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A NEW CONTROL SYSTEM FOR THE IMPROVED λ 8-CM RADIOHELIOGRAPH

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Abstract

The purpose of this paper is to describe a new control system adopted to the improved λ 8-cm radioheliograph at Toyokawa. This control system consists of two micro-processor sub-systems. These sub-systems are loosely coupled by a serial communicaton channel. For the software of this system, the "N-FORTH" and its support system were developed. "N-FORTH" is a quasi-interpreter system with high-level language, by which observers can make their own programs by themselves. This new control system is expected to improve the flexibility and the reliability of the λ 8-cm radioheliograph.

1. Introduction

The λ 8 cm radioheliograph at Toyokawa has been operated since 1975(Ishiguro et al., 1975; Shibasaki et al., 1976). This system is an important tool to study the spatial structure of the solar atmosphere and its time variation.

The antenna system is composed of a T-shaped array of 3-m paraboloids, (32+2) elements in the E-W direction and (16+1) elements in the N-S direction. The baseline length is about 400m in the E-W direction and about 100m in the N-S direction. A project to improve the phase stability and the sensitivity of this system is in progress since 1978 (Ishiguro et al., 1979 ; Naito, 1979). In the present system, the microwave signal received by each antenna is directly transmitted to the remote front-end receiver at the phase center of the antenna array via the waveguides without amplification and frequency conversion. In the improved system, the microwave signal received by each antenna is amplified and frequency-converted by front-end receiver placed close to each antenna and 2nd IF stage at the phase center of the antenna array. The back-end system is placed in a remote observation house.

Each part of the radioheliograph is so widely spread out that the concentrative management of the whole system is very difficult. For this reason, the work to develop the new control system has been started.

The control system controls the following parts:

(1) Dicke switches in the front-ends;

(2) 8-bit digital phase shifters installed at the 2nd IF;

(3) switches to select antenna combinations at the 2nd IF;

(4) selectors of bandwidth, integration time, attenuation and switching mode (Dicke switching or phase switching), which are installed in the back-end.

Two adjacent front-end receivers are put together in a small temperature-controlled box. The temperature inside the front-end box, an over-temperature alarm and a lock-indication of the phase-locked oscillator(PLO) can be monitored by the control system.

On designing a control system, following two types may be considered;

(A) a system which closely depends on hardware,

(B) a system which closely depends on software.

(A) is superior than (B) in execution speed, but (A) is inferior than (B) in the flexibility of implementation. In this control system, the speed will not be a main problem, because the integration time is longer than 3 msec. Therefore we adopted the control system of type (B).

In Section 2, the general description of the new control system is given. In Sections 3 and 4, hardware and software of the new control system are described in some detail. In Section 5, the automatic phase error calibration of the radioheliograph is shown as an application.

2. General description of the new control system

The micro-processor based products have been undergoing a major evolution in recent years according to the remarkable progress of the IC(Integrated Circuit) technology and the art of software programming. For example, in many laboratories an automated instrumentation system which uses the CAMAC or GP-IB (or IEEE Standard 488) Interface Bus (Loughry and Allen, 1978) is becoming standard. In these systems the instruments and computers are linked effectively to reduce the load of experimentalist and to increase the ability of each instrument. Therefore we decided to adopt micro-processor based control system.

This system employs two loosely coupled micro-processors to separate the control functions and to improve the flexibility of the system. For software, the author developed a flexible control software, called "N-FORTH", which is based on FORTH (Moore 1974) and its support system, called "I/O control system". FORTH, adopted at NRAO of U.S.A., is flexible and 'transplantable' (to be easy to transfer the software from one machine to another) language. It provides a single language that covers the range usually requiring assembler language, compiler language, job-control language and application language. It uses the reverse Polish notation, which is better to develop flexible operations.

In radioastronomy, a software system which is used for telescope control and data processing can be divided into the following three levels of system operation (Chikada, 1979):

(1) parameter system level in which the system has fixed programs and observers can only set parameters;

(2) command system level in which the system is composed of several programs (or program modules) and command interpreter, and observers can issue commands to set parameters, to select a desired program and to combine programs;

(3) language system level in which the system is based on a compiler (or an interpreter) of a high-level language and obserbers can develop programs for observation by themselves.

