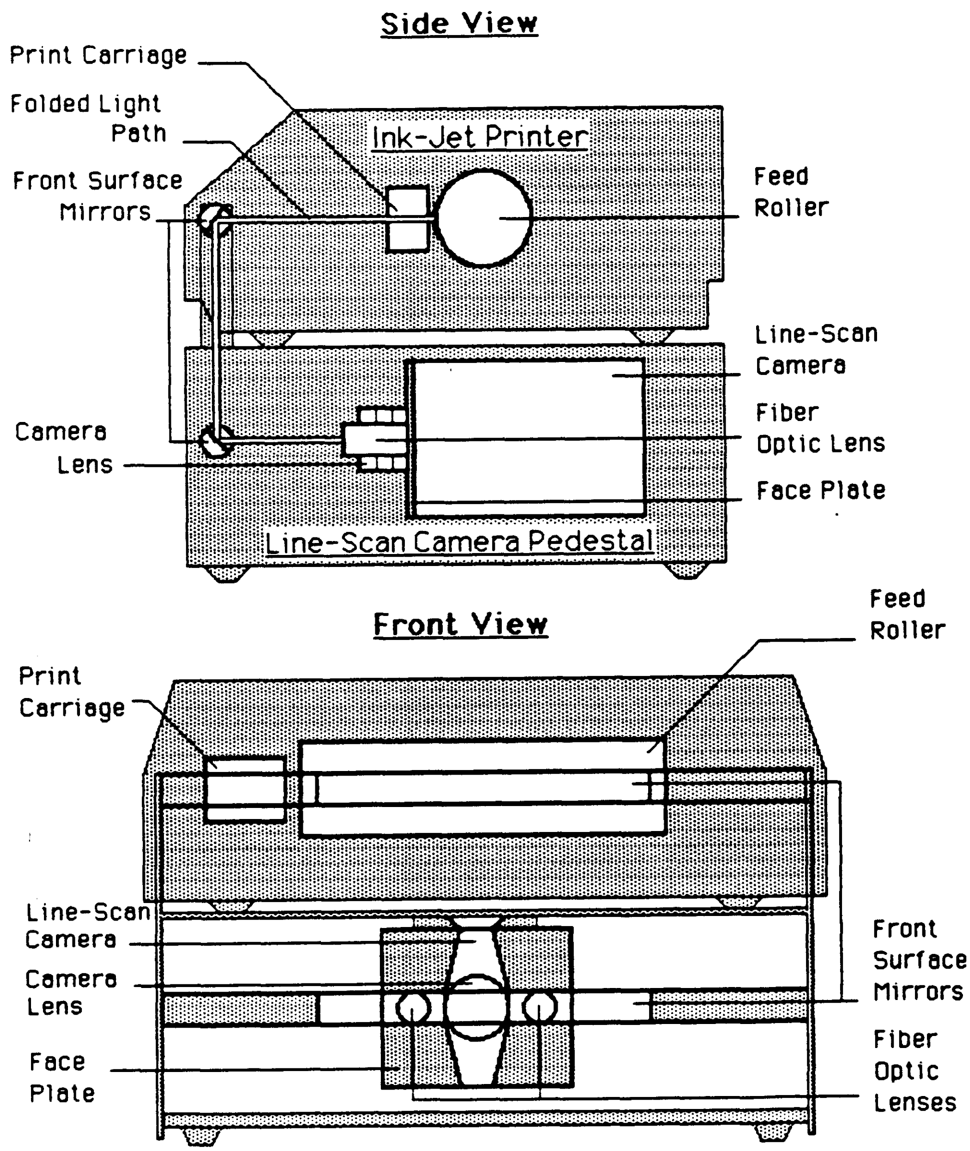


Figure 2.2 - Diagram of Printer/Scanner Testbed.

This design provides for a compact yet flexible testbed from which to work. Line-scan cameras with a range of resolutions can be accomodated. Focusing and scaling is accomplished by changing camera to document distance. The camera's movement is along the optical axis and made possible by a dovetail mounting arrangement. Adjustment of the folded light path is accomplished by rotating the mirrors. The mirrors are .750 x 8.500 inches in size and bonded to flats machined in .750 inch diameter aluminum bar stock. Two fiber optic light pipes carry light from the microscope illuminator to their rectangular aperture terminuses. These are attached at a 4.500 x 5.000 x .187 inch face plate mounted to the front of the camera. Lenses project light from the apertures through the folded light path to illuminate documents in the printer during scanning. The pedestal was constructed out of bent pieces of .187 inch aluminum sheet and 1.000 by .500 inch aluminum bar stock. Aluminum pieces were anodized black and assembled using machine screws. Photographs of the testbed are shown in Figure 2.3.

