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DIGITAL REPRESENTATIONS OF ENGINEERING DRAWINGS.(U)

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Methods for producing the digital representation of engineering drawings are discussed. Particular attention is paid to the interactive creation of such drawings with computer-controlled drafting and design equipment and the automatic scanning of existing drawings. Hardware, software, and human interaction for interactive and scanning methods are discussed, with comments on where the systems are now and how they need to be improved in the future.

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CONTENTS

1. INTRODUCTION

At present, there is a great deal of interest in digitally storing and manipulating the pictorial information contained on an engineering drawing. This digital information in its simplest form contains only enough information to reproduce the "picture" representing the original drawing. In a more complex form, the digital data may contain not only the pictorial information, but also data on revision levels, related drawings, manufacturing data, and even data to drive machines that will produce the part depicted in the drawing.

Just as there are many types of data, there are many ways to put the data into a digital form suitable for computer storage and manipulation. The most logical method involves creating the drawing with computer assistance. This could simply involve describing a drawing parametrically on a point-by-point and line-by-line basis and entering the data by punch cards or from a terminal into a computer. On a higher level, the drawing can be produced on an interactive computer graphics terminal and thus directly produce a usable digital representation of the drawing.

The above and many similar methods are currently used by many companies. However, this still leaves a large volume of conventionally produced drawings whose number continues to increase. Putting these drawings into a digital form in a cost-effective manner is a problem of considerable magnitude. The methods range from recreating the drawing "from scratch" on an interactive system, through manual "intelligent digitizing," to a fully automatic system that scans a drawing and produces a digital data base. All of these methods and many refinements are currently in use, but none of these methods currently reduces large quantities of drawings into a suitable digital representation.

This report will deal with two specific areas of the digital representation of engineering drawings. These areas are the computer-assisted generation of engineering drawings and the automated scanning and digitization of existing drawings. In each area, existing hardware and methodology will be discussed, with emphasis on what is needed to make such systems usable and cost effective.

2. INTERACTIVE COMPUTER-ASSISTED DRAFTING

2.1 Description of Interactive Drafting Systems

"Interactive computer-assisted drafting" is an all-encompassing phrase used to describe a system whereby a user creates and modifies graphical information by interacting with a computer in real time. The key words in the above definition are "interacting" and "real time," because to effectively create drawings, the user must be able to issue a command, such as creation of a line or circle, and see the results immediately on some type of graphics output device. The use of the word "drafting" above does not preclude the use of such a system from other uses such as design, numerically controlled (NC) machine data generation cartography, and printed-circuit board artwork generation.

The key hardware elements of an interactive computer-assisted drafting system are:

(a) A two-dimensional (2-D) input device such as a digitizer tablet or drafting table digitizer used to input graphical data freehand or by digitizing a rough or finished drawing.

(b) A cathode ray tube (CRT) used to display the drawing being created.

(c) A plotter or Computer Output Microfilm (COM) device to produce the actual drawing from the digital data base.

(d) A keyboard or program function key (PFK) arrangement to enter alphanumeric data and commands into the system.

(e) A storage medium, such as a disk, for short-term fast-access storage and retrieval.

(f) A "carry away" storage medium, such as magnetic tape or a cassette, for long-term archival storage.

(g) A computer to control the drafting process and associated "bookkeeping" operations.

While there are systems that may include some of the above functions and add others, this is a minimum workable configuration for producing drawings in an interactive environment. Whether the computer is local or remote, bit or small, or servicing one or many interactive stations is incidental. The many commercial vendors for such interactive systems include such companies as Adage, Applicon, Auto-trol, Bendix, Calma, Computervision (CV), Gerber, and Information Displays, Inc. (IDI). Also, many company proprietary systems are in use in industry, and several universities are doing research in the interactive design and drafting areas.

