A SURVEY OF DIGITAL AND OPTICAL SMALL MEDIA FOR STORAGE OF LANDSAT DATA

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ABSTRACT

During the past ten years several alternatives to the storage of large volumes of data on high density tapes have evolved. In particular the use of new digital media and new optical media are becoming of more importance as their costs are diminished. This paper will present a summary of information generated by the Landsat Technical Working Group in their attempt to find cheaper and more reliable archive media. State of the Art descriptions for CDROM, WORM, Optical Tapes, Magnetic storage, helical scan technologies, and the projection for the future in each of these areas will be presented.

INTRODUCTION

This document contains a survey of technology related to digital and optical data storage using small media, i.e., media compatible with small computers. These include tape cassettes, streaming tapes, VHS tapes, and other new magnetic media. They also include CDROM, WORM, Read Many Write Many, and other magneto optical media. All of these new media are now compatible with personal computers and can be thought of as the media of choice by the small computer user in the future. Initial contents of the document were derived using inputs from surveys gathered for the Optical Recording Subgroup of the Landsat Technical Working Group (LTWG). These data reflect the result of worldwide vendor surveys and research inputs from all member stations. The second source of information consists of data extracted from an independent ongoing survey of multiple vendors within the USA and from articles and textbooks available to the public on these topics since 1986.

During the survey performed for this paper it was discovered that the LTWG had not taken into account recent strides in digital recording technology achieved by researchers around the world. Research into these areas was ongoing at the time of the initial survey. However, it was outside the charter of the working group to evaluate these new technologies. Therefore, when specifications became available for both it was a natural step to cross compare media in terms of packing density, size, and cost. This is the goal of the paper to follow.

STORAGE MEDIA TRADEOFF ANALYSIS

Background During the past five years there has been an explosion in the capabilities of mass storage media and its applications. Magnetic tapes, electro optical devices, and magneto optical devices are currently under development that far surpass the capabilities of systems available in the mid 1985 time frame. In order to illustrate the speed of evolution of this new technology, current technology will be compared directly with the article entitled "The Evolution of Mass Storage" published by BYTE magazine in May 1986 and written by Leonard Laub. Other references will be provided to new technologies that are currently under development. State of the art extensions for these technologies will be addressed first for magnetic media and then for optical media.

MAGNETIC MEDIA

From the 1986 article referenced above the following paragraphs are important.

"Mainframe magnetic tape recently made a big jump with the introduction of the IBM 3080 one half inch cartridge product. This cartridge is a package four inches square that stores 200 megabytes. This is a dramatic change from 6250 bit per inch (bpi) tapes that store up to 180 megabytes on a reel 10.5 inches in diameter.

Quarter inch microcomputer cartridge tape does almost as well storing 60 megabytes in a small package. However, none of the computer formats store as densely as several others based on videotape technology."

Since this article was written (1986), significant strides have been made in the area of magnetic storage. Image manipulation systems sold by multiple vendors are configured with the capability to transfer data using 120 megabyte cartridges. The cartridges are small (3.5 inches x 1/2 inch x 5 inches) and compatible with image processing systems that require transport from one compatible microcomputer system to another. The tape width is 1/4 inch. This capacity should be compared with that of the 1985 article that mentioned that such tapes could hold only 60 Mb of data. Relative to ease of use one should note that the entire tape can be written from a host computer to the cartridge in less than one hour. From that point forward in operations the access to information on the cartridge depends on the computer chip used to drive the read/write activity. Using a 386 based system - similar to a standard COMPAQ 386 microcomputer - the complete 120 megabytes of data can be ingested on microcomputer system using 286,386, 486, and 586 chip based systems in less than 30 minutes. As faster architectures, such as those based on the Motorola 68020 and 68030, 68040, and 68050 chip sets, evolve to maturity this time can be expected to diminish significantly.

This technology is not restricted to COMPAQ architectures. According to PC Magazine, Vol. 8., No. 3, February 1989, pp. 48, "IBM chose an 80 Mb internal tape system based on the small DC-2000 cartridge for its PS/2 models."

