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FOR USE AT THE NATIONAL SYNCHROTRON LIGHT SOURCE***

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A SPECTROMETER CONTROL SUBSYSTEM WITH HIGH LEVEL FUNCTIONALITY FOR USE AT THE NATIONAL SYNCHROTRON LIGHT SOURCE*

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Abstract

We have developed a subsystem capable of controlling stepping motors in a wide variety of VUV and x-ray spectrometers to be used at the National Synchrotron Light Source. The subsystem is capable of controlling up to 15 motors with encoder readback and ramped acceleration/deceleration. Both absolute and incremental encoders may be used in any mixture. Function commands to the subsystem are communicated via ASCII characters over an asynchronous serial link in a well-defined protocol in decipherable English. Thus the unit can be controlled via write statements in a high-level language. Details of hardware implementation will be presented.

Introduction

The National Synchrotron Light Source at Brookhaven National Laboratory will supply experimenters in many diverse scientific fields with beams of vacuum ultraviolet (VUV) light and x-rays. Almost all of the experiments being planned for the Light Source will require a monochromator for incident wavelength (energy) selection. Many of the experiments will also require a spectrometer for sample and detector manipulation. It is also possible that other optical elements in an experiment beam line may require mechanical adjustment or positioning. While the adjustment of some instrument settings and detector and sample positions will be made so infrequently that manual methods will suffice, it is clear that many experiments will benefit from and even require automated mechanical actuation.

An attempt has been made to define and satisfy the mechanical actuation requirements of as large a fraction as possible of the anticipated experimental devices with a single type of motor control system. An obvious consequence of this approach is that no account can be taken of the detailed dynamic response to actuation of individual mechanical structures. An open loop method of effecting motion must be employed, i.e., closed loop servo techniques cannot be used. A widely used method for implementing open loop mechanical position control is to employ stepping motors with digital encoder position readback. While stepping motors have some well-known drawbacks, i.e., low shaft power, low torque, high power consumption, and susceptibility to vibration during movement, their open loop control property is the dominant consideration and they have been chosen for use at the Light Source. It is believed that the effects of the undesirable properties of stepping motors can be minimized by carefully establishing an allowed range of parameters of their operation and allowing the experimenter to choose parameters within this range. The establishment of a method for setting values (both default and actively specified) for the parameters of stepping motor operation has been considered to be an integral part of the design of the motor controller subsystem. It is important that the

method used for effecting positioning operations be similar to that used for setting values of the parameters of motor operation.

The next section gives operating specifications for a spectrometer motor control subsystem that we believe can be used in "black box" mode for apparatus controlled in a majority of experiments. The subsystem does not represent a universal solution to position control problems because there are specialized functions it does not perform. Some of these specialized functions will be mentioned below.

System Specifications

This section contains a series of specifications which the National Synchrotron Light Source motor controller subsystem meets. The specifications are described starting from the input/output port accessible to the experiment control device and continuing back through the subsystem to the stepping motors and associated encoders. The facilities provided to the experimenter for naming motor-encoder pairs and assigning coordinates to the controlled motions are considered to be of great importance and are therefore discussed in detail.

The experiment control device has supervisory responsibility for data acquisition from and control of all experimental apparatus. This device may range from a simple terminal to a 32-bit computer. A fairly general method for communication between the experiment control device and the spectrometer controller is via an RS-232 full-duplex serial link operating at 9600 baud. All communication over this link is in ASCII characters in a high level protocol in decipherable English. This communication method does not limit system speed since a typical command contains ~ 20 characters, and one is dealing with mechanical systems that are relatively slow. Furthermore, this protocol is an aid in debugging because the experimenter can monitor the information exchange on commercially available RS-232 serial-line logic analyzers. Synchronization between the experiment control device and the spectrometer motor controller requires a handshake response to every command under all conditions. The experiment control device must have error information returned to it in the case of an erroneous command and must have motor controller status information available on command.

The communication protocol must provide a satisfactory way to specify four basic types of information: (1) motor names, character strings for labeling the motor-encoder pairs; (2) coordinate systems, a method of describing position of any motion; (3) function codes, a set of English language mnemonics to specify controller actions; and (4) status indicators, appropriate character strings to specify the status of both the overall system and individual motors within it.