"N-FORTH" can be classified as a language system. Therefore it is easy for observers themselves to develop new programs, for example a program for the automatic calibration of phase errors. It is suitable not only to routine observation but also to specialized observations.

The "I/O control system" manages input and output(I/O) devices of the system. It includes interrupt management programs, so that it is capable of managing concurrent processes.

3. Hardware system

This control system employs two micro-processors installed parallel to the receiver system. One of the processors, called "micro-processor(1)", which is placed in the observation house, communicates with an operator and controls the whole system according to his commands. The other, called "micro-processor(2)", which is placed at the phase center of the array, controls and monitors the front-ends and the 2nd IF's. Usually the latter is the slave-processor of the former and does not directly communicate with the operator, but in a case of a malfuntion of the micro-processor(1) the operator can communicate with the micro-processor(2) directly. The relation of the control system and the receiver system is shown in Fig.1.

The new control system is so designed as to increase the flexibility, the operational ability and the reliability of the radioheliograph system without the large alteration of the existing part of the system.

In the radio-interferometric observations, calibration of phase errors is very important. For this purpose, the color graphic CRT is

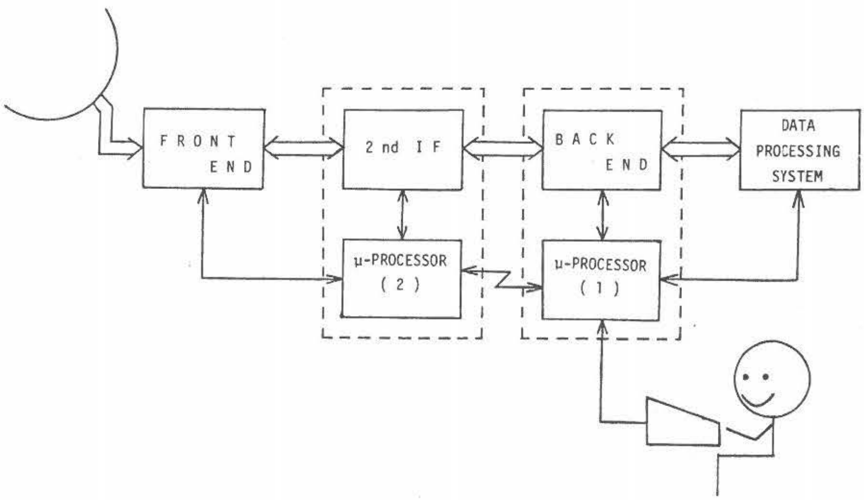


Fig. 1. The relation between the control system and the receiver system.

installed in the control system to display the raw data or the status of the whole system. The operator can check the phase errors by the CRT data and, if necessary, he can start the calibration program by a simple keyboard command.

Micro-processor(1) system

The signal lines from CPU are classified into three groups which are data bus, address bus and control bus, respectively. In the board called "bus-driver and chip-selector", these lines are rearranged into two groups, called I/O data bus and I/O control bus, and are connected to each I/O interface board. This is a common configulation for complex instrument.

The micro-processor(1) system includes four serial I/O controllers, four parallel I/O controllers, a timer, an A/D converter, a color graphic CRT controller and a floppy disk controller. These are connected to CPU via the interface buses described above. The block diagram of the micro-processor(1) system is shown in Fig.2.

The serial I/O controllers are employed to communicate with the micro-processor(2) system and with a minicomputer (NOVA 1200), which processes received data. By adopting standard serial communication channel, the processors are seemed to be tele-typewriters (TTY) to each other and the modification of the system can be done almost independently with each other. The parallel I/O controllers are employed to control the back-end receivers in the observation house. The timer is a time standard of the control system and is synchronized with a digital clock of the minicomputer. When something abnormal happens in the radioheliograph, the micro-processor reads the time from this timer and records it with the name code of the part where the failure happened. The A/D converter is employed to record and monitor the outputs of the back-end receivers and 3.75 GHz automatic radiopolarimeter (Torii et al., 1979). The data sampled by this A/D converter is used for the calibration of phase errors and the automatic setting of step-attenuator. The color graphic CRT is employed to display the sampled data as one or two dimensional maps without phase correction. The operator can check phase errors through the display.