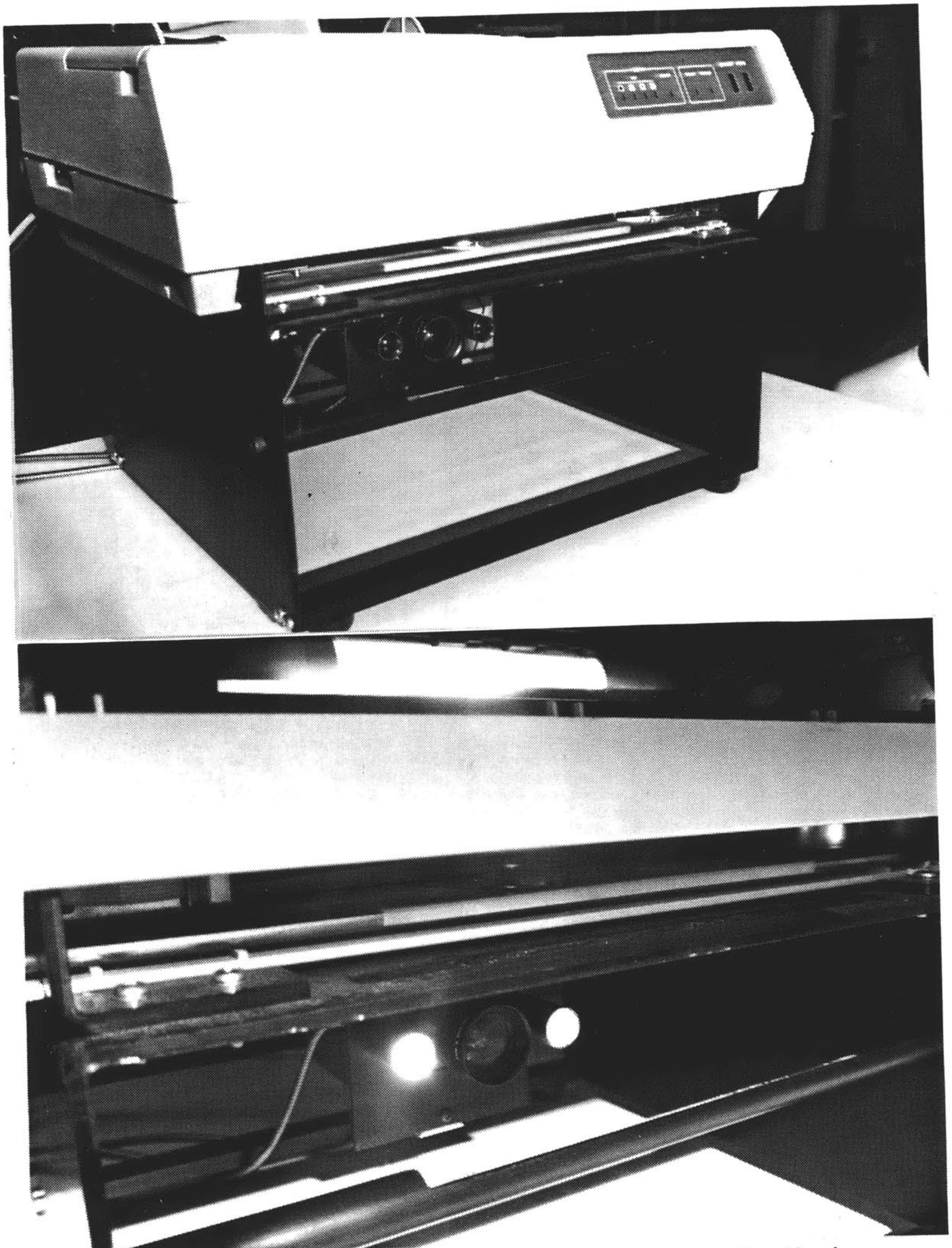


Figure 2.3 - Photographs of Printer/Scanner Testbed.

Chapter Three

Functional Description of System

3.1 System Function Overview

The printer/scanner can be viewed as a digital image processing and analysis system that is capable of functioning in three different modes. First, it possesses all normal functions of the Tektronix printer, allowing printing of PC text files, graphics files, and picture files. Second, documents 8 1/2 inches wide up to any length can be scanned, digitized and stored, within the memory capacity of the PC. Third, both scanning and printing can occur concurrently. In this way documents scanned can be analyzed, and an appropriate printing action given by the PC. A functional diagram of the printer/scanner system is shown in Figure 3.1.

