Photogrammetrische Woche 1977
Institut für Photogrammetrie
Schriftenreihe, Heft 4, 1977

DIGITAL COMPUTERS FOR PHOTOGRAMMETRIC PROCESS CONTROL - PRESENT STATE AND FUTURE DEVELOPMENT OF THEIR TECHNOLOGY

E. Baeck, Oberkochen

General

The C-100 PLANICOMP analytical stereoplotter uses a type HP21MX on-line process-control computer. This computer is an integral part of the overall system that has several aspects: it is a physical unit set up beside the plotter; it is responsible for the high efficiency of the C-100 PLANICOMP; it can be used as an autonomous computer, and, last but not least, it is reflected in the price of the equipment. It is only logical that the great importance which the computer thus has within the overall system should arouse a due measure of interest in process-control equipment as such.

It is the purpose of this paper to summarize some essential information on computers, using the HP21MX as an example of a process-control application.

Anyone who has ever dealt with computers will be impressed or even confused by the multitude of equipment on the market. In fact, there are computers from a few hundred German marks to some million, and from the size of a pocket calendar right up to rooms full of hardware.

In an attempt to put some order into this chaos, I shall follow the history of computer development.

The first program-controlled computer that actually worked was designed in Germany by Konrad Z u s e in 1934 and presented in 1941. Independently, Howard A i k e n of Harvard University in the United States developed his own computer which he presented to the world in 1944. The two computers "Z3" by Zuse and "Harvard Mark I" by Aikens thus are the forefathers of the computers we are using today.

It is interesting to note that as early as 1833 the English mathematician Charles B a b b a g e designed the first complex program-controlled computer ever conceived. The British Government invested 20,000 pounds in the project to sponsor research and development. After more than 20 years, construction of the machine finally failed due to mechanical problems. In spite of this, Babbage undoubtedly deserves the designation as spiritual father of the computer for his ingenious idea.

Purpose of a computer

Originally, computers were designed to solve mathematical problems numerically with high speed and accuracy by program control.

The peripheral equipment for input and output was of only minor importance for this type of work. However, soon after program-controlled computers had started operating, people realized that the new technology could also be put to excellent use for non-scientific purposes. Input and output-intensive data processing for commercial and administrative purposes thus were added to the calculation-intensive mathematical uses of the computer. This development provided a considerable stimulus to the design of peripheral equipment for data input and output and for external data storage, resulting in ever more efficient hardware.

At the beginning, electronics and computer technology were extremely expensive. An acceptable price-to-efficiency ratio could be obtained only with computers of a certain minimum size. However, once computers came to be used on a larger scale for scientific and commercial purposes, efficient equipment could be offered at reasonable prices.

The new hardware typically had the form of a large computer.

Large computers

Large computers not only were and still are rather expensive, they also impose rather stiff requirements regarding space, environment and power supply. In addition, they can be operated economically only in two or even three shifts. Large computers are typical of the equipment used in data-processing centers with card reader, line printer, tape decks, disk memories and various input/output terminals.

Operation is usually by the batch-processing mode in which the different tasks are performed one after another. It is here quite possible that several tasks are simultaneously retained in the working memory and processed intermittently, so to speak. Whenever one program has to wait, for instance for an external unit, the computer can be temporarily made available to another program in the working memory. This is called m u l t i p r o g r a m m i n g . If, on the other hand, the computer is briefly and repeatedly made available to all competing programs in the form of time slices, each of the users at the terminals will have the impression that the computer is working for him alone, provided that the machine has a sufficient capacity. This type of data processing, which in most large computers is generally possible in parallel with batch processing, is called t i m e s h a r i n g.

Typical examples of large computers are the series IBM-360, IBM-370, CDC-6000, CDC-Cyber, Siemens-4004, UNIVAC-1100, DEC10/20, etc., the order in which these are mentioned here being entirely arbitrary and unweighted.