The following tasks are managed by the micro-processor(1) system:

(1) selection of observation modes;

(2) display of selected obsevational data;

(3) display of selected monitoring data;

(4) separate control of each part of the radioheliograph system

(this is used for maintenance);

(5) automatic calibration of phase errors;

(6) detection and indication of system failures;

(7) selection of bandwidth, integration time, attenuation and switching mode.

These tasks are carried out by commands from a console keyboard.

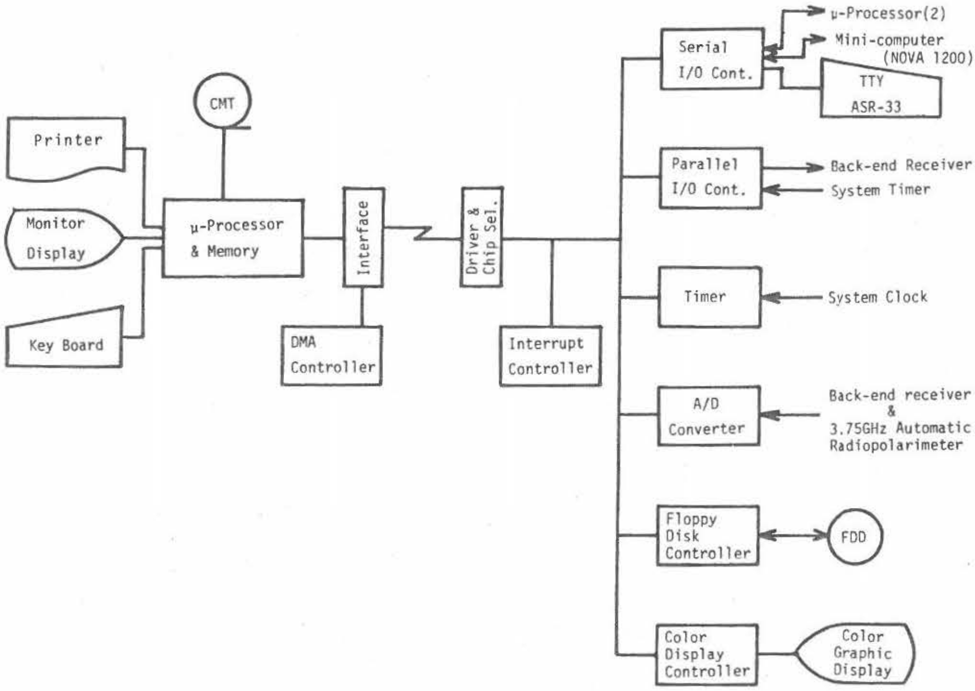


Fig. 2. Block diagram of the micro-processor(1) system.

Micro-processor(2) system

This system controls the front-ends and the 2nd IF's. It is relatively easy to realize this system with a fixed sequential control system using hard-wired logics (a hardware dependent system), but introduction of micro-processor makes this part intelligent and flexible. Procedures in this system are composed of (1) selection of a desired program and (2) its execution. Fig.3 indicates the block diagram of the system. Each module of this system can be regarded as the memory by CPU, and called "memory mapped I/O".

The followings are the items which are controlled or monitored by this systm.

< Control >

(1) ON/OFF of the reference signals for Dicke switching which are transmitted to the front-end receivers.

(2) Switching some IF channels to the matched load at the 2nd IF stages to select antenna combinations.

(3) Presetting of 8-bit digital phase shifters at the 2nd IF stages.

< Monitor >

(1) Temperatures inside the front-end boxes and over-temperature alarms.

(2) Lock-indications of PLO's.