The future of this technology appears to be one of the driving factors for creation of small physical volume, highly accessible video data archives. Data compression methodologies coupled with higher packing densities make this a very favorable option for the future. Cartridges are listed for sale for less than $50. Each cartridge has a capacity of from 150 to 300 megabytes (unformatted). Cartridges contain 1/4 inch wide tape compatible with the IBM line of equipment, i.e., the AT, XT, PS/2 or compatible microcomputer or work station. These tapes must be formatted, much the same as a floppy disk.

VHS Tapes Again, paraphrasing the 1986 article: "In a standard video tape recorder the heads are mounted on a rapidly spinning drum. As the tape passes slowly over the drum, the heads move quite rapidly over the tape in a diagonal pattern. The heads are very narrow. This allows adjacent tracks of recording to be spaced very closely. This results in about one order of magnitude more areal density of storage than is practical with fixed heads. In this streaming mode up to 1382 megabytes are available on a single cassette. Honeywell uses a different approach to VCR technology. They dispense with video encoding altogether, use proprietary electronics, and are purported to achieve the capacity of 10 gigabytes on a single VHS cassette."

Advances in this technology were projected to allow up to 40 gigabytes per cassette. These systems were initially designed for use as a tape backup for mass storage systems. As they entered the market better search hardware/software was developed and some systems today treat them as logical devices routinely addressable for daily operations. Due to their recent entry in the market, there is no knowledge yet relative to shelf life of these systems and/or their reliability. Nonetheless, their cost, portability, and compatibility with multiple recorders due to existing industry standards for the "read/write" formats will make them an attractive alternative to other magnetic media in the future.

Currently operational VHS systems for use as unattended backup are available from multiple vendors. A typical system provides 2.5 Gigabytes of data storage on a single T-120 VHS video cartridge. The system uses read-after-write coupled with powerful error correction. The error rate is less than 1 in 10E23 bits. In addition it provides a high speed search capability not available in most nine track tape drives. This system can be written to at the rate of more than 120 megabytes per second. Data are retrieved using a nominal 14 megabytes/second search rate.

Summary for Magnetic Media Large volume archives, such as Landsat, require that we use a High Density Digital Tape (HDT). In order to place the capabilities of the microcomputer based systems in perspective one should note that each HDT can hold up to 30 Thematic Mapper (TM) scenes. Each scene contains 300 Mb of combined video and ancillary information. Thus, each tape is capable of 9 gigabytes of storage. This technology was developed in the 1970's and was implemented by NASA in the 1978-1980 time frame. Tapes have a one inch width and a diameter of thirty inches. They are readable only by special recorders that read/write on either 14, 28, or 42 tracks. Tapes cost approximately $200 apiece when purchased in volume. Tape recorders cost on the order of $250,000. Newer technologies, have resulted in tapes for small media that have nearly the same capacity. The savings in recorder cost is, however, nontrivial. Recorders for the cassette and the VHS systems cost less than one tenth of those for HDT. In addition, the physical volume taken by the cassette is smaller and the operational storage methodology is simplified using the newer media. (HDT's must be rewound every quarter; due to the number of HDT's used for the archive, they cost the Landsat project thousands of dollars/month to store, and must be stored in a near clean room environment. This is not the case for VHS systems.) In March 1992 companies were advertising VHS tape recorders capable of storage of 14.5 Gigabytes per tape. Data burst rates of four megabytes per second and sustained rates of two megabytes per second in the streaming mode are possible and any one place on the 14.5 gigabyte tape can be accessed in under 60 seconds. Other technologies, especially those reflecting electro optical and electro magnetic recording schemes have only recently become available. These will be discussed in the paragraphs that follow.

Recent Advances During 1989 the evolution of new digital audio tapes (DAT) escalated as larger companies (IBM,DEC, HP,etc.,) recognized that they could become future de facto standards for cartridge data tapes in future systems. The article "A New Twist on an Old Technology", written by Jay Bretzmann for the November 1989 issue of BYTE magazine discusses this technology in some detail.

