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Future Trends in Microcomputer Image Processing Technology

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Abstract

The progress in computer technology has significantly improved the capabilities of the microcomputer image processing systems and brought down their hardware costs. This on-going trend of technological development seems to bring further substantive improvements in microcomputer image processing and decreasing hardware costs. The technical development in microcomputer image processing system including VLSI technology, semiconductor memory, disk and tape storage, and image display subsystems have been reviewed and their future trend have been projected. The impact of this technology to the development of image processing has been assessed in the time period of immediate future (2-3 years) and near future (5 years).

1. Introduction

Progress in computer technology, including:

- significant advances in the computing power of the microcomputer,
- development of custom image processing and display controller integrated circuits,
- vastly expanded random access disk storage, and
- progressively larger capacity memory chips

indicate that there will be further substantive improvements in microcomputer image processing and decreasing hardware costs. Microcomputer, memory, and low-cost peripheral technology continues to evolve at such a rapid pace that it is difficult to predict its status and assess its impact beyond 1 or 2 years. However, it is reasonable to project, based on past experience, that each new generation of microcomputers (a 2 to 4 year cycle) will start with an average four-fold increase in all capacities and incrementally increase during its life cycle to 10 times with subsequent enhancements in most subsections. For example, the initial memory expansion of the second generation IBM PC, relative to the first generation 8-bit machines, was from 64K byte to 256K byte and has subsequently been raised by upgrades to 640K byte.

Applications in image processing, remote sensing, and geographic data system require that a tremendous amount of data be processed. Thus, the design of such systems must be very sensitive to emerging technologies which can be adapted to handle the peculiar needs of these specific applications. This subsection discusses the expected advancement in some of the interrelated technological areas which will have a significant impact on remote sensing applications at the end user level. Very Large Scale Integration (VLSI) is a key technological area from which larger capacity memories, custom chips, and faster processors will be developed.

2. VLSI technology

The capabilities of available computers and integrated circuit design and fabrication technology have become increasingly interdependent. Progress in one of these disciplines precipitates advances in the other. For example, increasing computer capability has provided a basis for computer-assisted VLSI design and thus permitted major advances in Integrated Circuit (IC) complexity. On the other hand, advances in IC technology have made high-capacity semiconductor memories readily available.

VLSI

Five generations of IC have emerged from the progress of device design and fabrication technology over the last two decades. Small, medium, large, very large, and ultralarge integration – or SSI, MSI, LSI, VLSI, ULSI. These generations are typically represented by ranges of chip complexity in number of components per chip such that the upper limit on each range is 32 times the lower limit (Burger et al., 1984):

- SSI 2-64
- MSI 64-2000
- LSI 2000-64.000
- VLSI 64,000-2,000,000
- ULSI 2,000,000-64,000,000

Since its invention in 1959, the IC has undergone rapid growth in which chip complexity has increased dramatically by doubling every year. This complexity reached nearly 8,000 components per chip in 1973 and has doubled every 1.5 to two years since then. This trend is known as Moore's law (Figure 1). Complexity growth has been mainly due to the decrease of the components' sizes and an increase in the chip size. The chip area has increased by an order of magnitude in the last two decades as silicon substrate quality and process controls have advanced to permit economically acceptable yields at these large chip sizes (Figure 1).

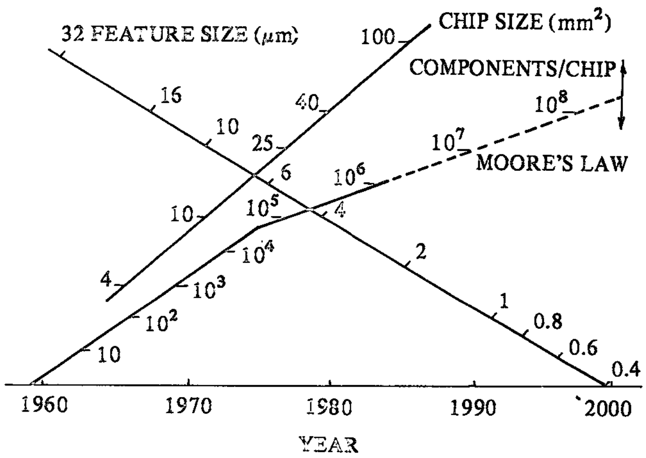

Fig. 1. INTEGRATED CIRCUIT COMPLEXITY TRENDS. IC chip complexity has doubled since it was introduced in 1959. Chip area has increased by an order of magnitude in the last two decades. Component feature size has decreased by 20 times during the same time period (after Burger et al., 1984)

The cost of an IC has decreased dramatically and during the last decade the cost per bit of semiconductor memory has declined from about 0.5 cents to about 0.01 cents. It is conservative to project another order of magnitude increase in circuit performance by the end of this decade through a continuing reduction in the feature size of the devices on the chip. Advances due to further increases in chip size may also be accomplished such as the full wafer sized massive memory chips currently being tested.