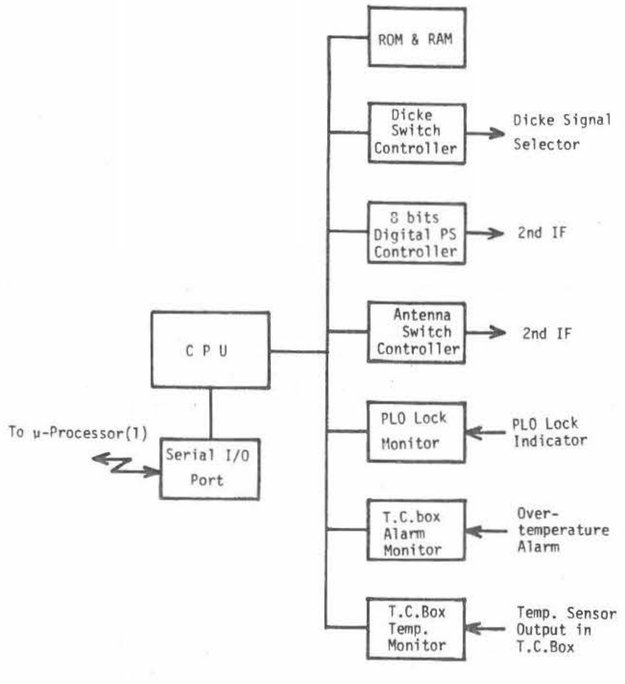


Fig. 3. Block diagram of the micro-processor(2) system.

Communication between the micro-processors

The communications between the two micro-processors are carried out by exchanging ASCII character codes by a serial channel. An idea of using the ASCII character codes for communications is also adopted in GP-IB (or IEEE Standard 488) Interface Bus (Loughry and Allen, 1978). The transmission rate is 110 BPS or 1200 BPS, and it can be selected by manual switching. Usual communications are carried out by the higher rate. A tele-typewriter (TTY) is connected with the lower transmission rate to check both micro-processor systems(Fig.4).

The merits and demerits of this method are as follows:-

< Merits >

(1) Independency of each processor is beneficial to the software management.

(2) Checking of system becomes easy.

(3) Monitoring of the communication channel is easy (because ASCII character codes are used for communication)

(4) Long-distance transmission is relatively easy.

< Demerits >

(1) It is difficult to increase the transmission rate so fast.

(2) (In comparison with the man-machine communication) the "deadlock" tends to happen, in which state the both micro-oprocessors are waiting each other for a command.

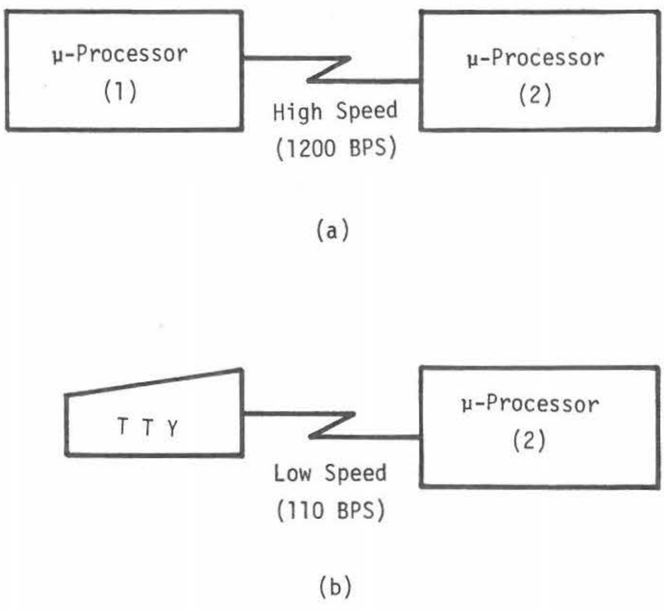


Fig. 4. Serial communication channel between the micro-processor(1) and the micro-processor(2). (a) High Speed Mode (=Normal Mode) and (b) Low Speed Mode. These are selected by manual switching.

4. Software system

The software of this control system is divided into two parts according to the hardware structure. One is stored in the micro-processor(1) system and the other in the micro-processor(2) system respectively. Furthermore, the part of the software in micro-processor(1) system is divided into two sub-parts, one is the main part of the control system and the other is its support system. The block diagram of the software system is shown in Fig.5.