New products based on 4 mm wide DAT technology are expected to hold up to 1.3 gigabytes per unit in a package two inches wide and three inches long equivalent to that used for cassettes in existing audio recorders. Early units were expensive. However, by late 1990 these devices became relatively inexpensive and widely available making them viable alternatives to the 8 mm VHS technology existent today. The time delay in implementation of this technology is market driven. Prior to their introduction in the USA the market for audio recordings has been largely transitioned over to compact disc (CD) recording schemes. The threat that the DAT could take over the CD market has made some vendors extremely cautious in adopting this technology. The main concern has been that these tapes could easily be copied and pirated. Multiple copy protection schemes have been developed but these were only marginally successful. Recently a compromise between the Japanese manufacturers and the recording industry has been reached wherein extra circuits are added to the recorders to defeat unlimited copying. In this scheme, a digital sub code identifies the input source of the information and prevents copying except from the original DAT. This compromise has allowed the technology to enter the market. It is expected to mature during the decade of the 1990's. During that time it can be expected that standards for video recording will be developed for this media.

OPTICAL MEDIA

Compact Disc Read Only (CDROM) In the early 1970's several companies developed proprietary digital formats based on LaserVision laser disks. These formats store between 800 and 1000 megabytes per twelve inch disk. With the advent of Compact Disk-Read Only Memory (CD-ROM) these formats receded to a specialty position, serving applications in which a large quantity of TV imagery is to be stored and retrieved along with digital data.

Referencing the 1986 article again: "CDROM systems are now operational. Over the next two years new formats will appear that will be read only version of high performance alterable optical disk formats.

These will provide higher data rate, faster access, and finer addressability than CD-ROM, and they will be directly compatible with what may become the mainstream mass storage devices for small computers."

INFOWORLD, (January 30, 1989) gives a quick update to the earlier statements made by Laub.

"Many corporate users are now beginning to produce their own CDROM discs for in-house use or for distribution to employees at field locations. In fact, a wide variety of mastering software packages is available for creating the files that will be put onto CDROM. Microsoft has been one of the major proponents of CDROM technology. In addition to marketing reference disks, the company has sponsored annual conferences to define the standards for data storage on CDROM discs. This format allows the disc to be addressed as a logical device."

Further discussion of the format, called the "High Sierra Format" can be found in the book CD ROM, Optical Publishing, Edited by Suzanne Ropiequet with John Einberger and Bill Zoellick, Microsoft Press, Redmond, Washington (1987), ISBN 1-555615-000-8. Routine updated information on the current state of the art for CDROM technology can be found in the quarterly journal "CD-ROM Review - The Magazine of Optical Publishing", IDG Communications, Petersborough, N. H., ISSN 0891-3188.

According to the Infoworld article, "Several companies have developed search and retrieval software that allows the rapid location and retrieval of data on a CDROM. It is expected that the suite of software currently available for these discs will be significantly expanded during the next decade. The cost of disk drives for CDROM is also dropping. Some newer (but slower) drives are expected to retail for less than $200 by 1993.

Data storage capacities for the 5 1/4 inch CDROM have expanded significantly during the past three to five years. The first disk was capable of holding up to 200 Megabytes (Mb). Current systems hold up to 800 Mb per CDROM. Furthermore, this medium is highly ruggedized. It can be dropped, scratched, and damaged other ways yet still maintain its integrity as a storage medium. This occurs due to the manufacturing methodology and the recording scheme.

When CDROMs are made, input digital data tapes are used to drive an intense laser beam that permanently pits the medium. Pits are generated only for a "1" or a "0" depending on the manufacturer's convention. Each pit has the same physical dimension and it is this dimension that dictates the packing density. Higher intensity lasers, lasers that are more energetic, and/or lasers that have smaller beam diameters will be used to upgrade the density of data recording in the future. Data read from the pitted CDROM is accomplished by laser as well. During the read process the laser -- either at a different wavelength or at a reduced intensity -- is used to illuminate the disk. The relative amount of light reflected back to the optical system dictates whether or not the area is pitted. This "pitted" or "not-pitted" reflection return is equivalent to the string of ones and zeros encountered in normal binary magnetic recording.

The major problem with CDROM technology is mastering. In the first step of transfer all data on nine-track tapes must be converted over to nine track tapes on a format compatible with data blocks acceptable by the CDROM. In the second step the transferred data are written on the CDROM by laser. At the end of the write process the disk is hermetically sealed. The 5 1/4 inch disks are then encased in a hard plastic cover compatible with the CDROM readers.