It should be mentioned already now that computers of this type are unsuitable for connection to measuring equipment. This is true above all if the computer is always required to serve the measuring instrument without delay, as is the case in the PLANICOMP.

Minicomputers

Up to the early sixties, computers could be built only as very voluminous and expensive machines. This situation began to change with progress in semiconductor technology, where SSI (small-scale integration) was replaced by MSI (medium-scale integration). It then became possible to build minicomputers. These machines were considerably smaller and cheaper. They could and still can be connected to any wall outlet and are much less demanding as far as environmental conditions are concerned. The efficiency of minicomputers cannot directly be compared with that of the large computers. Nor would this be justified because minicomputers are special-purpose machines. Their specialization essentially covered two fields of application. One concerned commercial data-processing operations as are required by small and medium enterprises. The development here resulted in o f f i c e c o m p u t e r s . Since these are not relevant in our case, they will not be discussed in greater detail here.

Developments in the second field concerned the solution of technical problems, particularly in conjunction with data acquisition and process control. However, sophisticated computation problems were still left to large computers. In order to enable the minicomputers to handle this particular type of work in a suitable manner, they were provided with special process-control characteristics.

Process-control computers and their outstanding features

First of all, the process-control computers had to be provided with a sufficient number of inputs and outputs to which analog or digital measuring stations could be connected in a simple manner. With their aid, an up-to-date image of a complex computer periphery can quickly be obtained at any time, and the periphery can be checked and controlled by the rapid output of suitable control signals (real-time processing). Branch programs can be controlled with the aid of an internal real-time clock. Also, the clock allows the computer to start certain programs automatically at certain times. Another important requirement made of a process-control computer is its prompt response to time-critical outside events. If certain signals are received, the computer will interrupt the operation in progress, save its instantaneous state for subsequent resumption of the process and automatically start dealing with the unforeseen event. If more such events should occur simultaneously, these will be processed by the computer by given priorities. Ample use of this so-called interrupt control is made in the C-100 PLANICOMP.

When minicomputers appeared on the market in the mid-sixties, they had very small working memories because these were still very expensive. Consequently, the software was written in machine-dependent Assembler language, and larger programs frequently became inaccessible to users because of the time and cost involved in preparing them. In addition, software written in machine code generally was not compatible with successive models of computers. The necessity of higher programming lan-

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guages such as FORTRAN or BASIC therefore was obvious for minicomputers. The rapid development of simiconductor technology had made it possible to integrate a growing number of components in a minimum of space. The result was a dramatic reduction in price. The efficiency of minicomputers became ever greater, and in some respects the minis began to resemble the large computers: the minis turned into megaminis. Of course, the large computers for their part also benefited from this development. The increased capacity of working memories and the connection of rapid external memories laid the basis for equipping the minis with operating software, too.

Operating software

The operating system (OS) is a package of standard programs and program system that is offered by the computer manufacturer together with the computer. The OS expands the hardware structure of the computer in such a way that users are enabled to adapt the equipment optimally and conveniently to their specific type of work.

Purpose of operating system

The OS allows the user to employ the computer in the interactive mode via clear text. By input of a program name, the desired program can be loaded from the external memory - usually a magnetic disk - into the working memory and started automatically. The user need not bother with storage locations either on the disk or in the working memory. These are administrated by the OS in a completely autonomous manner. The OS provides the programmer with input/output routines with which data can easily be transferred without special knowledge of the peripheral equipment. During a transfer, which may be automatic, the OS makes the computer available to the waiting program of the highest priority. If several programs apply simultaneously for use of the computer, waiting lists are prepared, and the programs processed one after another. In this case it may happen that programs of lower priority are temporarily returned to the disk memory, an operation termed swapping. The OS also sees to it that time-dependent programs are activated at given times or time intervals.

In the C-100 PLANICOMP, for example, the LOOP program for photo-carriage control is started every 20 msec. The remaining time is made available to the programs on the waiting list in accordance with their priority. With the aid of special program keys on the control panel, the programs can be killed or interrupted at any time. Finally, the OS is designed to monitor programs that are in progress and to kill them, should they take an "unreasonable" course.