A common link between commercial systems is that they are being used day to day to produce real drawings for real people. Whether these drawings are being produced economically for all applications is, however, a question. Most managers of such systems will tell you, on one hand, that their systems are cost effective and, on the other hand, that they are fighting hardware and software problems daily. In other words, they are constantly battling with and not strictly using their systems.

There seems to be general agreement in the industry that the most cost-effective application for such systems is in the area of electrical schematic diagrams and the associated computer-generated data that will aid in the production of the electronic hardware described by the schematic. There is even a proposed joint standard by the Institute of Printed Circuits (IPC) and the American National Standards Institute (ANSI): Printed Board Description in Digital Form. This standard, if adopted, will go a long way toward promoting the exchange of computer-generated printed-circuit-board data between heretofore noncompatible computer systems. Electrical schematic and printed-circuit boards are successful for eight reasons:

(1) There is a set of well-defined symbology associated with these areas and, therefore, standard libraries of symbols can be defined and readily used to create drawings.

(2) The parameters assigned to the symbols are well defined for each symbol. For example, the packaging constraints are well defined for a standard 16-pin DIP (Dual-in-Line Package) integrated circuit.

(3) Printed-circuit boards are usually small; therefore, they can be easily displayed on a CRT.

(4) Schematics, while not always small, are usually easily modularized so they can be displayed and edited in a reasonable fashion on a CRT terminal.

(5) Symbols within a given schematic or on a given board tend to be repetitive and, thus, the total picture could be interactively constructed faster than if there were many different symbols.

(6) Information such as wiring diagrams, wirelists for wire-wrap machines, parts lists, artwork, and numerically controlled drill information for printed-circuit boards can automatically be extracted from a well-designed electrical schematic drawing system.

(7) Many systems have design aids such as automatic routers and design rules checking, which speed up the fabrication of the desired end item--the electronic board. These aids also insure that the end item conforms to certain physical constraints.

(8) The volume of electrical schematic and related drawings is very large, thereby creating a ready-made market for systems which effectively produce such drawings.

While electrical schematics and related drawings are idealy suited to interactive creation, many other classes of drawings can also be created interactively. In fact, anything that can be drawn by hand can be produced interactively with the computer. This, however, does not say that it is always best to use interactive drafting, since several trade-offs need to be considered:

(1) Is it quicker to create a drawing manually or with an interactive drawing system?

(2) Is there a possibility of many drawing updates?

(3) Is the drawing one of a class, so that other drawings can be produced by simply modifying a representative drawing?

(4) Is there a large quantity of lettering on the drawing?

(5) Does the drawing have a large number of repetitive parts?

(6) Can information be extracted from the drawing to produce the item being depicted by the drawing?

(7) Does the drawing lend itself to automatic dimensioning?

(8) Must the drawing be created at a precise scale factor?

(9) Must the drawing artwork be used to drive a machine (e.g., line following mills, printed-circuit board production)?

(10) Is the drawing a sketch with much line texture, imprecise lines, and shading?

(11) Is the drawing isometric, with hidden line removal and shading?

The answer to question (1) above, while perhaps clear cut, does not necessarily indicate which method is cheaper in the long term. For if it is quicker to create the original drawing manually, it may cost more in the future to modify such a drawing. If the answers to questions (2) through (9) are "yes," then use of an interactive system is best if the volume of such drawings warrants the capital investment for the equipment. If the answers to questions (10) and (11) are "yes," there may be a requirement for an expensive 3-D system which would have to be figured into an economic trade-off analysis.

These are just some of the questions to be considered. Other questions may present themselves within certain application areas. However, the key question which must be asked is, "Are interactive or manual methods more cost effective over the range of drawings being produced at my installation?"

2.2 Current and Future Technology

Some observations and comments are now appropriate concerning the present technology and future possibilities in interactive drafting and design systems.

(1) The software and hardware functions associated with electrical schematics and associated drawings are well defined. Short-term improvements in this type of drawing system will include more and better design aids, a data exchange system which will lend itself to the use of standardized symbol libraries, more sophisticated display techniques such as multicolor and larger economical display screens, and better design rules checking and post-processing techniques.