Semiconductor Memory

The microprocessor could not have been developed without semiconductor memories. The first Random Access Memory (RAM) chip was developed by Intel Corp. in 1969. Prior to this development, magnetic core was used in computers and was expensive and difficult to wire, required a large amount of space, and liberated significantly more heat per byte. IC semiconductor memory, on the other hand, was small, inexpensive, and easy to use. Dynamic RAMs have been through six generations of capacity improvement since 1970: 1K, 4K, 16K, 64K, 256K, and 1M bytes. Each generation has provided four times the storage density of the previous generation, accompanied by declining costs per bit stored. The speed-power product of this technology (often called the figure of merit) has improved by a factor of 1000 since 1972 (Pohm, 1984). Three rules of thumb have characterized the growth of the dynamic RAM portion of memory technology (Whittier, 1982):

- a density increase by a factor of four every three years,
- average bit size (square micrometer per bit) declining at an average rate of 25 percent a year, and
- smaller die sizes required to obtain greater yields and better economic viability and to maintain rapidly declining costs per bit.

Achieving continued development of IC memory technology requires the:

- use of materials such as a *Ga*llium *As*enide (GaAs) and titanium disilicide, which increase speed, and
- improved fabrication techniques, such as electron-beam lithography or molecular beam epitaxy, which reduce size, with a further increase in speed.

3. Disk and tape storage

Storage media and peripherals continually strive to attain higher capacities to provide faster access to the data and to achieve overall better performance by reducing system power and space requirements. Magnetic recording technology has managed to double in density every two years over last 30 years (Killmon, 1985). The capacity and performance of these magnetic devices will grow for the near future until they reach the physical limitations of magnetic recording technology as:

- controllers are acquiring more intelligence and memory to move data faster and
- technology is being developed for;
  - thin film coatings for media,
  - perpendicular recording,
  - advanced types of read/write heads, and
  - reducing head/media spacing.

Floppy disk

Floppy disk technology has made comparatively modest gains during a period when other mass storage technologies have improved significantly. Floppy disk capacity has increased from about 400K bytes in 1980 to 1.6M bytes today while during the same period micro-Winchester disk drives went from 5M bytes to over 100M bytes. Floppy disk capacity increases have been slow due to their removable and interchangeable medium which must be (Hirshon 1985):

- subjected to extreme environmental stress during transport and therefore their recording parameters must be kept conservative and
- fit into standard formats which is important, but also is a time consuming and technology-stifling process.

Nonetheless, there are active efforts in the U.S. and Japan to extend flexible disk technology. The near future trend of this technology seems to be focused on developing a smaller size, higher capacity, higher performance floppy disk, e.g. 3½" microfloppy disk. This small size floppy disk has several technical advantages over larger formats which include:

- lower power consumption,
- higher reliability, and
- smaller footprint.

The 3½" media's hard shell design offers added durability, more precise clamping (because of the addition of a metal hub) and high resistance to anisotropic deformation and expansion from thermal and hygroscopic effects (Hirshon, 1985). Current versions of microfloppy drives record about 8,000 bits per inch for a capacity of 1M bytes in a double-side format. Commercially avilable 5¼" floppy disks can also now hold 3M bytes on a single disk (Kodak and Drivetec) and a 6.6M byte version is being developed (by Drivetec and Hitachi).

The maximum recording density with conventional horizontal orientation method will be about 15K bit/inch. However, with the new vertical recording technology being developed, the density will be 100K bit/inch by the end of this decade in commercial devices (10M byte for 3½" floppy disk and 30M byte per 5¼" floppy disk) (Killmon, 1983).

Hard disk

Hard disk drives are presently available in several sizes-14", 8", 5¼", and less than 4" (e.g. 3½" and 3.9"). The 14" disks are generaly used with mainframe computers so only 8" and smaller diameter disks will be discussed. A large number of manufactures are presently offering 8" disk drives with capacities in the 40M to 200M byte range for drives with removable cartridges (Hobbs, 1984). Fixed/removable drives with 50M byte cartridge capacity and 100M to 500M byte fixed capacity are anticipated in the near future. It seems that within the next year or two, 5¼" drives will replace most 8" drives for applications requiring capacities below 100M bytes. At present, capacities for 5¼" fixed disk drives range from 5M to 140M bytes depending primarily on the number of heads and platters used. Increases in hard disk capacity anticipated within next 5 years are:

- 8" disk drives offering 100M to 1000M bytes,
- 5¼" disk drives offering 30 to 500M bytes, and
- 3½" disk drives offering 5M to 100M bytes.