Three modes of addressing the spectrometer control system through the protocol are provided to the user. Each of these modes is termed a position specification mode and has its own motor naming and coordinate

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description conventions. The function code format tends to be independent of mode, while the format of arguments required by the function code changes depending on mode. The three position specification modes are called physical absolute, physical scale, and logical experiment. These are names after the coordinate systems used for motions in each mode.

In physical absolute mode, each motor has a name consisting of a two-digit number associated with the position of physical connection to the control system. There is no logical-name-to-physical-device map provided at this level. The coordinate system provided in this mode is the direct reading of the position encoder. This number has a range of 0 to $2^{24}-1$.

In physical scale mode, the motor naming convention is the same as in physical absolute mode, but the coordinate system is different. Often a physical scale is associated with a motion to provide a visual check of motor position. The physical scale is usually in engineering or scientific units as opposed to encoder units. The spectrometer control system maintains a physical scale coordinate system and associates the physical scale with encoder readings via a linear transformation, which specifies a zero point and a scale factor. Additional information that must be supplied includes the engineering units of the scale (for display purposes) and whether the motion associated with the scale is linear, angular constrained, or angular unconstrained.

Linear physical scale systems increase monotonically from their most negative coordinate to their most positive coordinate. No wrap-around of this coordinate system is assumed. It is assumed that in many cases the correspondence between the physical absolute and linear physical scale coordinate systems associated with an axis can be established in a manner such that the physical absolute (encoder) system also never wraps around. That is, the encoder reading increases or decreases monotonically throughout the entire range of the linear scale coordinate system. However, this is not a necessary condition. The motor controller automatically takes into account encoder wrap-around when computing linear physical scale coordinates.

Angular physical-scale coordinate systems are assumed to wrap around. Thus an additional parameter, the wrap-around point, must be specified for this type of scale coordinate system. The wrap-around point is expressed in physical-scale coordinate units.

Two subtypes of angular physical scale coordinate system are possible. The angular type may be constrained or unconstrained. In the former case, high and low position limit switches act as constraining elements. The limit switches define an angular region of unattainable axis positions. The motor controller takes this region into account when computing the direction of travel to take in order to reach a specified target-position value. The controller also has commands for automatically locating the positions of the limit switches and computing the region of invalid positions.

Just as in the case of linear-scale coordinate systems, the motor controller automatically corrects for wrap-around of the absolute coordinate system even if it occurs within the region of valid scale coordinates.

In the angular unconstrained case, the axis is assumed to contain no limit switches, and hence a complete revolution of the axis may be traversed. However, this

type of scale coordinate system is still considered to be a single-valued function of encoder reading (absolute coordinate). Denote by s_{ps} and o_{ps} the scale factor and offset for this coordinate system. Also let n_{ps} denote the maximum count of the encoder used to coordinate the axis. Then the extrema of the scale coordinate system are (o_{ps}) and $(n_{ps}s_{ps} + o_{ps})$. All physical scale coordinates recognized by the motor controller subsystem lie within this range. The path taken to reach a specified target position is simply the shortest of the two possible paths. The motor controller does not count the number of consecutive (i.e., with no direction change) traversals of the entire axis (see the discussion of axes of the type angular unconstrained with multiple sheets, below).

Logical experiment mode is expected to be the position-specification mode in which experimenters will use the spectrometer control system most of the time. Thus, for ease of use in this mode, the experimenter may refer to each motion by a six-character logical name (e.g., PHI, OMEGA, THETA) within the protocol. This name is also used in the display readouts. This type of flexibility is also provided in determining the logical experiment coordinate system.

The logical experiment coordinate system has "logical" in its name because there will usually be no physical scale by which an experimenter can directly (visually) read out the coordinate which he has assigned to a particular position of his experiment device. For example, if the motions being serviced by the motor controller subsystem are those of a sample under study, the coordinate system with which the user will want to work will be defined by the properties of the sample itself. Thus no physical scale can be easily provided for the coordinate system. The motor controller subsystem will keep track of a logical experiment coordinate for each motor motion.