(2) The general area of automated mechanical design aids is still in its infancy. Although systems that now exist can do this type of drawing, their software and hardware do not approach the sophistication of the electrical schematic world. True, there are 3-D design systems that produce drawings and NC machine information, but one has to be a user to appreciate the problems of going from a design concept, through a drawing, and, ultimately, to the NC information. Certain drawings lend themselves very well to these systems, but a larger number do not. Aerospace industries are the leaders in this type of drafting and design, but for the most part their systems, though cost effective in their applications, are both costly, on a dollar outlay basis and are proprietary. It seems that before we have a good 3-D system, we must have a good 2-D mechanical drafting system. Some of the main drawbacks of mechanical design and drafting systems are:

(a) The lack of a large (F-size) interactive display system that corresponds to the old-fashioned drafting table. Large digitizers or digitizer/plotters with tiny CRT's which display a portion of the drawing are not the final solution to the problem. The consensus seems to be to let the draftsman or designer get used to the small world of the CRT. However, this attitude is responsible for discouraging the average draftsman who is using existing manual systems. Unfortunately, large interactive displays are not currently within the state of the art, unless we consider video projection techniques.

(b) A truly automatic dimensioning feature does not exist for all classes of mechanical drawings.

(c) Most systems do not do hidden line removal and insertion of phantom lines.

(d) Shading or highlighting is difficult with most systems, although some systems do have sophisticated cross-hatching features.

(3) Since interactive drafting and design systems are relatively new, there exists no tried and true method for applying human factors to create a cost-effective system that people will use happily. There is no training ground for the operators of such systems. Usually, operators are taken from their manual drafting boards and told to start using an interactive system.

(4) The hardware reliability of most systems currently in the field is suspect. Also, the mean time to repair (MTTR) is often excessive. Maintenance contracts for such systems are excessively costly, but in a production environment a maintenance contract is imperative to reduce system down time.

(5) Software reliability is also very suspect. Not only are there usually many "bugs" in production software, but there are too many ways for an operator to get into trouble when he communicates with the system. Too many undocumented or vaguely documented procedures impact on the overall system efficiency. If an operator does not know about certain system functions or peculiarities, he will not work at top effectiveness. Also, experience has shown that once an operator has had an unpleasant experience with some faulty function he will probably never use it again, even after the fault is corrected.

(6) For large or detailed drawings, existing systems are too slow in displaying all or part of the drawing. This problem is compounded in a multiuser system where there is a limited working storage area or where the auxiliary storage must be shared by many users. Also, many systems are constrained in speed by the system software, which does not adequately handle the drawing data base. The solution is within the state of the art in both the hardware and software areas. In software, the key is proper data organization with windowing algorithms that work on a zoned or partitioned data base that has flags indicating where on the display a particular graphic entity is to be displayed. In the hardware area there exist clipping, scaling, and translation devices which can operate directly on the graphics data. However, this method is not economical in the communication sense, if all graphics from the data base still have to be transmitted to the display upon each drawing of the picture or a window on the picture. The key to these problems seems to be a combination of hardware and software, where a facsimile of all or part of the drawing data base is maintained at the display. Not only should there be a refresh display list, but also a hierarchically structured data base which can be changed and updated locally at the display. This idea of satellite graphics is not new, but neither has it been done in an economical fashion, where the selected area of a drawing is displayed at the maximum drawing rate of the display device. This

brings up the point that the maximum drawing rates of storage tube, refresh, and video graphics must be increased so that a drawing or any portion thereof can be displayed essentially instantaneously (less than 1 s). Existing refresh hardware with built-in transformation and scaling hardware comes close to reaching this fast display goal, but the cost is prohibitive for a widespread application of such systems. The recent cost breakthroughs in memory cost, along with the advances in microprocessor design and cost, should go a long way to solving the above problems. There may also be a breakthrough in video-disk technology to improve this situation.