The surface storage density of hard disks, which increased from approximately 10,000 bits per square-inch in 1960 to 1 million bits in 1970 and 10 million bits per square-inch in 1980, is expected to be over 100 million bits by 1990 (Figure 2). This density will approach 200 million bits per square-inch which means storage capacities of 3, 2, and 1 gigabytes per surface using 8-, 5¼-, and 3½-inch diameter media (Killmon, 1985).

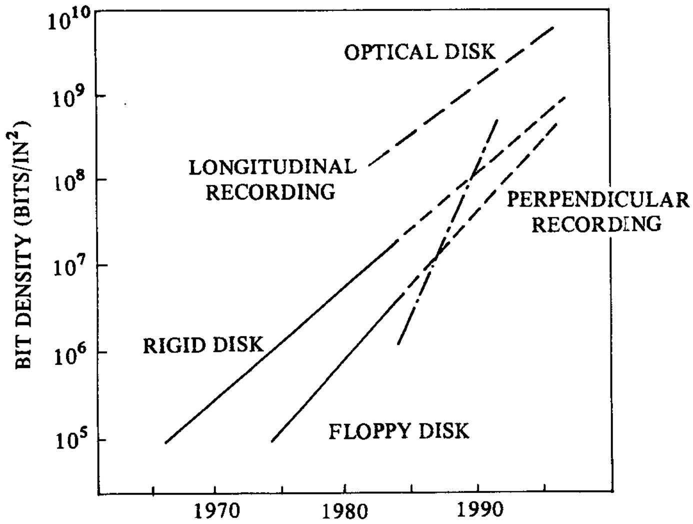

Fig. 2. DISK RECORDING DENSITY TRENDS. Magnetic recording technology has doubled in density every two years over last 30 years. The surface density of hard disks increased from approximately 10,000 bits per square-inch in 1960, 1 million bits in 1970, 10 million bits per square-inch in 1980, and is expected to be over 100 million bits by 1990. The current surface density of floppy disks is 5 million bits per square-inch and is expected to be 15 million bits by 1990 (after Killmon, 1985)

Magnetic tape device

Until now, the trends toward interactive and on-line microcomputer systems, combined with the availability of disks having much larger capacities, has favored disks drives rather than tape drives. Yet, standard magnetic tape devices are still used as a:

- data transportation media between micro systems and mainframes for the characteristically large volume images and other data bases,
- backup for hard disks, and
- historical or archival image storage.

The standard 9-track ½" tape transport is limited to approximately 40M bytes of formatted data per reel for the universal 1600 bpi recording density. The highest performance magnetic tape drives readily available today are the 6250 bpi tape drives. Recently introduced, low-cost ½" streamer tape drives record at 1600 or 6250 bpi. These streamer tape drives typically run in a streaming mode at 100 ips and have low-speed start/stop modes that run from 12.5 to 50 ips. Magnetic tape drives will be improved in the future by using thinner tapes, improved oxides, thin-film heads, bit densities of over 20,000 bpi, and lower costs. The capacity ranges anticipated for magnetic tape within next two years is 20-160M bytes.

4. Optical disks

Low-cost digital optical disk technology with the capability to be written upon at least once by the end user will dramatically improve the use and acceptance of microcomputer image processing systems. Optical digital disk technology is new and significantly different from anything available in the past. Currently, semi-experimental, expensive, write-once optical drives called Direct Read-After-Write (DRAW) or Write-Once-Read-Mostly (WORM) disk are becoming available with 100 to 400M bytes per 5¼" disk. However, wide spread digital optical disk technology has not been established yet since:

- there are no standards,
- different manufactures are taking different approaches in the technologies they use and products they develop,
- there is no system software written to optimize the use of optical storage, and
- application requirements and user needs are incompletely defined.

However, digital optical storage will be the next primary mass storage technology. The bit density within a track in typical initial systems presently under development, is approximately the same as that for advanced magnetic disks, but the track density is more than 10 times greater. The advantages of optical disk storage include:

- high density and total capacity,
- low cost per megabyte,

- high data rate,
- potential for *much* higher data retention life,
- tamper proof architecture,
- no head cracks or head crashes,
- intermixed digital, audio, video data storage, and
- fast access relative to magnetic tape.