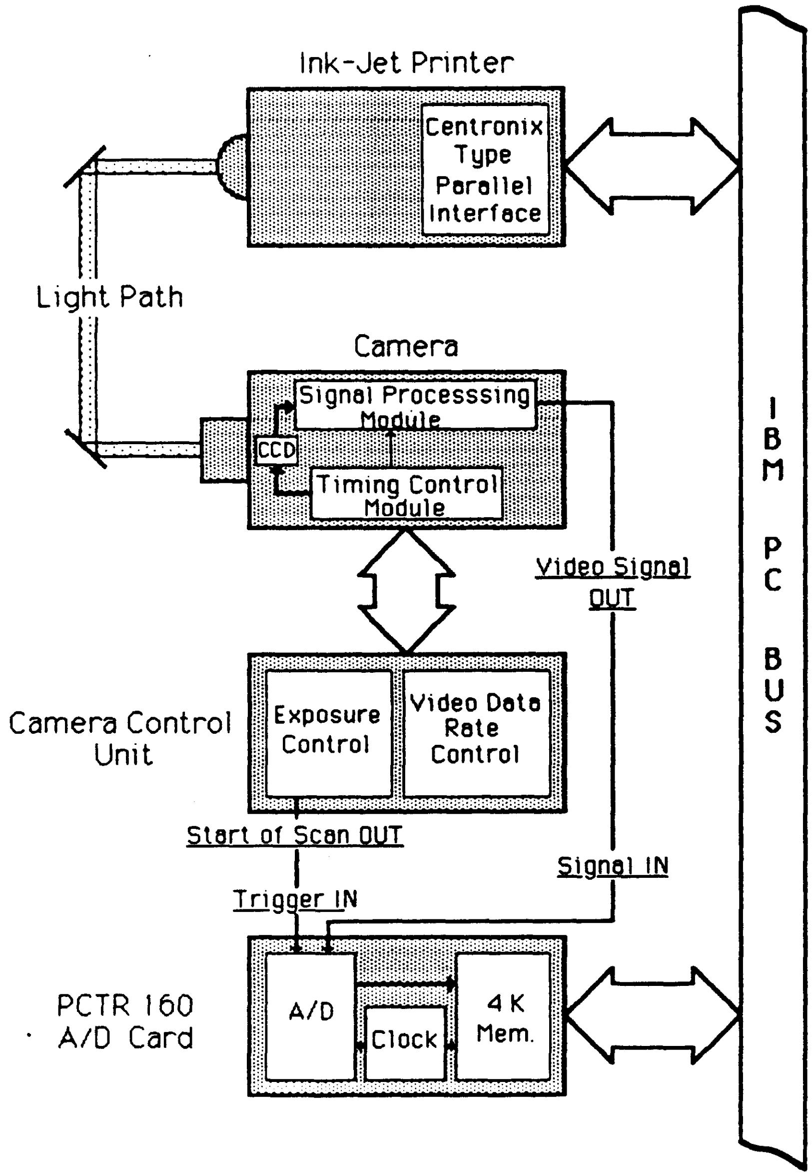


Figure 3.1 - Functional Diagram of Printer/Scanner.

3.2 Ink-Jet Printer

3.2.1 PC Printers

Most printers for personal computers are not used to print thousands of copies of a single document, but rather print a few copies of many different documents. The evolution of the computer printer begins with the functional equivalent of the typewriter. These are the so called impact printers. The Teletype model 33 is an example. A preformed image of a letter is struck though an inked ribbon on to paper.

The newer dot-matrix type printers employ a different method. A matrix of wires is driven into the ribbon by solenoid magnets. By using selected wires, a pattern approximating a letter or other symbol can imaged on paper.

The ink-jet printer is a dot-matrix style printer. A single jet is composed of three parts: a drop generator, a charge electrode and deflection plates. The drop generator emits a continuous jet of ink through a small oriafice. Because of surface tension, the ink forms into droplets. The drop generator functions as a diaphram pump with a vibrating piezoelectric crystal serving as a the diaphram. Drops emerge from the generator at frequencies greater than 100,000 per second and at velocities of nearly 20 meters per second. Each drop passes through a modulated charge electrode and then through the deflection plates. If a droplet has been charged, it will be deflected slightly towards the paper. If not charged, the droplet will travel straight through the deflection plates, not reaching the paper, but rather a gutter which leads to the ink reservoir. Modulation of the charge electrode determines which drops of ink will arrive at the paper [Kuhn 79].

3.2.2 Tektronix 4695

The Tektronix 4695 ink-jet printer has a resolution of 120 dots per inch and each dot can be one of 15 different colors or white, no color. The colors are created by any combination of four colored inks: black, yellow, magenta and cyan.

The ink is sprayed through a 4 by 4 matrix of jets. Each colored ink has its own column of four jets. Only after four horizontal lines worth of pixel data are loaded does the carriage sweep out in a raster.