(7) There are no standards for the interchange of data between systems manufactured by different vendors. There are two proposed standards, one in the printed circuit area and the other for the digital description of physical object shapes. Both of these proposed standards are a start, but there is still a long way to go.

Interactive computer-assisted drafting is here to stay. Most of the problems that now exist will be solved by the fierce competition that exists in the marketplace for such systems. Problems associated with small display screens will require technological breakthroughs and, therefore, the small-screen display will be with us for a while. Problems with standards and data interchange between systems will be addressed seriously only when government and industry make such digital data exchange part of their contracts.

3. AUTOMATED SCANNING AND DIGITIZATION OF DRAWINGS

Drawings to be scanned and digitized are on microfilm, paper, Mylar, or some similar medium. Therefore, the scanning hardware and resolution must be tailored to the medium being scanned. The scanning process moves some type of transmitter/sensor device over the area of a drawing and produces a quantized representation of the drawing. This quantization of the drawing is an array of discrete elements, each with a value which corresponds to the gray scale or color of the corresponding position on the scanned drawing. This smallest element of the scanned picture is called a pixel. In the simplest case, the value of the array element corresponding to the pixel is zero or one, which corresponds to white and black areas on the drawing. In more complicated cases, the value of an array element may correspond to the color intensity of its corresponding pixel.

In any scanning process, the resolution of the scanner is of prime importance. The resolution is what determines the size of the pixel. If the resolution is not fine enough, data will be lost. If the resolution is too fine, an unmanageable quantity of data will be generated. Studies to date indicate that a resolution between 200 to

250 pixels/in. is required to effectlvely scan a man-readable document. "Man-readable" means that the unaided eye can extract all the information from a document. For scanning microdocuments, such as aperture cards, this resolution is on the order of 8000 to 10,000 pixels/in. Therefore, the scanning of an E-size drawing (34 × 44 in.) where only black and white data are required would require approximately 80-million bits of data stored in an array called a bit map. That is, the drawing would be divided into 80-million pixels. It is readily apparent that the 80-million bits must be compacted in some way to reduce the amount of storage required for each picture. The type of compaction used depends on the method by which the data are acquired, the amount of working storage required to do and perhaps undo the compaction, the time allotted to do and undo the compaction, and the storage available for each drawing in long-term memory.

Given infinite time and working memory, the ideal compacted form of the drawing would be a glyph representation. In this approach, such graphic entities as lines, circles, and arcs are described by their geometric constructions. Furthermore, all groups of similar graphic entities are not represented repeatedly in the data base. Rather, a master glyph contains the necessary information to describe how a certain glyph is drawn. As instances of the glyph appear on the drawing, it is necessary to save only particulars such as the position, orientation, and scale factor of each instance. Details of the drawing aspects are then referenced to a master glyph. For example, if an electrical schematic drawing had 25 pictorial representations of an NPN transistor, then there would be one master glyph that describes how an NPN transistor should be drawn. For each occurrence of a transistor on the drawing, the data base contains an X,Y coordinate pair, a scale factor, an orientation, and a reference pointer to the master glyph. In fact, this master glyph might transcend the boundaries of an individual drawing and be available in a master parts library for use by all drawings in the data base.

This type of glyph-oriented data base is used for the lower bound in determining the storage required to represent a drawing. The upper bound is the uncompacted bit map. To date, the lower bound has not been reached. There has been some success in transforming scanned data into a straight-line representation of the drawing, and in some limited cases, certain constructions such as circles, squares, and triangles also have been identified. But for the most part, these techniques do not apply, even over a small range of drawing types. Such stumbling blocks as character data at other than horizontal orientation, glyphs at various angles and scales, and nonuniform line thicknesses have kept the lower bound, for all practical purposes, beyond the current state of the art.