Also there are a number of current disadvantages including:

- multiple read/write media will not be immediately commercially avilable,
- related software and systems concepts are not yet well developed,
- hardware standards have not yet developed, and
- media life (data retention) and error rates are unproven.

Several Japanese and U.S. companies have announced laboratory test units using reversible optical disks however, commercially available read/write optical storage products are not likely within the next two years. The capacity ranges anticipated for optical digital disk drives within the next two years is 1 to 5G bytes.

5. Image display

Advancing microcomputer and related technology has brought substantial reductions in the cost of its hardware while improving graphic and image display performance. The driving force for these improvements are the advances in:

- very large scale integration,
- custom IC design and fabrication techniques,
- semiconductor memory (e.g. 256K DRAM),
- bit map graphics, and
- system packaging.

Several general graphic chip sets were recently developed and introduced. They are VLSI based subsystems which are designed to perform some of common or generic graphics functions using a:

- graphics display controller chip,
- memory interface controller chip,
- text coprocessor,
- *character generator, etc.*

Properietary, custom-designed chip sets have also developed by several vendors (e.g. International Imaging System, Ramtek, Sun Microsystem, etc.). This use of proprietary VLSI custom designed display controllers helps micro systems out-perform much more expensive and powerful minicomputer based work stations' computer image displays. For example, IRIS's VLSI chip can handle geometric calculations faster than a VAX 780. This geometry engine offers 200 to 400 times the graphics performance of an advanced general purpose processor such as the Motorola MC68000 (Machover and Myers, 1984).

These kinds of advances in technology have also significantly reduced the price of the color image display controller. Five years ago a typical microcomputer color display controller (256 by 256 picture elements by 17 million colors) cost more than $10,000 and required 4 to 8 circuit boards. Today a comparable single display board costs less than $2,500 and its price is rapidly decreasing. It is reasonable to predict that a color image display controller of 512 by 512 picture elements with more than 4000 directly displayed colors will cost less than $1000 in a couple of years.

6. Future microcomputer image processing system

6.1 Hardware configuration

The microcomputer image processing systems which have been developed over the past few years can be categorized into three groups, first generation (until 1982), second generation (1982-1985), and with a development of third generation just being initiated. The typical first generation microcomputer image processing system consisted of an (Welch et al., 1983):

- 8-bit microprocessor,
- 64K bytes of direct access memory,
- 256 by 256 picture element by 8 bit color display board,
- 256 by 256 picture element by 8 bit video frame grabber,
- 360K to 1.2M types of floppy disk storage devices, and
- *optional* 800/1600bpi 9-track tape drive.

The typical 2nd generation microcomputer image processing system consisted of a (Miller et al., 1984):

- 16-bit microprocessor,
- 128 to 640K bytes of direct access memory,
- 512 by 512 picture element by 32 bit color display board,
- 512 by 512 picture element by 8 bit video frame grabber,
- 360K to 1.2M bytes of floppy disk storage devices,
- 10 to 20M bytes of hard disk storage device, and

- *optional* 1600 bpi 9-track tape drive.

The generally announced advancements in microcomputer related technology described in previous sections have initiated the design and initial development of the third generation of microcomputer image processing systems which will be available in 1 to 2 years (1986 or 1987) (Table 1). They will consist of a:

- 32-bit microprocessor,
- 2 to 16M bytes of direct access memory,

Table 1. HARDWARE ATTRIBUTES OF FUTURE GENERATIONS OF MICROCOMPUTER IMAGE PROCESSING SYSTEMS. Existing microcomputer image processing systems can be categorized into three groups, first generation with 8-bit microprocessor (until 1982), second generation with 16-bit microprocessor (1982-1985), and the development of third generation just being initiated. The third generation systems will be available in 1 to 2 years (1986 or 1987). A fourth generation microcomputer image processing system can be expected in 5 years (1990) and will have limited parallel processing capabilities

	3rd generation		4th generation	
	low end	high end	low end	high end
Microprocessor	32 bit	32 bit	32 bit	parallel processor
Memory	2 MB	16 MB	8-16 MB	16-64 MB
Floppy Disk	1.2 MB	4 MB	1-4 MB	4-10 MB
Hard Disk	20-50 MB	50-500 MB	50-500 MB*	100-1000 MB*
Opical Disk	none	400-1000 MB*	1-5 GB	1-10 GB
Magnetic Tape	none	1600 bpi*	1600/6250 bpi*	none
Color Display	512 by 512 pixels by 12 bit color	1024 by 1024 pixels by 32 bit colot	1024 by 1024 pixels by 32 bit color	2048 by 2048** pixels by 32 bit color
Video Digitizer	512 by 512 pixels by 8 bits frame grabber	1024 by 1024 pixels by 8 bits frame grabber	1024 by 1024 pixels by 8 bits frame grabber	2048 by 2048 pixels by 8 bits film scanner