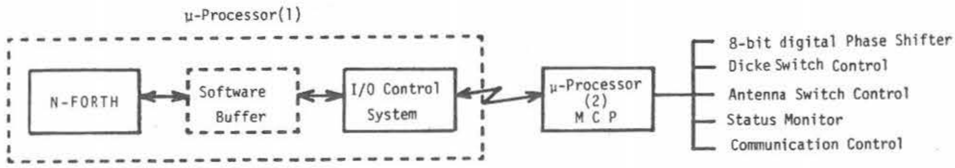


Fig. 5. Block diagram of the software system. MCP is Main Control Program, which combines the each task in the micro-processor(2).

On designing this software system, the following points are considered to increase the performance of the system:-

(1) To be flexible.

(2) To be easy to transfer the software from one machine to another ('transplantable'). Therefore the system is divided into two parts, one depends on the system and the other does not.

(3) To minimize the memory size as much as possible.

(4) To run with high speed as far as possible.

In addition to the above points, the author further considered the following points about the things relating to an operator:-

(1) Syntax is easy to read and learn.

(2) Operators can control the hardware directly and independently.

(3) Checks of erroneous operations are possible.

(4) Definition of words is easy.

(5) Any length of words is possible.

(6) Number of intrinsic variables is as small as possible.

The "N-FORTH" was developed to meet the above requirements.

The program stored in the micro-processor(2) system is made up of many program modules for basic operations.

N-FORTH

The "N-FORTH" is a multi-level language system which covers the range from machine language to high-level language. The machine language makes it possible for operators to control the hardware directly and independently and the high-level language is easy to revise the program. The "N-FORTH" fits the control system. The author developed it with reference to basic ideas of the "FORTH" (Moore 1974). Therefore its syntax and inner structure are similar to those in the "FORTH". The "N-FORTH" has an interpreter and a compiler of high-level language. Therefore an operator can perform flexible operations by the "N-FORTH" and an observer himself can describe his particular problems by the "N-FORTH". The "N-FORTH" is more transplantable than the "FORTH" because it separates the parts which are closely related to the hardware (for example, I/O devices and interrupt controller) from those not and the communications with the I/O devices are executed through a software buffer. Protections to the erroneous operations are more strengthened than the "FORTH".

The basic "N-FORTH" is made up of a combination of various basic operations, for example stack operations, 16-bit arithmetics, error checks, input and output operations of character and number. The machine instructions of the micro-processor are covered by these basic operations (Fig.6). Therefore, the "N-FORTH" is a <u>quasi</u>-interpreter system and runs on virtual stack-machines. Adopting the above structure, "N-FORTH" makes remarkable progress in the 'transplantability'.

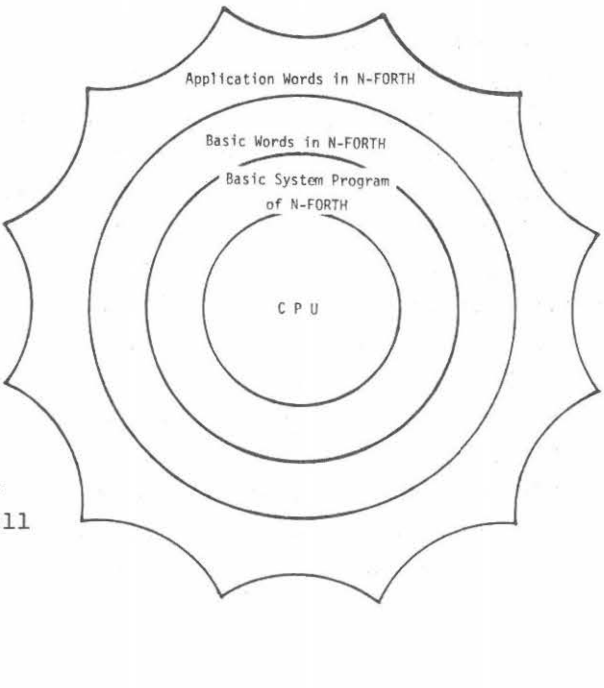
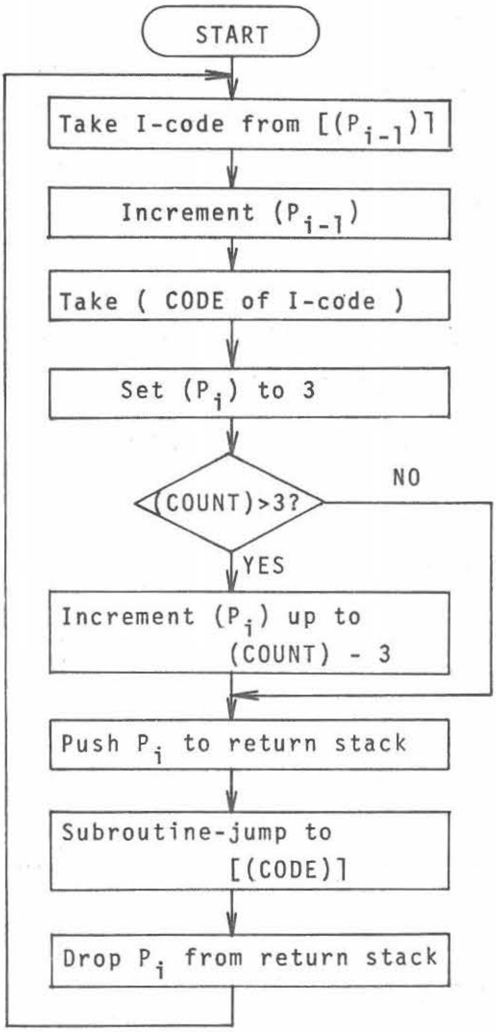