Logical experiment coordinate systems may have the same sub-types as physical scale coordinate systems, i.e., linear, angular constrained, and angular unconstrained. Each of these requires a scale factor (number of experiment units per encoder unit) and offset (number of experiment units). The angular system also requires a wrap-around point specification. The motor controller automatically corrects for encoder wrap-around anywhere in the range of the logical experiment coordinate system.

One additional coordinate system sub-type may be specified in the case of logical experiment coordinate systems. This sub-type is called angular unconstrained with multiple sheets. In this case the experiment coordinate system does not have to be a single-valued function of encoder coordinate. Coordinate specifications are not reduced modulo one complete axis revolution. The total travel required to reach a target-position value may correspond to several complete revolutions of the axis. This type of coordinate system is provided for those cases where an experiment sample may be scanned through several revolutions of an axis and a cable is wrapped around the axis in the process. The current position of the sample provides the experimenter with an indication of the number of cable wraps and thus allows the cable to be correctly unwound before the next scan is begun. The angular-unconstrained-with-multiple-sheets coordinate system requires no wrap-around point specification.

It is expected that, in most instances, the experiment control device will not display in real time the traffic over the communication link between it and the motor controller subsystem. Thus, to assure the user of proper experiment operation, the subsystem

itself provides the real-time display of the communicated information and, in addition, a display of subsystem current status. The experimenter must also have a display of the positions and status of all motions. This display is useful not only during automatic collection of data but also for manual positioning of the apparatus. Video displays are applicable for both these functions since composite video signals can be transmitted over a coaxial cable to several monitors in series. This configuration gives the experimenter the ability to place monitors at positions appropriate for use during critical manual adjustments.

Although a simple device, something on the order of an ASCII character terminal, can be used as the experiment control device, the actual experiment control device for many Light Source experiments is expected to be a minicomputer which executes complex software routines for experiment control and data acquisition. For these experiments, a simple auxiliary experiment control device would be useful for "manually" manipulating the motor control subsystem. Consequently, every motor controller has been provided with such an auxiliary control in the form of a manual function box. The function box contains switches for manually setting the parameters of motor controller operation and initiating axis positioning commands. A primary switch on the function box sets the active input port to the motor controller subsystem. If the experiment control device solicits a motor control function while the manual controller is active, it receives only an appropriate error message.

Many experiments at the National Synchrotron Light Source will have low level x-ray detectors that are sensitive to electrical noise and interference. One source of such interference can be ground loops in improperly electrically isolated experimental apparatus. A typical experiment has the experiment control device controlling both the x-ray detector and the spectrometer controller. Without high impedance isolation between two of these devices a direct ground loop exists. It is assumed that there will be no electrical isolation between the x-ray detector and experiment control device or between the detector and spectrometer. Thus we isolate the spectrometer motor controller from the motor driver power supplies and the encoder readback electronics by either opto-isolators or RS-422 differential driver/receivers. Unfortunately, RS-232 does not support electrical isolation, but it is such a widespread standard that we have chosen to overlook this failing. The above discussion does not address ground loops between the accelerator and the experiment, which must be eliminated by the experimenter.

The position of a motion translated by a stepping motor can be determined by three methods: (1) the number of steps sent to the motor may be counted directly; (2) the final position of the motion may be checked by accumulating counts from an incremental digital position encoder, and (3) the final position of the motion may be read directly by an absolute digital position encoder. All three methods of position determination are accommodated by the spectrometer motor controller. In all of the above methods, the position of a particular motion is continually updated within the system so this information is available on the real-time display and to the experiment control device via the protocol. The position range in encoder coordinates is 2^{24} .

The spectrometer motor controller is capable of handling up to 15 motors with associated position encoders. Each motor may be moved up to 2^{24} steps on a single command. Mechanical high and low limit points

are provided to protect equipment from possible damage due to system malfunction. The coordinate-system calibration point necessary for operation with no encoder or an incremental encoder is provided by a third mechanically sensed point called home position. An automatic search for this point on any motor is initiated by a protocol command. Mechanical backlash takeup is also provided.