Another approach that enjoys widespread popularity is to look at the scanned-data bit stream from the viewpoint of information and coding theory. The bit stream is usually coded line by line, where each line of the raster scanned data is considered one message. This message is then coded by techniques such as Huffman run-length encoding, where the probability of occurrence of run lengths of black or white is recomputed for each scan line. Other techniques used construct optimum black/white run length tables, construct black/white transition tables, or special line-type identifiers (i.e., if a line is all white or black or the same as a previous line). In many cases, a combination of techniques is used to optimize the compaction line by line. Compaction by raster line is an attractive technique that requires little working storage, can be done in real time, and, on the average, results in a compaction ratio of from 5:1 to 50:1. The above raster techniques are typified by the Singer Laser Aperture Card Scanner/Recorder, which scans an aperture card in 30 to 45 s and produces 80 million bits of information. These data are then compacted by one or more of the aforementioned raster scan methods.

Another method of compaction uses the raster scan data and processes them, either in their entirety or by groups of raster data, into a list of vectors which are defined by a list of vector end points. If this vectorization is done on the entire image at once, it requires a large working memory area. It also may require much processing time and, therefore, would not be economical. However, some experimental methods use edge-detection techniques and essentially do vectorization as the drawing is scanned. There are no known commercial versions of such a system, and only time will tell about the validity of such systems.

Besides raster scanning, there also is an area scan technique which scans a small area of the drawing and presents these data to a data compactor. This method can be thought of as a raster scan technique over a very small portion of the drawing. The idea behind this technique is that, on a drawing, data looked at by area contain more readily usable information than data obtained by a raster scan method. For example, if a line passes through a scanned area it is easier to vectorize because of the relatively small amount of bits representing the area. Similarly, a recursive technique can be employed to reconstruct a vector, made up of several segments, which passes through several contiguous areas. Also, depending on the size of the scanned area, many areas may be all white or all black, thereby reducing the computations and amount of data that must be saved. It is possible also to build special-purpose hardware which can vectorize the scanned data while they are being scanned ("on the fly"). This technique is demonstrated by the CV Auto-Scan system, which instantaneously scans a 1 × 1 in. area of a drawing with a 256 × 256 bit photodiode detector array. This system differentiates among three colors and also does some hardware vectorization. These data are then shipped to a postprocessor, where the data are worked into a form suitable for line manipulation on an interactive graphics terminal. The postprocessing time for an average drawing may run to several hours. The system works well for straight-line drawings but degrades quickly when arcs and text are introduced into a drawing.

Figure 1(a,b) depicts two very simple drawings and the compaction methods that have been achieved with several types of compactors. The number of bits used to represent each method is only approximate, but it is certainly close enough for comparison. The comparison of compaction ratios for each method will obviously vary over a wide range, depending on the drawing being scanned. This suggests that there may be a need for an adaptive scanning and compaction scheme which would scan and compact each drawing by the best of several methods. This type of adaptive method may require a gross, fast prescan to determine basic characteristics about the drawing.