Fig. 6. Basic structure of the "N-FORTH". The "N-FORTH" has a shell structure and is extensible.



( ) means a content of a memory address or a resister.

[ ] means a address defined by a content in the blanket.

I-code is a Intermediate code.

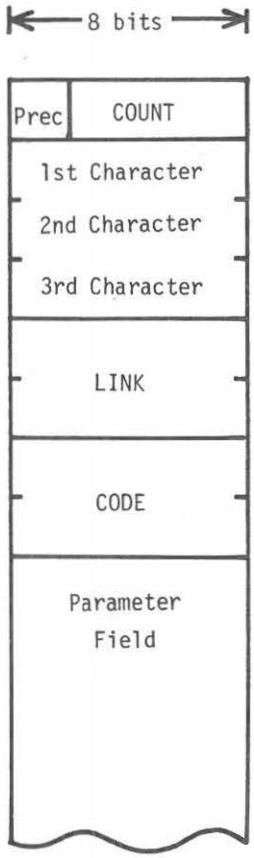
P_{i-1} and P_i are pointers.

Return stack is a stack used in "N-FORTH".

Fig. 7. Flow chart of the low-level interpreter. The low-level interpreter is the fundamental part of the "N-FORTH".

The most important part of the "N-FORTH" is "low-level interpreter". The fundamental structure of the "N-FORTH" is almost determined by this part. Its function is to take an intermediate code from a program module called "word" and call the corresponding system program module. It is also possible to call the low-level interpreter itself. The interpreter has end-less loop structure and is recursive. The flow chart of the low-level interpreter is shown in Fig.7. Therefore, the low-level interpreter interprets intermediate codes and gives instructions to the CPU.

In contrast, the part to manage the communications between the operator and the "N-FORTH" is "high-level interpreter". It translates a "word" inputted by the operator to a form which is readable to the



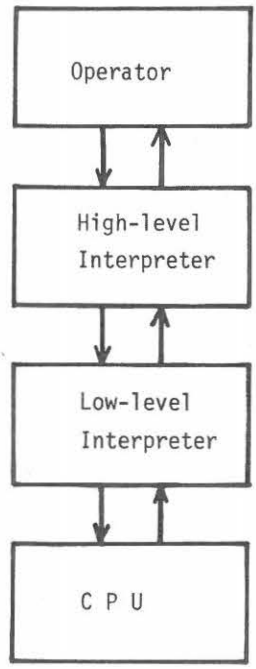


Fig. 8. The relation between the high-level interpreter and the low-level interpreter.

Fig. 9. Structure of a "word" in the dictionary for a 8-bit micro-processor.

low-level interpreter (Fig.8). The high-level interpreter itself is also in such a form as the low-level interpreter can read and run.