In mid 1985 a joint experiment between two Landsat user groups was initiated that attempted to utilize this media. Both organizations came to the same conclusion. This is an excellent medium!! However, the cost of mastering the CDROM was prohibitive. The cost at each site was on the order of $5000. At that time there were only four sites in the North American continent that could master the data. Since then, the number has grown to more than fifty and the ability to master data "in house" has become more widespread. According to the "Technology Update " column in the January 30, 1989 issue of INFOWORLD, the cost of mastering a CDROM had dropped to around $1500. Duplication of large quantities of disks cost on the order of $2 per disk. The projection made in the INFOWORLD article is that "by the end of 1989 nearly 100 of the Fortune 500 companies will be using at least one CDROM". As more large corporate users become aware of the cost benefit associated with this medium it is expected that further activities will be initiated in this area for a variety of data base applications. This will drive the cost downward in the future and makes the CDROM an even more viable candidate for future applications.

By 1991 there were more than twenty manufacturers of CDROM drives that collectively offered more than sixty different drive configurations. Currently more than 150 companies sell commercial CDROM data. Data types range from text to maps to book reviews in addition to imagery. Obviously this peripheral has started to become a routine element of many microcomputer systems.

Write Once Read Many (WORM) Media In 1985 the WORM technology was in early stages of development. According to the reference article for 1986 by Laub this technology was projected to be available in both 5 1/4 inch and larger diameter drives. Projections for storage capacity depend on materials research development. New laser technologies for writing or mastering these disks have led to the promise that these devices can have packing densities larger than those used for CDROM. Some 14 inch disks are projected to carry on the order of seven gigabytes per platter. Jukebox systems that contain up to one-hundred of these diskettes will be capable of accessing over 700 gigabytes of data. These systems were advertised as being available in 1989 and 1990 from multiple vendors. However, they are expensive. These disks can be written to. They can be considered as a logical and addressable device for the microcomputer. This provides the user with a distinct advantage in that readily available inputs from a variety of different tapes and tape formats can be read without a significant pre mastering effort to restructure the data as is needed for CDROM. However, there was no ISO standard for these systems as of February 1989. This means that the user must expect that the data may not be readable from one vendor's system to another. In early 1990 ISO standard 9660 was adopted by the CDROM industry. With the standard and the decreasing price of both drives and media it has been projected that the optical recording industry will grow to more than 2.5 billion dollars per year by the end of the decade. (Systems and Network INTEGRATION, Issue 544, March 16, 1992)

Erasable Media The following data are taken from the February 1989 issue of Personal Computing Magazine.

"The newest and most promising area of optical storage is erasable storage. Drives have been shipping for several months now. Erasable drives let you write, erase, and read data just as a hard disk does. But, the erasable media is in a removable cartridge. Storage capacity ranges from 500 Mb to 1 Gb. No removable hard disk product comes close to this storage capacity. The largest fixed hard disks also have hundreds of megabytes of storage. However, they don't allow the user to transport or lock files away."

When introduced to the market, many thought erasable products would replace CDROM and WORM. However, each technology is designed for a different purpose. Removable media drives offer the convenience of a Bernoulli Box and the immense storage capacity of the largest hard disks. However, prices are prohibitive for the small computer user. Costs comparable with those of 600Mb and 700Mb magnetic drives are not uncommon. Since these were introduced a number of companies have endorsed an ISO standard for erasable drives and media. This standard is still in its formative stages.

According to the PC Magazine article referenced above, all erasable drives use magneto optics to perform the read, write, and erase functions. Magneto optics is the leader in erasable technology over two other methods--phase change and dye polymer. Magneto optics is the slowest of the three. However, phase change and dye polymer are not practical now since the media can be overwritten approximately only 1000 times. With magneto optics the erase and overwrite activity can occur more than one million times.

A typical drive had a 30ms access time approaching the speed of many hard disks. Future systems are promised that will work with products that follow the recently proposed ISO standard.

Digital Paper The latest technology is digital paper. This is a write once optical storage medium. However it differs from existing WORM media in that it is flexible and can be produced in large sheets and reels. As a result, it can be cut, stamped, and otherwise built into a variety of products, including floppy Bernoulli disks, tapes, and credit cards. It promises to make smaller, faster, and cheaper WORM drives as available as floppy drives are today. Developed by a British firm, it relies on polymer films and dyestuffs.