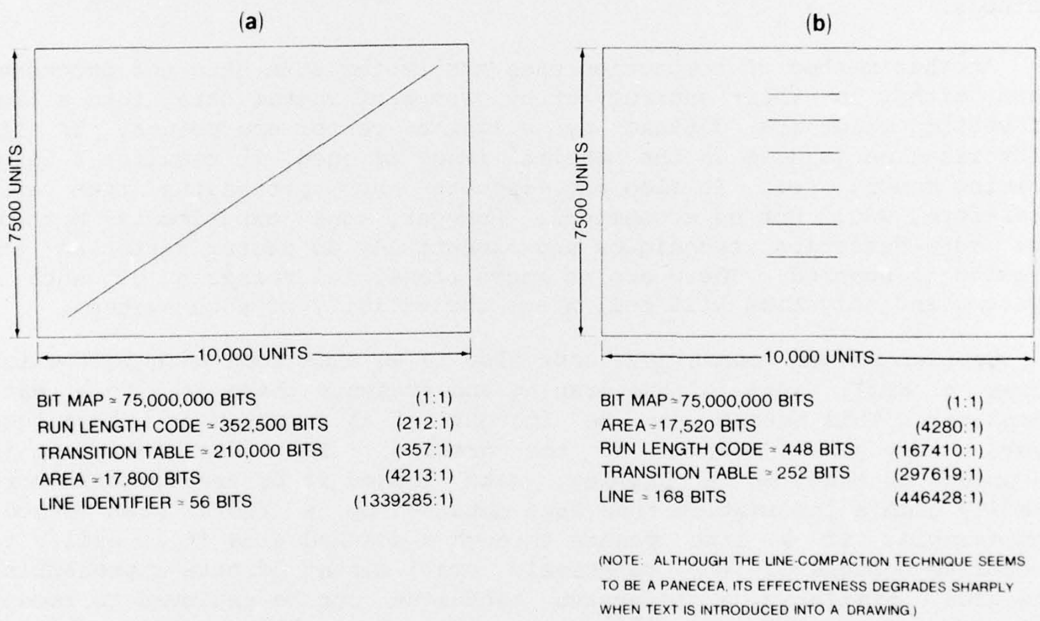

Figure 1. Sample compaction techniques.

Some possible adaptive approaches might be to determine the probabilistic occurrences of events, given knowledge of previous events. Or, from prescan information, the scanning axis could be altered to take advantage of the orientation of the drawing data. Other possible approaches might be found only in an artificial intelligence environment. As more and more drawings are scanned and characterized, new similarities among the various types of drawings will be discovered, bringing about new and better compaction techniques.

Besides the direct scanning of the drawing, methods have been devised also to scan and store the holographic image of a drawing. Since a hologram contains much redundant information, it may be possible to compact the digitized holographic data into some efficient form. This would necessitate the availability of more sophisticated input/output equipment to generate the hologram from the drawing and recreate the drawing from the digitized hologram. It is also not certain what scanning resolution would be required to scan the hologram with sufficient resolution so that the crispness and clarity of the original would be preserved on playback.

There are also new techniques in optical processing which may have some bearing on the scanning of drawings. A positive or negative transparency of a drawing can be illuminated by a laser, with the resultant image transformed by a series of images and then filtered in some fashion. The resultant transformed image then has less spectral content than the original and may be adaptable to a scanning resolution which is much larger than would otherwise be required. However, it is certain that the drawing quality would suffer. Another use for such a transformation system would be to use successive filter stages which would selectively enhance certain symbols in order to increase the chances of symbol recognition by identifying those areas where certain symbols were likely to exist.

None of the aforementioned methods of scanning, digitizing, and storing drawings are currently in use on a production basis. It is true that several companies can readily produce facsimile types of document scans, but none of these equals the resolution requirements needed by engineering drawings. The ill-fated AMACUS system, which attempted to scan and modify aperture cards and then create updated aperture cards by digital methods, had to be abandoned because the aperture cards produced by the system could not be rescanned by the system without loss of information from the original card.

So, given all this information, where do the automated scanning and digitization of drawings stand in terms of a realizable goal? What might be done to make them viable tools for storing existing drawings? Since no complete system now exists, it is necessary to look at the parts of a system that could be used to scan, digitize, retrieve, and possibly modify large quantities of existing and future engineering drawings. The term "possibly modify" is used because modification methods, while desirable, may introduce complexities into the system design. The basic functions of an automated scanning and digitization system are input scanning, compaction of digitized data, verification of compacted data, storage of compacted data, retrieval of compacted data, display of the original drawing from the compacted data, and possibly interaction and modification of stored data.

Input scanners exist to scan both aperture cards and full-size drawings. Their drawbacks include slow scanning and compaction times, nonavailability of automatic document loaders, lack of reliability, excessive cost, and nonavailability as off-the-shelf items. Research money could be applied to the above areas of concern, with a goal of a cheap (under $5,000) commercially producible scanner station that could be automatically fed with aperture cards at a rate of one card every 30 s. The scanner should do at least some compaction to reduce the amount of data passed to the working-storage medium.