Stepping motors have the unfortunate property that the output torque falls sharply with increasing motor speed up to a maximum where they lose synchronous torque entirely, and the motor stalls. High motor speeds must be approached and reduced gradually to stay within the speed/torque curve of the motor. Thus the spectrometer motor control system has selectable acceleration/deceleration. For a commanded motion, the motor speed increases linearly in time until a speed selected by a protocol command is reached. Towards the end of the commanded motion, motor speed decreases linearly with time so that speed is low at the target position. The acceleration and deceleration rates are equal and are selectable via the control protocol from a set of allowed values fixed at the time of default-parameter-value specification.

It is useful at this point to indicate some functions that the spectrometer motor controller does not support. In some instruments motions tend to be correlated or non-orthogonal, in which case the trajectories of the correlated motions must be specified in time. While the spectrometer control system can move all 15 motors simultaneously, no correlation between trajectories is guaranteed. This property is not a limitation for the majority of instruments where one is dealing with independent rotations and orthogonal rectilinear motions. A similar restriction applies to arbitrary velocity profiles. The system is intended as a position commanded system with velocity and acceleration specified to stay within the dynamic limitations of the instrument being positioned.

Having enumerated the specifications of the motor control system, we will explore the way in which these characteristics are implemented in the following two sections.

Implementation

The position which a motor controller unit will occupy within a Light Source experiment is illustrated in Fig. 1. As mentioned above, a 9600-baud full-duplex serial communication line connects the experiment control device with the "front end" of the motor controller subsystem. At the "back end" of the unit, up to 15 stepping motor power supplies and up to 15 digital position encoders may be connected. These power supplies and encoders are not considered to be part of the motor controller unit. The controller unit supplies TTL-compatible step pulses to the motor power supplies. Encoder readout is via serial communication lines which adhere to the RS-422 electrical signal standard. The encoder-data serializer, which converts the parallel encoder output into serial form, is considered to be part of the motor control unit. It is this relatively small part of the subsystem which must have the most flexibility. The encoder-data serializer must not only accommodate different types of parallel encoder readouts, but must also contain a scaler to handle the incremental encoder case.

The main body of the motor controller is divided functionally into three parts. Each part contains the hardware and software required to carry out the controller subfunctions assigned to it. The functional parts

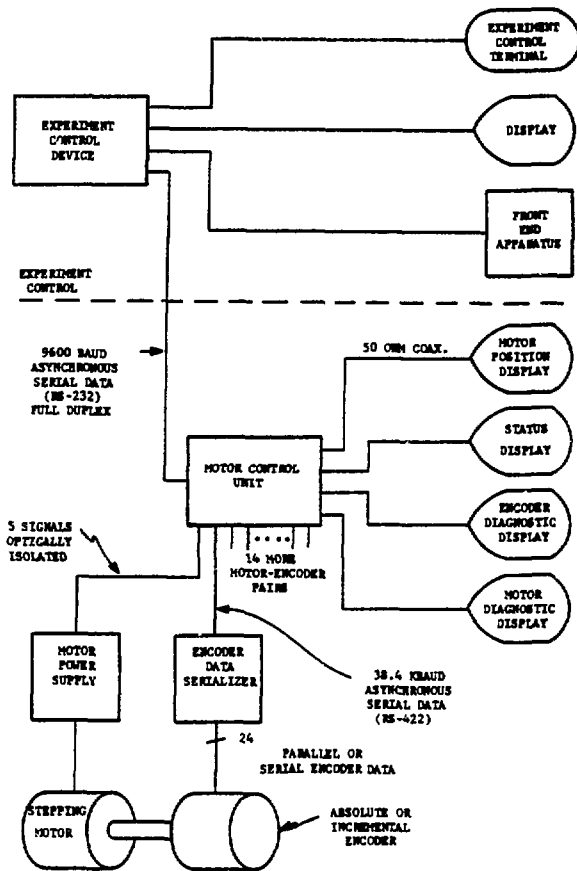


Fig. 1. The interconnection of the spectrometer motor control subsystem between an experiment control device and a spectrometer.

share the power, cooling, and structural support elements of the chassis box. The three parts utilize the shared memory subsystem for intercommunication.¹

The first part of the main body of the motor controller is the protocol handler section. This part handles communication with the experiment control device (and the manual function box) and decodes the submitted function codes. The protocol handler is also responsible for converting the ASCII fields of motor label and position values into internal binary representation (and vice versa for returned output information). This functional unit also generates two video displays which show the status of the control unit as a whole. Included in these displays are the lines of ASCII characters received and transmitted over the serial communication links. Figure 2 shows a typical example of these displays for the test case of two motor-encoder pairs. In the example the position-specification mode of the subsystem is "logical experiment". If a motor-positioning operation is to be performed, the protocol handler passes the position parameters, in binary form, to the next part of the unit, the motor driver subsystem.