The different tasks are assigned to the operating system by the operator with the aid of the control panel or suitable program requests.

The operating software also includes a few important auxiliary routines for program development. The most important of these are Editor, Assembler, Compiler and Link Loader. In addition, there is a multitude of library programs.

Before discussing the example of the HP21MX process-control computer in greater detail, a few remarks might be in order regarding the latest development of computer technology: microprocessors and microcomputers.

Microcomputers

The general consensus among experts is that microprocessors (MPs) have ushered in a new era not only of electronics but of technology as a whole. MPs are semiconductor components of extremely small size and high calculating capacity. They allow computer capabilities to be incorporated into conventional circuits and equipment where this was formerly impossible due to lack of space and high cost. In view of its high flexibility, an MP can be adapted to solve practically any problem. Experts of the German AEG-Telefunken company except that by 1980 some 10,000 electronics functions will be available for as little as 1 DM. This extreme reduction in cost will further stimulate the use of MPs. As a result, MP manufacturers will be able to make ever larger numbers, which in turn will entail a further reduction in cost. Experts have estimated that by 1980 some 30 % of conventional logic and 20 % of the minicomputers will have been replaced by microcomputers.

An MP is a central processing unit (CPU) with a word length of 4, 8 and sometimes 16 bits. Instructions are carried out in 1 to 10 microseconds. An MP is not yet a computer. Only the integration of MP, memory, data bus, input/output channels, interface, etc., will turn an MP into a microcomputer (MC).

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Like its large-scale predecessors, an MC performs sequentially all those operations that are defined by the program in its memory. As a result, functions that formerly had to be obtained by fixed hardware, can now be replaced by easily variable software. A gate function can normally be realized by an average of 8 to 16 programmed bits.

Microcomputers will find a wide field of application wherever complex problems are now being solved by conventional electronic means. Assembly lines, balances, cash registers, numerically controlled machine tools, programmable pocket calculators, automotive electronics, radar equipment, automatic analyzers, etc., are just a few examples.

The microcomputers presently available cannot be a cheap replacement of the minicomputer used in the C-100 PLANICOMP because they do not have the necessary speed and real-time operating system.

The situation can thus be summarized as follows:

A large computer is not suitable for controlling the C-100 PLANICOMP because neither its hardware nor its software offer the real-time capabilities. There is no suitable electronic periphery nor are the software functions available on which the PLANICOMP software is based.

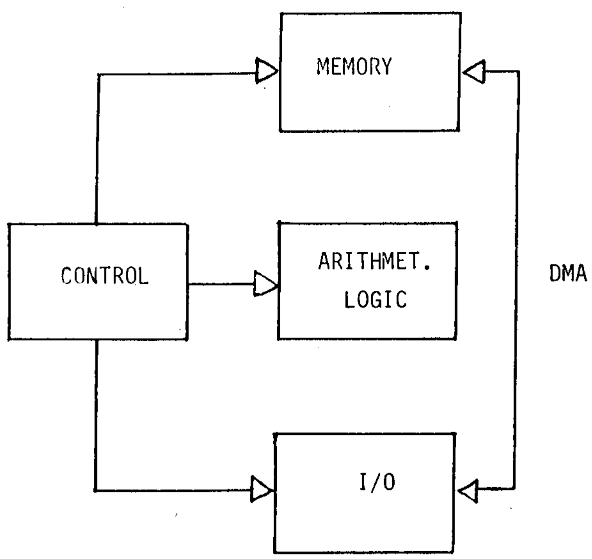
The hard and software aspect of a minicomputer, however, makes the latter suitable for process control of the PLANICOMP. Consequently, the problem consisted in selecting an "optimum" computer from the multitude of process-control computers on the market, making due allowance for the experience gathered in this field within the CARL ZEISS company.