The state of the "N-FORTH" consists of three phases, "Executing", "Compiling" and "Assembling". "Executing" is selected when the "N-FORTH" interprets an inputted "word" and executes it immediately. "Compiling" is used to define the "word". For the description of a new "word", all "words" that have been already defined are usable. In this phase, the "word" is not executed immediately, but is stored temporarily in the memory area called "dictionary". The defined "word" can be executed immediately except that it is used in the compiling phase. "Assembling" is used to translate a program to the machine instructions.

The "words" in the dictionary are made in the compiling phase and the assembling phase. These consist of the following fields; Precedence, COUNT, Characters, LINK, CODE and Parameter. The structure of the "word" in the dictionary is shown in Fig.9.

The execution of the N-FORTH is done almost by interpreting the intermediate codes. Therefore it is slower than the direct execution of compiled machine codes. This problem will be resolved by employing a physical memory address as the intermediate code, by programming a part necessary to be fast by the machine instruction ("Assembler") and/or by translating the intermediate codes to the machine instruction codes after optimization.

I/O Control System

This system supports the N-FORTH and treats tasks relating to the hardware, for example I/O control. Its main part is interrupt management programs. The communication between the "N-FORTH" and this system is done through software buffers. The I/O control system is made up of a system start-up program, five kinds of interrupt management program, six kinds of I/O device control program. The block-diagram of this system is shown in Fig.10.

The operator can directly control the I/O devices controlled by the programs shown in Fig.10 through the "N-FORTH". But I/O control programs are made as an independent system, beacuse of the following reasons:

(1) These programs are closely related to the hardware and if these programs are included in the "N-FORTH" these will reduce the 'transplantability' of the "N-FORTH";

(2) These programs are relatively fixed and changes are few;

(3) To treat the concurrent processes.

Each software included in this system is regarded as to be the utility programs to the "N-FORTH". These are connected to the "N-FORTH" by " MLCONNECT " command of the "N-FORTH".

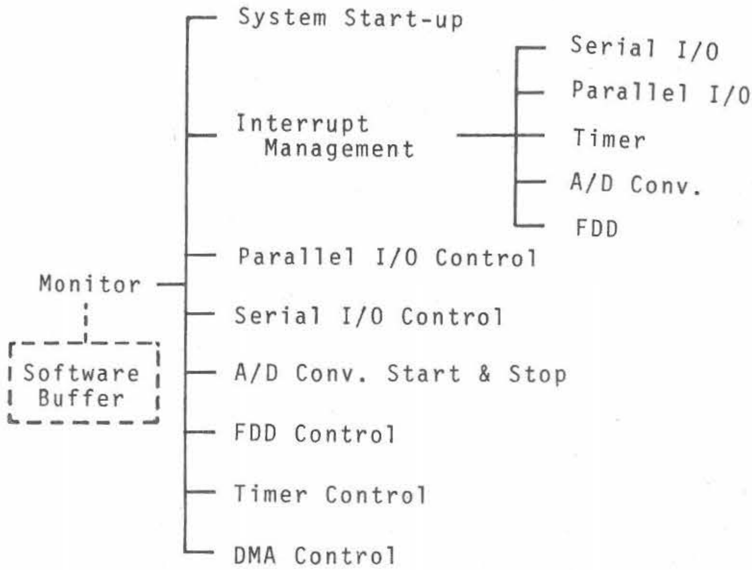


Fig. 10. Basic structure of the I/O control system.

5. Application : The automatic calibration of phase errors

This section describes the automatic calibration of phase errors as an application of the new control system.

This method uses the sun itself as the calibration source. The basic principle is simple but the waveguide branching network in the present system is a burden for this method. The improved radioheliograph system and the new control system makes it more convenient and faster than before.

The calibration procedure is as follows:-

(1) Scan the sun with the interference patterns of the two successive antennas and find the phases, $\phi_{i,i+1}$,of their sinusoidal fringe patterns.