The ink-jet printer is controlled by the PC through a Centronics type 8 bit parallel interface. The printer can be commanded to operate in one of two modes. In what Tektronix calls alpha mode, the PC can send ASCII character codes which are processed by the printer and converted to character dot patterns representing the images of the characters. The dot patterns for each character are stored in the printer's ROM. One line of characters is printed in four raster passes or sixteen rows of worth of data.

In graphics mode, the PC can load color values for each pixel for a rasters worth of data, and then have them printed. In this way, the PC can create is own character fonts, line graphics or pseudo-half-tone images.

3.3 Line-Scan Camera

3.3.1 Computer Imaging

There are a number of technologies employed in the acquisition of images for computer. A photograph or document can be sampled by the scanning microdensitometer. In this device a small spot of light is projected onto a document while a photomultiplier tube receives the reflected light. The document is scanned by a motor-driven table which moves it under the spot.

In the flying-spot scanner, an electron beam sweeps out in a raster on the surface of a cathode ray tube. The beam forms a spot of light when hitting phosphor on the inside surface of the tube. The spot of light is focused through a lens onto a stationary document while the reflected light is received by a photomultiplier tube [Cannon 81].

3.3.2 Fairchild CCD Sensor

The sensor used in the printer/scanner is based on a solid state technology called charged coupling, developed in the 1970's. Charge coupling is the collective transfer of electrons from one semiconductor storage element to an adjacent element by manipulation of voltages. Electrons are stored in what is called a potential well and held in place by a positive charge. In the shifting of the electrons to the next well, the positive charge of the initial cell is lowered and then a positive charge is applied to the next cell [Fairchild 84].

As an image sensor, the silicon used in the fabrication of a CCD is subject to the Einstein photoelectric effect. That is, the silicon is light sensitive and upon receiving and absorbing radiation, electrons are accumulated. The amount of electrons accumulated is directly in proportion to the incident light. It is this time integration of electron charge which is used in CCD image sensors. CCD sensors generally come in two configurations: linear and area. The line type comes in a row of sensor sites set adjacent to one another. The area type is a two-dimensional matrix of sensor sites.

One of the significant advantages of the CCD imaging device over the vidicon or other analog scanning sensors is the precise location of the sensors sites, as they are etched in place by a mask. In the vidicon and flying-spot scanner, the scanning electron beam is controlled by analog sweep amplifers which are subject to noise. Thus, the beam position varies during scanning.

The line-scan camera unit used in the printer/scanner has 2048 sensor sites. Each site is 13 microns square and all sites are on 13 micron centers. Optical equations involved in determining horizontal slice size on the document for a given sensor are provided in Appendix A.

The camera control unit permits manual setting of both the exposure time for the sensor sites and the rate at which the data is clocked out. The camera and control unit function in the following way:

- *Wait one exposure period.*
- *Transfer all accumulated charges from sensor sites to corresponding shift register locations.*
- *Set the start-of-scan TTL level signal to high.*

- *Clock out charge values from the shift registers through the camera's video-signal-out port, at the manually set clock rate.*

3.4 Analog To Digital Converter

3.4.1 Digitizing

In order that a picture be processed by computer, it must be described or represented in numerical form. One way to define an image is as a continuous two-dimensional function f(x, y), where each X-Y pair represents the light intensity at that point in the image. Since the computer must deal with an image representation which is finite, a continuous tone image must be sampled at a number of discrete points [Gonzalez 77].

The sampling theorem states that a signal with a bandwidth of B cycles per unit length can be exactly reconstructed from 2B samples per unit length [Shannon 49]. Since the printer/scanner's CCD sensor has 2048 discrete sites, its highest possible spatial frequency response is 1024 samples per line in the X-axis. See Appendix B for a description of the printer gear train and equations as they are applied to sampling in the Y-axis.

Whenever an analog signal is digitized a quantizing error is introduced. The peak-to-peak signal-to-RMS quantizing error ratio in dB can be approximated as

$$SER = 6.02 \times (\text{number of bits}) + 10.8$$

[Goldberg 76]. In general we would like the quantizing error to be as small as possible, but this is done at the expense of more bits per sample. Moreover, as the precision of a sample increases, the least significant bits begin to reflect only the noise of the sampled signal. This suggests that it becomes wasteful when the quantizing error is reduced below the noise already inherent to the sampled signal.

The peak-to-peak voltage of the camera's video signal is rated at 1.0 V and the RMS noise level is 3.6 mV. This results in a signal-to-RMS noise ratio of 49dB. Using this value and working from the equation above, implies that quantizing the signal at more than 6.35 bits per sample would only result in storing camera signal noise to greater precision.

The PCTR quantizes each sample into 8 bits. Althougth at least one bit of each sample is probably noise, the choice of this 8 bit A/D is based on additional factors. A 8 bit sample safely insures sufficient precision in quantizing the signal. The 8 bit byte is more efficiently dealt with than 6 or 7 bits by the IBM hardware and software.