The ultimate compaction of the data should be on the order of 100:1, thereby reducing an 80-million-bit digitized drawing to 800,000 bits, or, equivalently, 100,000 octets. Research still needs to be done in compaction, although existing methods are suitable in the short term. All methods should be able to run in real time with the input scanner. Research should continue into more sophisticated compaction technologies involving symbol- and character-recognition schemes.

Visual verification would require the use of a CRT type of display where the compacted drawing would be uncompacted and displayed. This display would be visually examined by a trained operator to make sure that the drawing suffered no harmful degradation in the digitization process. The facility would exist to notify the data base of an unsatisfactory drawing and to rescan the respective document either immediately or at some later time. Although display technology is abundant, it may be necessary to have a large-screen device which could display the drawing in its original man-readable form. At this time, projection video is the only device that might satisfy this requirement. Another possible alternative is a storage tube and scan converter which, with a joystick, would allow rapid zooming and windowing over the entire picture area. This quick-look capability into the data base would help assure the existence of a valid data base and would also allow users of such a system to visually examine the data base rapidly and efficiently.

Hardware does exist to do verification in some fashion. While this is not the final solution, it fills the short-term gap for visual verification.

The storage of the data requires large, expandable, medium-speed, low-cost digital storage which is of archival quality at least equal to that of aperture cards. The memory must be large and expandable because of the wide variety of storage requirements of various installations. The following table gives an indication of the memory size required for various quantities of stored drawings, if a conservative value of 100,000 octets per drawing is used.

Number of drawings	Memory requirements (megaoctets)
1,000	100
10,000	1,000
100,000	10,000
1,000,000	100,000

It can be seen that the memory requiremments become enormous for drawing files which are handled easily now in aperture card form. If a typical data base of 10,000 drawings is selected, the data base's data storage requirements approach 1-billion octets. Let us assume that we want to store each drawing in the digital data base at an initial cost of $1, which covers the storage medium and storage device and excludes the processing cost. Then, for the 10,000-drawing system, a capital equipment expenditure of $10,000 would be in order. This would include memory only and no processor or other overhead. This then breaks down to a memory cost of $0.000125 per bit. This magnitude of cost and memory size leaves out conventional core memories, semiconductor memories, disks, and drums. In current and near-future technology, we are left with laser memories (e.g., Precision Instruments), video disks and tapes, bubble and charged coupled device (CCD) memories, high-density magnetic tape or strip mediums (e.g., Control Data Corp. MSS) and holographic memories (e.g., Holofile). Currently, the laser memory looks most attractive from the point of cost and archival quality, but falls short in the question of power and space requirements. However, its "write once," "read forever" memory structure does not lend itself to easy modification of an existing drawing. However, with a reasonable file structure, this permanence of the original drawing can be turned into an advantage. For example, if we want to modify a drawing in the data base, the drawing is called into a working file and then modified interactively. Now, depending on the extent of the modifications, either a completely new drawing is stored or an audit trail of only the modifications is stored, with the original drawing referencing the modifications. Obviously, the storage area for the original drawing must have some unused space where pointer data can be written as modifications are added.

The medium-speed requirement allows for mass-storage memory devices which contain many physical storage devices which must be first selected and then moved to a reading port of some type. Once the device is moved to the port, the data transfer rates are equal to existing mass-storage systems such as disks. However, it may take several seconds to get the storage device to the port.

Memories to do the storage are currently available, although not necessarily at the cost required. However, memory technology has been moving very rapidly over the past several years and the trend is expected to continue. This trend increases the probability that larger memory systems with lower bit costs will exist in the not-too-distant future.