The motor driver section uses current and target position value information to compute motor travel



Fig. 2(a) Examples of spectrometer motor control subsystem position display.

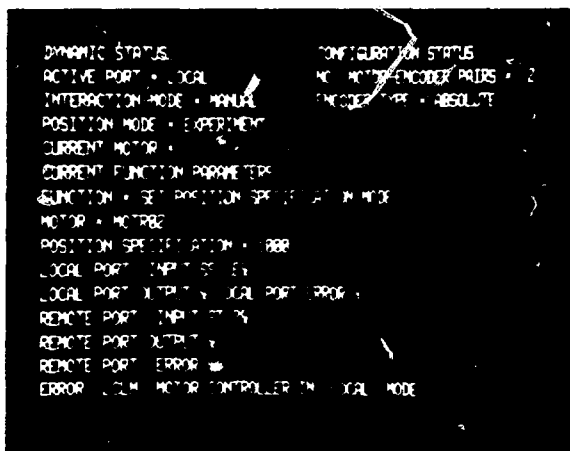


Fig. 2(b) Subsystem status display.

values and generate the required number of step pulses for the motor power supplies. The motor driver section is further partitioned into lower level functions by having individual functional elements for each motor. These functional elements are capable of handling complete motor move operations (with acceleration, deceleration, and backlash takeup) once they are provided with the motor travel and maximum stepping velocity parameters. These elements also handle readout of limit switch and home switch information. Hardware used to implement these lower level functional units includes an Intel 8085 microprocessor and associated support chip elements; the software consists of approximately 1000(8) bytes of Intel 8085 assembly language code.

In order for the protocol handler subsystem to obtain a current position value, or for the motor driver subsystem to compute the total travel required for a motor move, the encoder associated with a motor must be read out. This function is performed by the encoder

reader section, which reads back the current encoder values (either continually or upon demand) and converts the returned bits into standard internal binary representation. A display of current position in absolute encoder units is also generated.

The hardware associated with each of the three parts of the motor controller unit consists of a DEC LSI-11/2 processor, a variable size RAM memory module, and a video display unit. These elements are shown in Fig. 3. In addition, the motor driver section contains as many as fifteen of the motor drive elements described above. The encoder reader section utilizes the DEC DL^r-11J serial line units for encoder readback.

Each of the three sections also contains an access port for reading and writing memory locations within the shared memory module. This module is used both for interprocessor communication and for storage of a common database of motor drive and encoder parameter information. The design and operation of the shared memory system have been discussed in detail elsewhere.

The software associated with each section of the motor controller subsystem consists of a FORTRAN main program and a host of subroutines written in FDP-11 assembly language. Only the control and program organization properties of the FORTRAN language have been utilized. All of the format conversions required have been programmed in assembly language because of speed requirements.

The code for each processor is stored in a read-

only section of shared memory. On subsystem utilization (by means of a switch located on the front panel of the subsystem chassis box), the code is brought into processor-local memory by a small bootstrap program in each processor. Thus subsystem initialization does not require that the experimenter manually position any external media on a subsystem peripheral device. In an alternative method of subsystem initialization, the experiment control device may send a TTL-compatible pulse to an input provided on the motor controller subsystem. It is expected that most computer controlled experiments at the Light Source will utilize this second method.

Control Protocol Organization

As mentioned above, the experiment control device interacts with the motor control subsystem via a full-duplex serial-communication line operating at 9600 baud. The electrical signal levels and designations utilized for communication over this line adhere to the RS-232 standard. The marks and spaces defined by this standard are communicated in groups of eight data bits; the groups are interpreted according to the ASCII character standard.