After this rather general review of computers, let me now discus the HP21MX process-control computer selected for the C-100 PLANICOMP in greater detail.

Hardware of HP21MX

Basically, every computer comprises four fundamental sections:

1. The memory section.
2. The arithmetic logic section.
3. The control section.
4. The input/output section.



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The memory section

The HP21MX/M20 processor used for the C-100 PLANICOMP has 32K MOS semiconductor memories with a cycle time of 650 nsec and a word length of 16 bits. The size of the memory modules is 8 K or 16K, organized in so-called pages of 1024 words each. Two pages can be addressed directly and up to 32K indirectly.

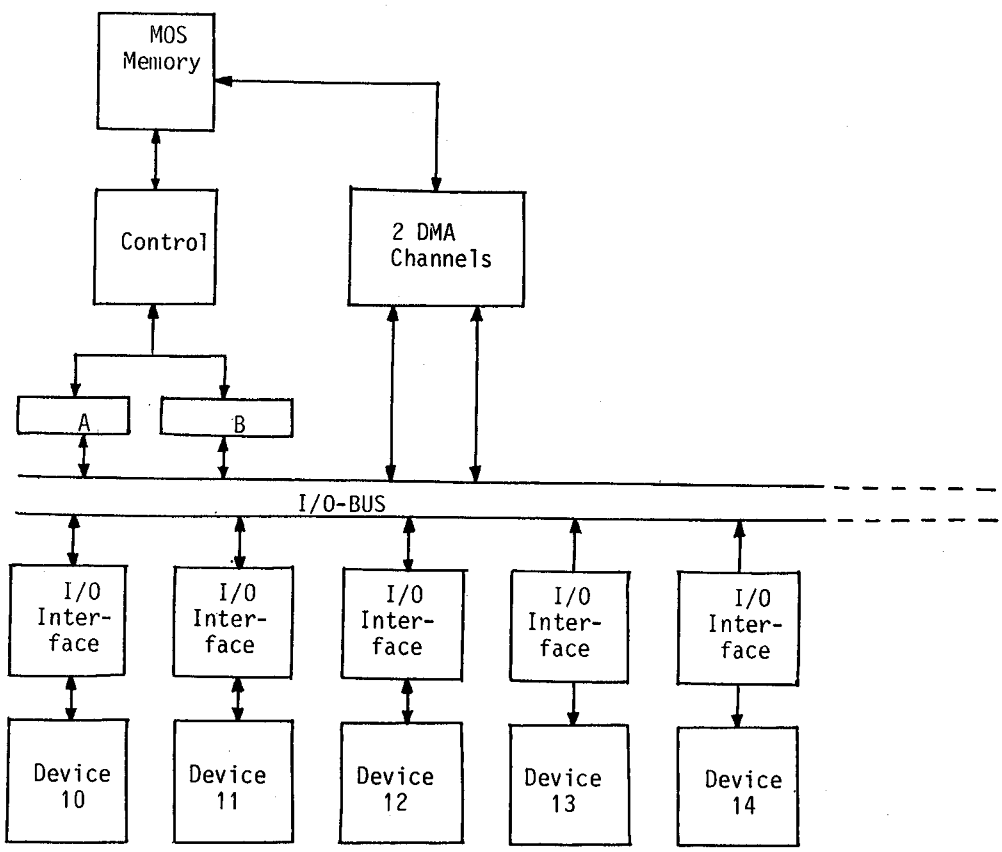
All words read out from the memories are checked for parity. If a parity error is detected, the computer will stop, and an interrupt will be generated.

If additional hardware is used, such as a Dynamic Mapping System or a Memory Extender, the memory can be extended up to over 100K words.

The arithmetic logic section

This section links the adressed operands arithmetically or logically. The two accumulators A and B are available for the purpose.