(2) Take the one-dimensional image of the sun with 32-element (or

16-element) synthesized beam and perform the Fourier transform to find the phase, ϕ_0 , of the fundamental Fourier component. The fundamental spatial-frequency component of the grating interferometer is a vector sum of the responses of 31 (or 15) antenna pairs. If the phase error of each antenna pair is small and random, the resultant vector sum will contain less phase error. Therefore, the phase of the fundamental Fourier component of the image can be considered as that of the true source structure.

(3) Subtract ϕ_0 from $\phi_{i,i+1}$. This treatment eliminates the phase bias due to the source structure and leaves the relative phases between the two adjacent antennas.

(4) Accumulate these relative phases to obtain antenna-based phase errors.

(5) Correct the 8-bits phase shifters according to the result of (4). (In present system, this is done by the manual adjustment

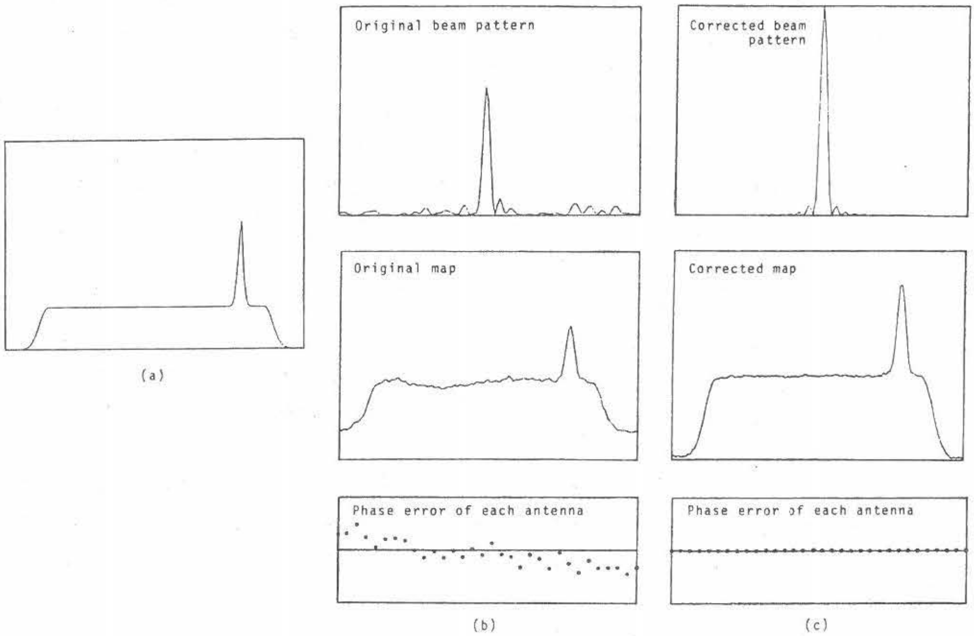


Fig. 11. An example of the computer simulation of automatic phase error calibration. (a) Test data of the solar brightness distribution. (b) Before calibration. The beam pattern and solar map are disturbed. (c) After calibration. The clean beam pattern and solar map are obtained. In this case, the random noise of which standard deviation is 0.5 percent of signal level is added to the signal of each antenna.

of mechanical rotary phase shifters and it takes much time.)
The iteration of above procedure improves the estimation of the phase errors.

Before including this application program in the actual system, the performance is checked by a computer simulation. (Fig.11)

6. Summary

This new control system was designed to contribute the improvement of the λ 8 cm radioheliograph, particularly in the flexibility and the reliability of the whole system.

Some special features about the hardware and the software of this system are

(1) introduction of two loosely coupled micro-processors to separate the control functions and to improve the flexibility of the system;

(2) the use of the standard serial channel and ASCII character codes for the communications between the processors, in oder to make the maintainance and the monitoring of the channel easy;

(3) development of the control language "N-FORTH", which makes the programming flexible and extensible;

and

(4) the concurrent processing.

The "N-FORTH" grows up by itself, because it does not distinguish between system programs and user's programs. Therefore the more it is used, the better it becomes.

To reduce the "deadlock" of the both micro-processors and to increase the speed of calculations are left as future problems. Furthermore a powerful text editor for the "N-FORTH" may be necessary to reduce efforts of programming.

The author believes that this system can bear the various attempts to take more precise and interesting data.

Acknowledgment

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