Thus the basic elements of the control protocol are ASCII characters. As a result, any device capable of generating ASCII characters on a serial line may serve as the experiment control device. In the simplest case, the experiment control device may be an inexpensive character-oriented terminal.

The next higher level of the communication protocol

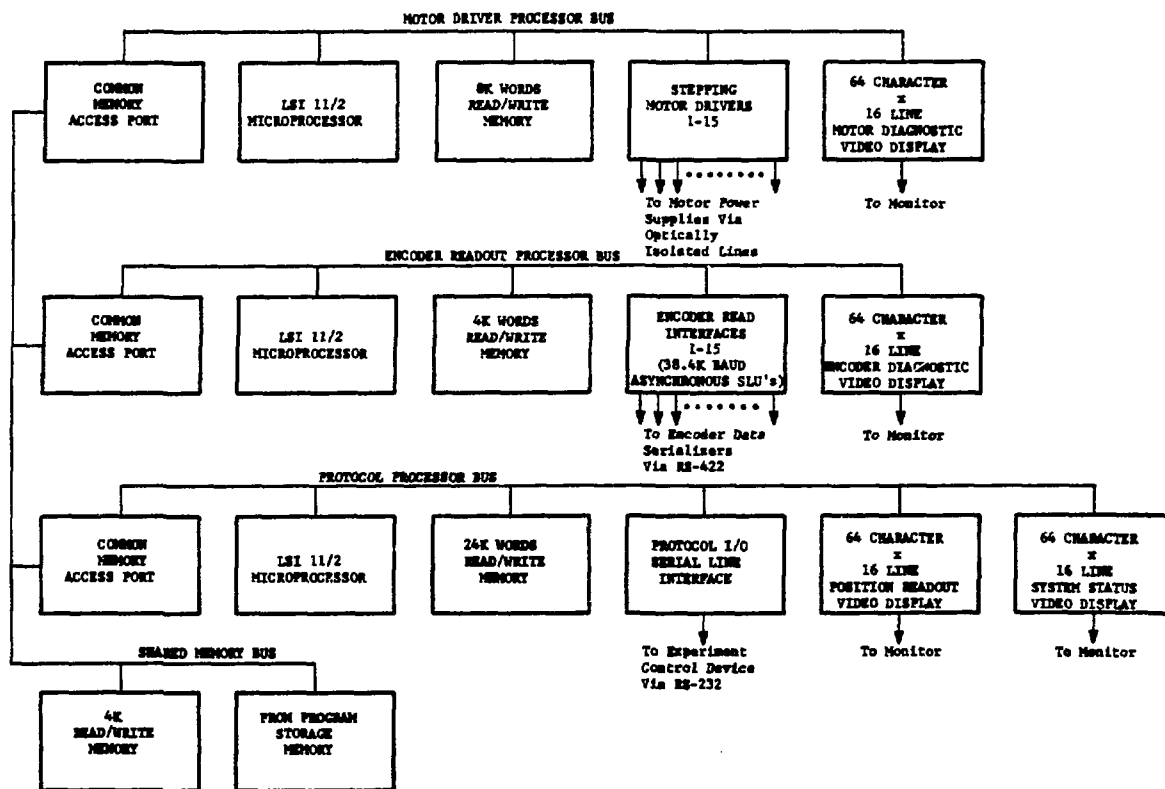


Fig. 3. Block diagram of the spectrometer motor control subsystem showing three microprocessor controlled sections sharing a common memory.

is a group of ASCII characters referred to as a line. The line may contain up to eighty characters and is terminated by the two-ASCII-character sequence <carriage return> followed by <line feed>. The typical command line directed to the motor control unit contains approximately twenty characters.

The complete command protocol used with the motor controller consists of a total of three lines. The first line is termed the request line and is transmitted from the experiment control device to the motor control unit. The request line specifies the function that the motor control unit is requested to perform. The line also contains arguments associated with the requested function. Typically, these arguments are a motor label and a position specification. The motor control unit transmits the second and third lines of the command protocol back to the experiment control device. The second line is termed the response line and typically contains position or status information solicited in the request line. If the particular command implies no explicit information be returned in response, the response line still appears, but contains no data characters and thus consists of only the <carriage return> and <line feed> pair.