3.4.1 General Research PCTR-160

The PCTR will accept a video signal of 1.0 V peak-to-peak and take up to 4096 samples at 20 MHz or at 2, 4, or 8 times this rate or at binary submultiples of the basic rate of 1/2 to 1/128. The samples are stored in the PCTR's high speed local memory which also appears in the IBM's address space. As earlier mentioned, each sample contains 8 bits of data. The board was confiquired to begin sampling upon receiving an external trigger from the CCU. The following pseudo-code for the simple driver used in digitizing a document illustrates a basic function of the printer/scanner system.

```
;The CCD camera is free running.
;The CCU gives a start-of-scan pulse to
;trigger the PCTR's sampling of one video line.

DIGITIZE_PICTURE
   begin
      open-PC-picture-file-for-writing
      set-PCTR-sample-frequency
      while not end-of-picture
         do
            arm-PCTR-for-external-trigger
            while not video-sample-ready
               wait
            append-sample-data-to-picture-file
            index-paper-feeder
         end
      close-PC-picture-file
   end
```

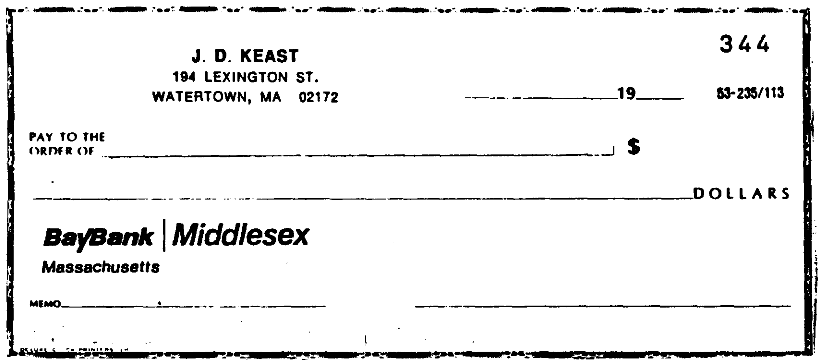
Chapter Four

System Applications

4.1 Anotation of Standard Forms

One class of problems encountered when using a printer or typewriter involves the placement of printed letters inside boxes or between lines of a standard form. Invariably the spacing between boxes and lines do not correspond with the pitch of the printing device. The printer/scanner, through analysis of the document form, enables proper placement of the text within the given boundaries.

To demonstrate printing anotation of forms we chose to fill out a personal check. A check inserted anywhere along the back of the paper feed roller is found and filled out automatically. First the check is dropped into the printer's paper feeder. Then the paper feeder is indexed until the scanner finds the upper left hand corner of the check. Finally, the printer carriage moves to the designated areas and prints. A sample check of before and after printing is shown in Figure 4.1.



J. D. KEAST
194 LEXINGTON ST.
WATERTOWN, MA 02172

344

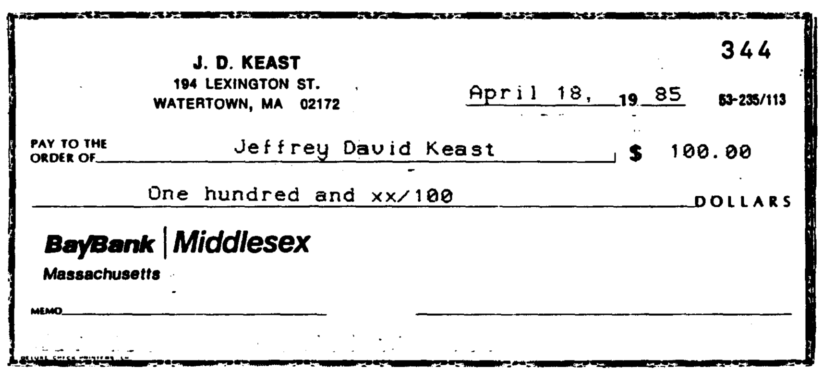
19____ 53-235/113

PAY TO THE
ORDER OF ____________________ $

____________________ DOLLARS

BayBank | Middlesex
Massachusetts

MEMO



J. D. KEAST
194 LEXINGTON ST.
WATERTOWN, MA 02172

344

April 18, 19 85 53-235/113

PAY TO THE
ORDER OF Jeffrey David Keast $ 100.00

One hundred and xx/100 DOLLARS

BayBank | Middlesex
Massachusetts

MEMO

Figure 4.1 - Sample Output of Automated Check Writing.

4.2 Handwriting For Electronic Text Editing

Neither the typewriter or word processor offers the freedom and portability of pen and paper when preparing documents. In this application we investigated using handwriting as an off-line means to perform electronic text editing. This process begins with the printing of a PC text file. Then the resulting document is carried away for anotation with proofreaders' marks. Later, the document is scanned into the system, the proofreaders' marks are interpreted and the original PC text file is updated accordingly.