* optional
** with alternative multimode display features (e.g. 16 planes of 1024 by picture elements by 8 bit color resolution)

bpi : *b*its-*p*er-*i*nch
MB : *M*ega *B*yte
GB : *G*iga *B*yte
pixels : picture elements

- 1.2 to 4M bytes of floppy disk storage,
- 20 to 100M bytes of hard disk storage,
- 1024 by 1024 picture element by 32 bit color display board,
- 1024 by 1024 picture element by 8 bit video frame grabber,
- *optional* 1600/6250 bpi 9-track tape drive,
- *optional* 400 to 1000M bytes of write-once optical disk, and
- *optional* 2048 by 2048 film scanner.

The fourth generation microcomputer image processing system which might be expected by 1990 (Table 1) will consist of a:

- 32-bit microprocessor with some parallel processing capability (e.g. at least co-processors),
- 8 to 64M bytes of direct access memory,
- 1 to 10M bytes of floppy disk storage,
- 2048 by 2048 picture element by 32 bit color resolution with alternative multimode display features (e.g. 16 planes of 1024 by 1024 picture elements by 8 bit color resolution),
- 2048 by 2048 picture element by 8 bit film scanner,
- 1 to 10G bytes of read-and-write optical disk,
- *optional* 50 to 500M byte hard disk storage, and
- *optional* 1600/6250 bpi 9-track tape drive,

The fixed head hard disks will probably be replaced by low-cost, large-capacity, read-and-write optical disks in the fourth generation systems. However, the 1¼″ or 3½″ floppy disks will remain as data and software transportation media between microcomputer systems. The 1600/6250 9-track tape drive will remain as an optional, but much less important, transportation media for moving images between their source and microcomputer systems as the optical disk becomes the standard media of image distribution, storage, and on-line access and as images grow in resolution and thus in size.

6.2 Impact of new technology on microcomputer image processing

The new and advancing technologies described in previous sections will significantly affect the use and application of microcomputer image processing systems. Large capacity (1 to 10G byte) optical disks will revolutionize and popularize the use of microcomputer image processing systems. Their typical user will be able to:

- store large volume of imagery such as entire multidate Landsat *T*hematic *M*apper (TM) scenes (e.g. 3 full TM scenes are about 1G byte), hundreds of the preprocessed 7½-minute image maps, hundreds of digitized video images, etc. and
- randomly access and retrieve any subportion of these stored images for instant display and

analysis.

Designing an efficient data management system for optimum utilization of the huge data volume offered by the optical disk is an important immediate task. This new image data base management system should include:

- an optimum image file format for the fast access of any subportion of the image (e.g. the selection of band interleaved by line, band sequential, or band interleaved by pixel formats; header record contents; etc.),
- defining the image management unit (i.e. the size of the image the user wants to store, extract, and analyze) (e.g. 7½′ USGS map, 1/62,500 map, county, etc.), and
- implementing an efficient storage and retrieval scheme for collateral, non-image data.

Even more powerful and sophisticated proprietary image processing oriented chips will become available to control the:

- user interface,
- color display,
- image data base management system,
- processing floating point intensive image operation such as:
  - interpolation,
  - geometric correction,
  - multivariable data transformation, etc.

These new tailor-made chips will allow the user of microcomputer systems to have:

- better control of their color image display operations,
- simple, user-friendly interaction with the system based on an expert system or the "friendly technician" approach,
- direct interaction with a huge library of satellite images covering entire states,
- fast, interactive analyses including classification thus giving the user more time to enhance the accuracy of his results rather than tying him down in the mechanical processes involved.

The currently separate display and regular memories will increase in size and merge into one huge memory space which would enable the user to analyze and display even larger areas using:

- pan,
- scroll,
- alternate displays, and
- graphics overlays (e.g. cultural features, state coordinate system, etc.).

However, image display technology will not advance to provide low-cost, full direct display of such large images in near future (e.g. 2048 by 2048 picture elements). Implementing efficient real time scheme for the windowing and display of smaller areas from large images is thus an important task. However, this windowing approach can be coupled with low-cost, high resolution laser film recorders to display suitably processed large image areas such as full frames or state level mosaics.

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