The input/output section



Every device is connected to the I/O bus via an interface, and every interface is located in a separate slot in the CPU. The M20 processor has nine slots and thus allows a maximum of nine units to be connected. However, since some units require two interfaces (disk memory, tape deck, PLANICOMP), the actual number of units is lower. The use of I/O extenders allows the number of slots to be increased up to 41. The priority of device 10 is always the highest. By exchanging the interfaces in the slots, the priorities of the different units can be changed at the user's choise.

Data transfer can be program-controlled in either direction via the I/O bus in conjunction with one of the two accumulators (A, B). If one the two DMA channels is used, the data can be transmitted directly between the machine and the working memory with a high transfer rate (approx.

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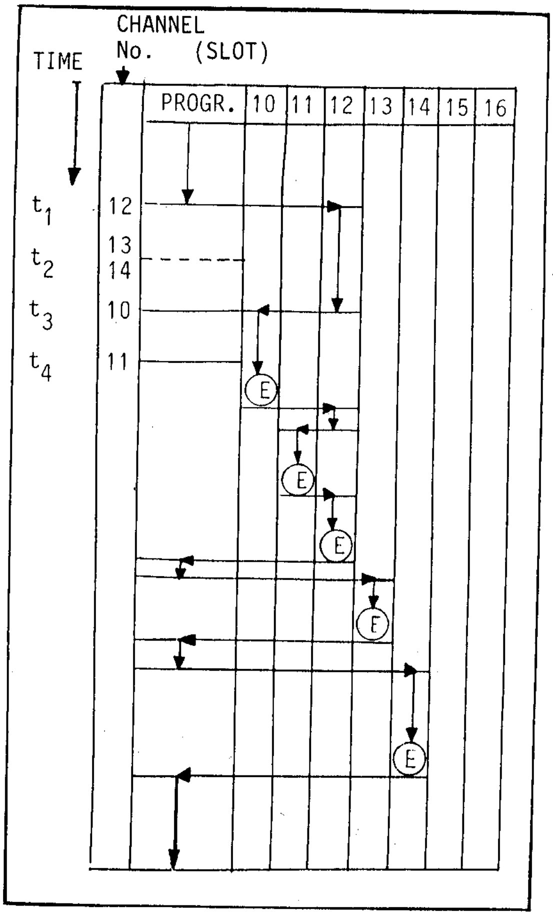
600,000 words/sec), without use of the accumulators. In this case, the transfer is only triggered by the program and will then proceed independently without any further software-assistance. The end of the transfer is signalled to the system by a special interrupt. The DMA channels are primarily used for data transfer between the working memory and external memory.

Interrupt control

This is closely related to input and output. The diagrammatic representation below illustrates the situation.



In the schematic example, a program is interrupted at instant t_1 by an interrupt request from channel 12, and the interrupt service routine ISR12 for channel 12 is started automatically. At instant t_2, interrupt requests are received from channels 13 and 14. These are deferred due to their lower priority. At instant t_3, the next-higher channel 10 comes in. This interrupts ISR12 and is immediately served with ISR10. At instant t_4, channel 11 comes in but is not served for the time being because ISR10 is of higher priority.

When ISR10 has come to an end, the control returns to ISR12. However, since a request from channel 11 is still open, ISR12 is immediately interrupted again and ISR11 started and completed. Next, ISR12 is completed. At the end of ISR12, the control returns to the program interrupted by channel 12. However, since an interrupt request from channel 13 is still open, the program is immediately interrupted again and channel 13 served with ISR13. Next, channel 14 is served with ISR14 after brief return to the program, and the program is finally continued after all interrupt requests have processed.

At the end of every ISR, the program returns to the program from which the jump was made for interrupt to ISR.

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It should also be noted that all program jumps are automatic and do not require any additional programming.

The control section

The control section of a computer serves to realize the different machine instructions. In conventional computers, every instruction requires a large number of electronic circuits. As a result, the control section contains a multitude of fixed circuits. However, since a computer of this type is fully hard-wired, any modification or extension of computer functions is very difficult and costly.