A program was developed to demonstrate the feasibility of such an editing system. First a document was printed out, as it appears at the top of Figure 4.2. Then the document was taken away and the user drew a line between the two solid black boxes. This information is necessary for determining processing parameters used in scanning. From the two rectangular black boxes, an offset and scale factor are calculated. The line drawn, is used to set the intensity thresholds for finding the other marks made in the main body of the text.

At the top of Figure 4.3, we see the document after some words have been underlined by hand. After scanning and analyzing the anotated document, the selected words were underlined in the original file and then printed out as appears at the bottom of Figure 4.3.

Please cross this out

Please cross out or underline the text bellow.

To the Editor:

On May 3 The Tech printed an
editorial regarding protests
against investments in South Africa.
The editorial chastised students
for not knowing enough facts regarding
divestment and for their childish
confrontation with the administration.
The editorial continued with a self-
righteous call for students and others
at MIT to become more informed.

Figure 4.2 - Text Editing: Sample One.

~~Please cross this out~~

Please cross out or underline the text bellow.

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Figure 4.3 - Text Editing: Sample Two.

4.3 Future Work

The printer/scanner hardware has been configured to permit unencumbered expansion. One possible step in hardware augmentation would be to provide the capability of performing color separations. By placing a color wheel with red, green and blue filters either in front of the camera lens or the fiber optic illuminator, color documents may be scanned. Adding a frame buffer to the PC would permit softcopy viewing of scanned documents.

The check finding algorithm touches on an entire class of document generation applications. Long streams of document material can be put through the printer without the constraints of mechanical registration. With fiducials marked on documents, the scanner could provide feedback to maintain proper printing registration.

Research has been directed towards the recognition of handwritten engineering drawings [Hoska 82]. Along with recognizing other types of proofreaders' marks as an extension of the work described earlier, interpretation of graphics for personal use could be investigated. For instance, sketches off the back of a napkin could be scanned, and output as finished straight-edged line drawings.

Digital representations of images take relatively large amounts of computer memory. A ten megabyte disc drive can store about 200 television quality images which are digitized directly. However, storage of pictures can be optimized through methods of encoding. When we sample a picture, and use eight bits per sample to represent it, we are using a constant size code. This would be the most efficient means of storing a picture provided that each pixel value had an equal probability of occurring in the image. However in real world systems this is not the case. In fact most real world systems have information content with unequal probabilities of occuring. For example, Morse code is optimized based on the probability of english letters appearing in english text.

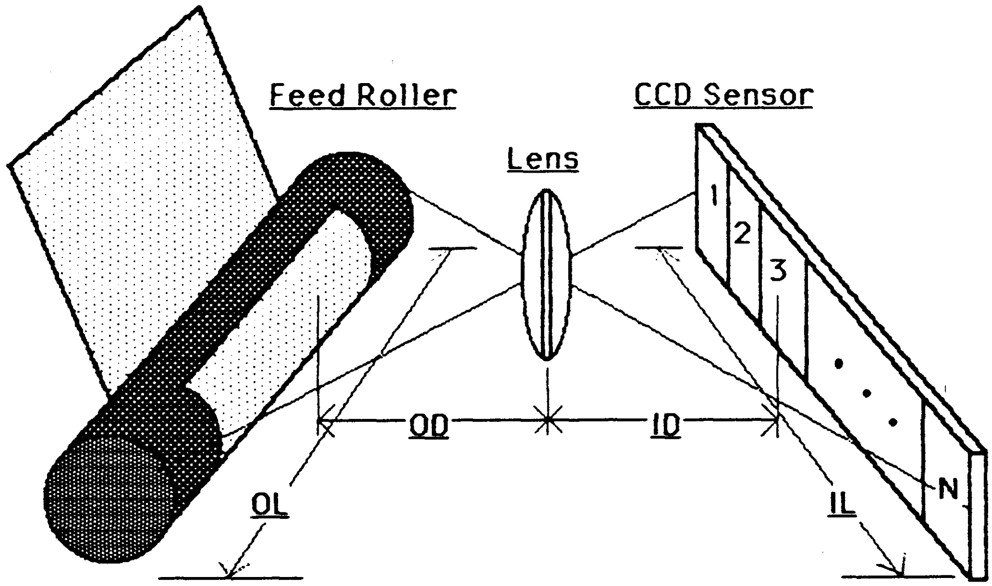
A personal document system could perform adaptive coding of illustrated documents for storage in a database. This system would analyize each document and locally select appropriate encoding techniques to optimize the use of storage space. Ordinary text could be processed through optical character recognition, so only the font style, size, and ASCII character codes would be stored. Line drawings could be stored through run-length encoding. Black and white images are stored with eight bits per pixel, color with 24 bits. Each image could also be compressed. The challenge is to create image analysis techniques for determining the best encoding scheme.