The third line of the command protocol contains error information. The error line is always present; if no error is detected during performance of the requested function, an empty error line is returned. Typically, errors result from specification of invalid motor-encoder-pair labels and from erroneous formats for position values. A common error during use of the motor controller with a computer as the experiment control device might be an attempt by the computer to request a motor controller function while the subsystem is in local mode, i.e., while it is responding to commands from the manual function box.

The choice of a communication protocol as a series of lines of ASCII characters has two major advantages. The first advantage is that the motor controller appears as a simple ASCII terminal to the experiment control device, and vice versa. Since most computer operating systems have highly developed routines for carrying out input/output operations from/to character terminals, development of software for communicating with the motor control unit should be a relatively straightforward task. As an example, motor control software for an experiment control computer system which supports the FORTRAN language could be written using FORTRAN READ and WRITE statements. Conversely, since the experiment control device always appears as a character terminal to the motor control unit, the experiment control device, no matter what its level of complexity, can always be replaced by a simple character terminal. Such a replacement may be very beneficial during initial experiment set-up and later diagnosis of motor controller (or computer) failure.

The second advantage of the protocol is that it lends itself easily to continuous monitoring of motor controller operation. Since the part of the motor controller unit which handles the communication protocol is equipped with a character-oriented video display, it is a simple matter to display every incoming character as it is received and to display every outgoing character immediately prior to its transmission. This immediate display of the motor controller communication dialogue is expected to be very useful in diagnosing motor controller (or experiment control device) failures, especially if a large number of motor control units are placed into operation.

The disadvantage of serial, character-oriented

communication lines usually cited, namely insufficient speed, does not apply here because of the overall functional definition of the motor control unit. Since the overall function of the unit is the positioning of relatively simple mechanical devices, the small part of the total function time spent in communication with the external device is not a factor detrimental to its operation.

The command request line is divided into fields in the usual manner. Fields are delimited by space characters. The first field in the command line is the two-character function code. The function code determines how the fields which follow (if any) are to be interpreted.

Function codes which change the status of the motor controller as a whole require either no or only one additional argument. These function codes, their associated arguments, and a short description of their effect on the motor controller subsystem are shown in Table I. The most important of these is the function (SM) which changes the position specification mode of the controller. The current position-specification mode determines the format of all position values recognized by the controller as well as the motor-encoder pair labels (names). The initialize (IT) and finalize (FN) commands are included so that a program operating in a programmable experiment control device may place the motor controller in a known state (with respect to its default parameter values) at the beginning and end of its execution. Once the controller is in a known state, modifications (if any) to the default parameter values of any motor-encoder pair can be carried out automatically in a well-defined manner.

Function codes which request operations on individual motor-encoder pairs are listed in Table II. These function codes are typically accompanied by motor labels and position values (which must be in the format dictated by the current position-specification mode). In Table III are shown function codes for operations functionally similar to those in Table II, but with the difference that the requested operation is carried out for all motor-encoder pairs serviced by the controller unit.

Note that the times required to perform motor positioning operations divide the motor controller functions quite naturally into two main classes. Some functions, such as obtaining status information and changing parameters of operation, can be performed in a time interval of 10-100 milliseconds. The positioning operations themselves can require many seconds for their completion. Since the experiment control device in many instances is expected to be a programmed computer, it is possible that the control device can be performing other tasks while a motor (or motors) is moving toward its target position. Hence the motor positioning commands have been broken up into the usual pair of commands corresponding to "start operation" and "check status". Motor-encoder pairs may be started toward their target or home positions and then checked periodically to determine if they have arrived at these positions. Thus a function with a long completion time is converted into two functions with completion times consistent with other functions in the set. Alternatively, the experiment control device may still request the "move motor to target position" or "move motor to home position" function. These functions wait for completion of the motor-control-system process before returning the response and error lines.