Digital paper uses a write-once ablative technique. Digital paper consists of a multi-layer sandwich of thin films. The substrate is made from one of the established polyester films, called Melinex. A reflective layer of metal is deposited onto the substrate using a sputtering process. The result is a product that looks like silver plastic foil. Over the metal layer is the active layer composed of a transparent polymer containing an infrared absorbing dye. To write a dot on digital paper an infrared laser is beamed onto the paper using a laser active at the absorption wavelength of the dye. The dye absorbs the radiation and converts it into heat energy. This local heating of the active layer polymer in which the dye is dispersed causes the polymer to deform. The deformation causes the active layer to contract into a pit surrounding the laser beam or spot. To read the pit, the same laser is used at a lower intensity, optical interference is used to determine whether or not the region has deformed, and the data can be extracted. There is a fourth protective layer of transparent coating overlaying the active layer. In addition there is a fifth layer, normally a low-friction polymer for use as a backing to allow it to slip smoothly when coiled in reels of tape or fitted into a floppy disk cartridge. The marriage of this technology with existing Bernoulli drive technologies promises to provide the user with 5 1/4 inch diskette capable of holding up to one gigabyte per platter.

One 12-inch reel of this 35 mm wide digital paper tape can store 1 terabyte of data. To grasp the significance of this volume the BYTE article indicates that one such tape could hold the equivalent of 5000 conventional magnetic tape cartridges or 1600 CD's. The cost is advertised to be on the order of 1/2 cent per megabyte. The system uses a small computer system interface (SCSI) and can sustain a data transfer rate of three megabytes per second. It takes an average of 28 seconds to select any single byte from a full 1 - terabyte tape. Current activities required to use this medium in the future for near real time data capture and access are being carried out by multiple vendors in their Internal R&D programs.

The first prototype units are now installed at multiple sites that deal with large archives of data. The tape recorders are expensive. They cost on the order of $250,000. Tapes cost on the order of $2000. However, tape recorders are plug compatible with the high density digital tape recorders used for standard satellite image archiving. This means that during off hours data from HDT in the archive can be rerecorded on this medium. A single tape made using this medium will hold up to 1000 Landsat High Density Tapes. Operationally, then, the effort will be one of filling the optical tape with the 1000 HDT's, and then replacing the 1000 30 inch HDT reels with a single optical tape reel. This is a nontrivial savings in archiving costs recognized worldwide.

Development of this medium into a format compatible with diskettes will depend on the advances made in the future relative to more compact solid state laser systems used for the read/write activity.

Technology Update The November 1989 issue of BYTE magazine contains two updates to the above mentioned technology for optical recording. The article entitled "Paper, Magnets, and Light", by Robert R Gaskin,pp.391, states that as technology evolves a larger user group will investigate and implement these drives in the future. It is projected that CDROM drives will be readily available for $600 within the next year and are projected to drop to $300 (mastering will still be expensive). WORM products that are 5 1/4 inches will stabilize in capacity at around 650 megabytes PER diskette due to their inclusion in the NeXT computer though some manufacturers will offer proprietary systems with capacities of from 1 to 2 gigabytes per disc for those users who do not care about data interchange. Furthermore, it is projected that the digital paper based 5 1/4 inch drive will become available in the next five years with a capacity of up to 1.2 gigabytes at a cost of about $50 per cartridge.

SUMMARY

From this survey one may note that both digital tape storage and optical storage are in process of significant changes. These will benefit both the large and small user of digital data in the future by providing memory at a fraction of the cost available today. Some technologies are mature. Others are in their formative stages and these are not guaranteed to be the technology of choice in the future. Most large corporations that deal with materials for storage (IBM, DEC, 3M, Kodak, N.V. Philips, etc.,) have internal research and development (IR&D) activities underway that could further revolutionize the future of mass storage. Storage and timely retrieval for the data base of note can be met today using either magnetic tapes (cartridges) or streaming tapes (VHS) or optical systems. Proven technologies such as cartridges and CDROM are used in image processing laboratories around the world. As packing densities increase we can expect to see a larger share of the world's archives converted over to the newer technologies.

Since a multitude of new technologies are coming on-line the focus for new systems for data archiving and distribution should be on the construction of a functional system capable of supporting an "open" architecture. By this we mean a system capable of performing the job today in a timely fashion but one also capable of expansion for the future as needs arise. The use of closed systems will continue unless we emphasize new technology for the future. This emphasis is vitally important should we be required to structure new image hardware/software systems for users around the world.

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