The retrieval of the data from the mass memory is well within the state of the art of existing operating systems. The only challenge in this area is to create file-management structures that allow retrieval of drawings based not only on individual drawing numbers, but also on other characteristics of the drawing as well. This might require combining existing Configuration Management (CM) data bases with the digital data base containing the actual drawing referred to in the CM data base.

We face similar problems in the display of drawings, as was mentioned earlier in the verification section. Most displays of the required resolution are not geared to displaying the rasterized data produced by the input scanner. In most cases, this would require that the raster data be converted to some vectorized format suitable for driving vector-oriented displays. The display function may also include such output devices as COM, electrostatic plotters, laser reproducers (opposite of laser scanners), or pen-and-ink-type plotters. Each of these devices presents its own set of requirements, but in general it is the data-conversion problem that is a stumbling block. Given infinite memory and computing time and power, the data-conversion problem disappears. However, if the desired time between drawing request and drawing display is only several seconds, then a real problem exists. Of the above output devices, either the electrostatic plotter or the laser reproducer offers the best means for directly displaying the uncompacted raster data because their output formats are compatible with the raster scan formatted data.

Display technology is probably adequate at this time if the user is willing to pay the price of longer display times and small-screen interactive displays. Except for the development of a large, fast interactive display, the best development in the display area would be fast, accurate conversion routines which would convert high-resolution raster scan data into a hierarchical, structured, graphics data base.

Modification techniques, while not essential, would perhaps offer the best dollar return over the life of a digital drawing. If a drawing could be automatically scanned and then interactively modified and reproduced with the original quality, then such a system would contribute much time and cost savings over the lifetime of a drawing. Such a system would enhance current manual redrawing techniques, as well as reprographic techniques. Many systems already exist to manipulate graphics data bases. The problem, then, is to produce such data bases from the scanned raster graphics data. Another problem in modifying drawings is to maintain an audit trail of changes which will satisfy current Engineering Change Order (ECO) requirements. Obviously, a well-designed drawing modification system will maintain the quality of the original and also automatically produce ECO paperwork to keep those with a need-to-know up to date on drawing changes. Such a system could also easily supply noncurrent revision-level drawings if required.

Although all the elements are not now ideally suited for an automated scanning system, there is still time to start putting together a pilot system to more fully evaluate the concept of fully automatic scan digitizing of engineering drawings. All existing technology has to be pulled together and demonstrated to show industry and government that there is a serious market for devices which would markedly improve such a pilot system.

4. CONCLUSIONS AND RECOMMENDATIONS

(a) The interactive creation of electronic schematics and printed-circuit manufacturing data is well defined, and standards should be created and used to provide the exchange of such digital data between interested parties. The joint ANSI/IPC proposed standard, Printed Board Description, in Digital Form is a good start, but it must be used and specified in contracts.

(b) Interactive creation of mechanical drawings needs to be improved in both the hardware and software areas.

(c) Standards for the interchange of mechanical data in digital form should be pursued. The ANSI Y14.26 subcommittee document, Digital Representation of Physical Object Shapes is a start, but more needs to be done.

(d) More human engineering is needed on current interactive systems with attention given to proper training, job descriptions, and promotional considerations.

(e) Hardware reliability in all interactive systems needs to be increased, with attention given to reducing costly maintenance contracts and decreasing MTTR on such systems.

(f) Larger fast interactive displays should be developed. This is true for both interactive and scanning systems.

(g) Display times for complicated drawings and windows on the drawings must be decreased without large system cost increases. This is true for both interactive and scanning systems.

(h) An effort must be made to develop a production type of automatic scanner/digitizer for engineering drawings. Such a scanner should be geared to scanning microdocuments rather than full-size drawings.

(i) Data compaction techniques on both software and hardware should be pursued.

(j) Economical techniques to produce hierarchical graphics data bases from raster or area scan data should be pursued.

(k) A pilot automatic scanner/digitizer should be built to wring out the problems associated with scanning at a system level. It is hoped that this pilot would also push the state of the art in related technology areas.

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