Results

A prototype motor controller subsystem, using a

wire-wrapped version of the motor driver board, has been operated intermittently with a Lear Siegler ADM-3A terminal as the experiment control device since March of 1980. Construction is well underway of a second wire-wrapped model to be used at the BNL Biology x-ray small-angle scattering experiment station at the National Synchrotron Light Source. This second model is scheduled for completion in October, 1981 to coincide with the start of x-ray experiments at the Light Source. Funds for four additional units have recently been allocated and their construction has begun. These latter four units will incorporate a printed circuit version of the motor driver board.

Reference

1. D. G. Dimmler and W. H. Hardy, II; IEEE Trans. Nuc. Sci. NS-24, 1 February (1977) 469-475.

<u>FUNCTION</u>	<u>FUNCTION CODE</u>	<u>ARGUMENTS</u>	<u>EFFECT ON MOTOR CONTROLLER SUBSYSTEM</u>
Initialize	IT	None	All subsystem parameters of operation assume their default values.
Finalize	FN	None	All motor motion ceases. The overall status of the subsystem becomes 'FINAL' and the subsystem will accept no other function requests until it has been initialized.
Set Position Specification Mode	SM	PA, PS, or LE	The position specification mode of the subsystem is set to physical absolute, physical scale, or logical experiment. The position specification mode determines the format of motor labels and position values.

TABLE I. MOTOR CONTROLLER SUBSYSTEM FUNCTIONS WHICH AFFECT THE STATUS OF THE ENTIRE SUBSYSTEM

<u>FUNCTION</u>	<u>FUNCTION CODE</u>	<u>ARGUMENTS</u>	<u>EFFECT ON MOTOR CONTROLLER SUBSYSTEM</u>
Set Target Value Position	TV	<Motor Label> and <Position Value>	The position value to which the motor is to move on its next START MOTOR command is set.
Start Motor Toward Target Position Value	ST	<Motor Label>	The specified motor-encoder pair is started toward its target position value. In general, the motor will still be in motion when the response and error lines have been returned to the experiment control device.
Start Motor Toward Home Position Value	SH	<Motor Label>	The specified motor is started toward its home position value. No motion results for motor-encoder pairs having absolute encoders.
Stop Motor	SP	<Motor Label>	The specified motor-encoder pair is stopped. Once a motor has been stopped, it may be assigned a new target value.
Get Motor Position Value	PV	<Motor Label> (Position Value Returned)	The current position value of the specified motor-encoder pair is returned in the response line. The motor may be moving when its current position value is obtained.
Get Motor Status	MS	<Motor Label> (Motor Status Returned)	A series of eleven "T" or "F" characters is returned in the response line. The characters represent logical "true" or "false" values for the following logical variables as applied to the specified motor: moving, moving toward target, moving toward home, located at target, located at home, located at clockwise limit, located at counterclockwise limit, located at minimum limit, located at maximum limit, unable to reach target, and unable to reach home.
Move Motor To Target Position Value	MT	<Motor Label> and <Position Value>	The specified motor-encoder pair is moved to the specified target position value. The response and error lines are not returned until the target position value is reached.
Move Motor To Home Position Value	MH	<Motor Label>	The specified motor-encoder pair is moved to its home position value. The response and error lines are not returned until the home position is reached.

TABLE II. MOTOR CONTROLLER SUBSYSTEM FUNCTIONS WHICH AFFECT THE STATUS OF INDIVIDUAL MOTOR-ENCODER PAIRS

<u>FUNCTION</u>	<u>FUNCTION CODE</u>	<u>ARGUMENTS</u>	<u>EFFECT ON MOTOR CONTROLLER SUBSYSTEM</u>
Start Toward Target Position All Motors	TA	None	All motor-encoder pairs serviced by the subsystem are started toward their target position values.
Start Toward Home Position All Motors	HA	None	All motor-encoder pairs serviced by the subsystem are started toward their home position values.
Get Status of All Motors	GA	None (Logical "OR" of status of all motors is returned.)	A series of eleven "T" or "F" characters is returned in the response line. These characters represent logical "true" or "false" values for the inclusive OR function over all motor-encoder pairs serviced by the subsystem of the logical variables listed under the "MS" command, above.

TABLE III. MOTOR CONTROLLER SUBSYSTEM FUNCTIONS WHICH AFFECT THE STATUS OF ALL SUBSYSTEM MOTOR-ENCODER PAIRS