Appendix A

Optical Equations

The line-scan camera's CCD has 2048 sensor sites and was ordered with a 28mm focal length lens. If we wish to take 200 samples per inch across a document, we need to determine the correct camera to document distance. Problems of this type are easily solved with the equations given Figure A.1.

At 200 samples per inch we are able to resolve to .005 of an inch or 127µm. Let this be *object length* (OL). The corresponding *image length* (IL) of a 127µm object is set equal to a single sensor site size, 13µm for the Fairchild CCD. Since M = OL/IL; M = 9.769, and OD = f(M + 1);
28 (9.769 + 1) ≈ 308mm, for camera to object distance.



$$\frac{1}{f} = \frac{1}{ID} + \frac{1}{OD} \quad \text{and} \quad \frac{OL}{IL} = \frac{OD}{ID}$$

f = focal length.
ID = image distance (from lens to CCD).
OD = object distance (from lens to object).
M = magnification.
OL = object length.
IL = length of the image to be focused on CCD.

Figure A.1 - Document to Camera Diagram and Equations.

Appendix B

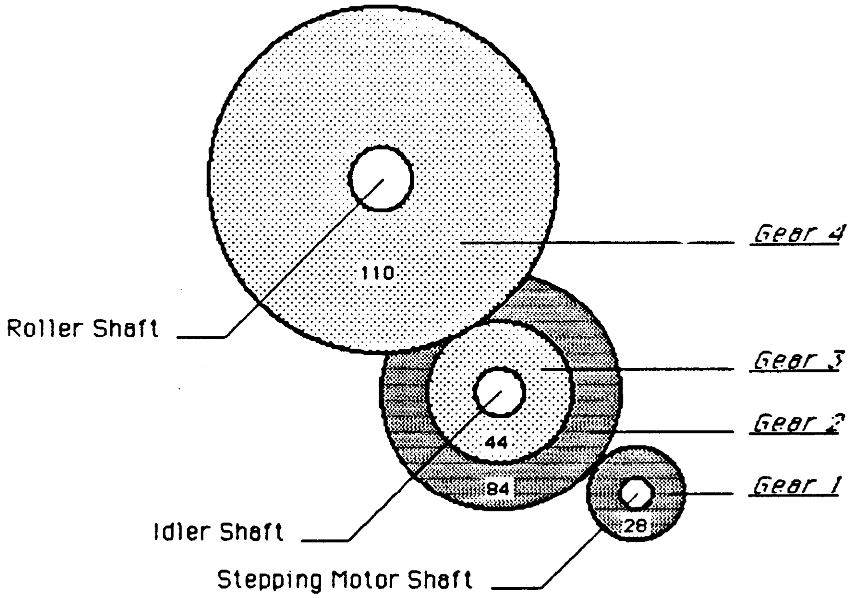
Printer Gear Train and Equations

In order to uniformly sample a document placed in the printer/scanner, the displacement caused by the paper feed roller with each index in *Y* should be the same as the distance between samples taken by the CCD in *X*.

In the printer, a stepping motor drives the paper feed roller via a gear train, as diagramed in Figure B.1. With this gear train, a *micro-line-feed* command from the PC will increment the paper feeder such that a document is indexed by .033 inch. This is partly a function of the *gear ratio*, as defined in the equation of Figure B.1. The standard gear ratio of the printer is .133.

If the CCD is optically sampling a document at 200 points per inch, the pitch between samples, or pixels, is .005 inch. Therefore the existing gear train indexes paper at 6.6 times the pixel pitch. To make the distance between samples taken in *Y* equal to those in *X*, we need to replace the standard gear train with a new one having a gear ratio of (.133 / 6.6), or .020.

In replacing the gear train it would be convenient if the new gears were to have the same shaft centers as the standard gears, or *center distances*. Therefore, looking for a gear set replacement which will have a given ratio, while still utilizing the existing shafts, requires a solution of three equations with four unknowns. A computational approach to this problem is implemented in C and is shown with the resulting data in Figure B.2.