In the HP21MX, the control section has been replaced by am microprocessor of very high capacity. Individual machine instructions are no longer hard-wired, but are composed of a few very fundamental microcommands in the microprocessor. Every single machine instruction corresponds to a so-called microprogram in the memory of the microprocessor. The capacity of the computer can be modified by exchanging or adding new microprograms. The hard-wired control section has thus been replaced by a very flexible system. Examples of subsequently added microprograms (instructions) are the floating-point instructions and the fast Fortran processor. The problem of compatibility has likewise been solved by implementing the instructions (microprograms) of earlier hardware versions (HP2114, HP2116, HP2100). Microprograms can be written and implemented even by users. This allows the computer to be optimally adapted to any specific problem even if extreme requirements are made.

The software of the HP21MX

There are several operating systems for the HP21MX. After a comprehensive study, CARL ZEISS decided to adopt Real Time Executive II (RTE-II). Most of the characteristics of these operating systems have already been described under operating software. For further details, interested readers are referred to special literature. It should be noted that RTE-II is a medium chain in an upward-compatible family of operating systems. Our experiments have shown that RET-II will perform all the functions that are essential in the C-100 PLANICOMP with a relatively limited working memory. A particularly important characteristic in this context is the extremely rapid reaction to certain external signals in the multiprogramming mode with several priority levels.

Abstract

Following the history of computers, these are classified in large computers, minicomputers and microcomputers. The most essential characteristics of these computers are discussed. As representatives of the minicomputer category, a more detailed description is given of process-control computers and their hardware and software aspects, using the HP21MX/M20 employed in conjunction with the C-100 PLANICOMP as an example. An outline is given of the computer characteristics that are most important for photogrammetric plotting.

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Digitalrechner für photogrammetrische Prozeßsteuerung, Stand und zukünftige Entwicklungen ihrer Technologie

Zusammenfassung

Anhand der historischen Entwicklung des Computers wird eine Klassifizierung in Großcomputer, Minicomputer und Mikrocomputer vorgenommen. Die wesentlichsten Eigenschaften dieser Computer werden behandelt. Als Vertreter der Minicomputer wird der Prozeßrechner mit seinen Hardware- und Softwareeigenschaften eingehender erörtert. Der am PLANICOMP C100 angeschlossene Prozeßrechner HP21MX/M20 wird als Beispiel näher besprochen. Dabei wird gezeigt, auf welche Eigenschaften des Computers es beim photogrammetrischen Auswerteprozeß besonders ankommt.

Calculateurs numériques pour la conduite des processus photogrammétriques. Situation actuelle et développement futur de leur technologie

Résumé

L'exposé se base sur le développement historique du calculateur pour la classification en gros calculateurs, minicalculateurs et microcalculateurs. Il passe en revue les caractéristiques les plus importantes des différentes générations de calculateurs. Comme représentant des minicalculateurs. Le calculateur pour la conduite des processus est étudié en détail, avec les caractéristiques de son hardware et de son software. Le calculateur HP21MX/M20 associé avec le stéréorestituteur analytique PLANICOMP C100 fait l'objet d'une description précise. L'exposé insiste sur les particularités qui jouent un rôle essentiel pour les processus de restitution photogrammétriques.

Computadoras digitales para control de procesos fotogramétricos - Situación actual y desarrollo futuro de su tecnología

Resumen

Siguiendo el desarrollo histórico de las computadoras, se hace una clasificación en computadoras grandes, minicomputadoras y microcomputadoras. Se discuten las características esenciales de estos equipos. Como representante de las minicomputadoras se discute en más detalle la computadora de procesos en sus aspectos de hardware y de software. Como ejemplo, se describe en más detalle la computadora de procesos HP21MX/M20 conectada el PLANICOMP C100, destacando las características de la computadora que son de especial importancia para la restitución fotogramétrica.

Dr. Ernst Baeck, Wissenschaftlicher Mitarbeiter der Firma
CARL ZEISS, Rechenzentrum 2,
7082 Oberkochen, West Germany, Postfach 1369/1380