Gear Set One:

$$C_D = .5 * \left(\frac{28}{2} + \frac{84}{2} \right)$$

$$C_D = 28\text{mm}$$

Gear Set Two:

$$C_D = .5 * \left(\frac{44}{2} + \frac{110}{2} \right)$$

$$C_D = 38.5\text{mm}$$

Gear Ratio: $\dfrac{\text{Gear1} * \text{Gear3}}{\text{Gear2} * \text{Gear4}}$

P_D = Pitch Diameter

N = Number of Teeth

P = Pitch (2mm)

C_D = Center Distance

$$P_D = \frac{N}{P}$$

$$C_D = .5 * \left(\frac{\text{Gear1}}{2} + \frac{\text{Gear2}}{2} \right)$$

Figure B.1 - Gear Train Diagram and Equations.

```
#include "/pub/c/math.h"
#include "/pub/c/stdio.h"

main()
 {
  float n1, n2, n3, n4;
  float cd1, cd2, ratio, pitch;

  cd1 = 28.0;
  cd2 = 38.5;
  ratio = 0.019;
  pitch = 2.0;

  for (n1 = 13; n1 < 20; n1++)
   for (n2 = 44; n2 < 100; n2++)
    for (n3 = 13; n3 < 20; n3++)
     for (n4 = 100; n4 < 200; n4++)
      if (0.5 * (n1/pitch + n2/pitch) == cd1)
       if (0.5 * (n3/pitch + n4/pitch) == cd2)
        {
         ratio = (n1 * n3) / (n2 * n4);
         printf ("%f, %f, %f, %f, %f\n\r", n1, n2, n3, n4, ratio);
        }
 }
```

Gear1	Gear2	Gear3	Gear4	Ratio
13.000000,	99.000000,	13.000000,	141.000000,	0.012107
13.000000,	99.000000,	14.000000,	140.000000,	0.013131
13.000000,	99.000000,	15.000000,	139.000000,	0.014170
13.000000,	99.000000,	16.000000,	138.000000,	0.015225
13.000000,	99.000000,	17.000000,	137.000000,	0.016294
13.000000,	99.000000,	18.000000,	136.000000,	0.017380
13.000000,	99.000000,	19.000000,	135.000000,	0.018481
14.000000,	98.000000,	13.000000,	141.000000,	0.013171
14.000000,	98.000000,	14.000000,	140.000000,	0.014286
14.000000,	98.000000,	15.000000,	139.000000,	0.015416
14.000000,	98.000000,	16.000000,	138.000000,	0.016563
14.000000,	98.000000,	17.000000,	137.000000,	0.017727
14.000000,	98.000000,	18.000000,	136.000000,	0.018908
14.000000,	98.000000,	19.000000,	135.000000,	0.020106
15.000000,	97.000000,	13.000000,	141.000000,	0.014258
15.000000,	97.000000,	14.000000,	140.000000,	0.015464
15.000000,	97.000000,	15.000000,	139.000000,	0.016688
15.000000,	97.000000,	16.000000,	138.000000,	0.017929
15.000000,	97.000000,	17.000000,	137.000000,	0.019189
15.000000,	97.000000,	18.000000,	136.000000,	0.020467
15.000000,	97.000000,	19.000000,	135.000000,	0.021764
16.000000,	96.000000,	13.000000,	141.000000,	0.015366
16.000000,	96.000000,	14.000000,	140.000000,	0.016667
16.000000,	96.000000,	15.000000,	139.000000,	0.017986
16.000000,	96.000000,	16.000000,	138.000000,	0.019324
16.000000,	96.000000,	17.000000,	137.000000,	0.020681
16.000000,	96.000000,	18.000000,	136.000000,	0.022059
16.000000,	96.000000,	19.000000,	135.000000,	0.023457
17.000000,	95.000000,	13.000000,	141.000000,	0.016499
17.000000,	95.000000,	14.000000,	140.000000,	0.017895
17.000000,	95.000000,	15.000000,	139.000000,	0.019311
17.000000,	95.000000,	16.000000,	138.000000,	0.020748
17.000000,	95.000000,	17.000000,	137.000000,	0.022205
17.000000,	95.000000,	18.000000,	136.000000,	0.023684
17.000000,	95.000000,	19.000000,	135.000000,	0.025185
18.000000,	94.000000,	13.000000,	141.000000,	0.017655
18.000000,	94.000000,	14.000000,	140.000000,	0.019149
18.000000,	94.000000,	15.000000,	139.000000,	0.020664
18.000000,	94.000000,	16.000000,	138.000000,	0.022202
18.000000,	94.000000,	17.000000,	137.000000,	0.023761
18.000000,	94.000000,	18.000000,	136.000000,	0.025344
18.000000,	94.000000,	19.000000,	135.000000,	0.026950
19.000000,	93.000000,	13.000000,	141.000000,	0.018836
19.000000,	93.000000,	14.000000,	140.000000,	0.020430
19.000000,	93.000000,	15.000000,	139.000000,	0.022047
19.000000,	93.000000,	16.000000,	138.000000,	0.023687
19.000000,	93.000000,	17.000000,	137.000000,	0.025351
19.000000,	93.000000,	18.000000,	136.000000,	0.027040
19.000000,	93.000000,	19.000000,	135.000000,	0.028753

Figure B.2 - Computational Approach to New Gear Train.

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