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CONTROLLER AND SOFTWARE DEVELOPMENT FOR THE XM91 AUTOLOADER

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Some of the important aspects of Benet Laboratories controller/software package developed for the XM91 autoloader are presented and summarized in this report. Consideration is given to the transfer of technology from research to development of the servocontrol approach used and to the characteristics and features of the developed software with a discussion of lessons learned. The controller/software package has been used for the overall development and testing of the mechanical, electrical, and electronic elements that make up the autoloader.

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INTRODUCTION

The XM91 autoloader was successfully demonstrated 57 times at the U.S. Army Technology Show held at Aberdeen Proving Ground, MD, from 1 to 4 October 1990. Each demonstration included both a loading and downloading of a full-length 140-mm dummy round of ammunition in a full-size gun. The demonstrations were attended by numerous dignitaries from the press, military, Department of Defense, and Congress.

The successful development and demonstration of the autoloader included important efforts in design and fabrication of mechanical, electrical, and computer software components and subsystems. This report describes key elements in the development of the controller/software package, which has been used in the overall development and testing of the physical autoloader. Descriptions of the mechanical, electrical, and electronic characteristics of the autoloader are planned for future reports. In addition, see Reference 1 for a physical description of the autoloader.

The autoloader controller is embedded in a general software package that contains a number of other features not directly related to control functions. First, this report presents a discussion of the main software/hardware elements that relate directly to control functions. Emphasis is given to the transfer of technology from research to development of the servocontrol approach used. Secondly, some of the interesting and important characteristics of the overall software package are discussed to provide a summary of lessons learned for future software development projects.

The remainder of this report is summarized as follows:

<u>CONTROLLER</u>:

<u>Data Acquisition</u>. Real-time digital and analog input/output computer boards were used in an IBM-compatible PC to communicate with the motors,

encoders, actuators, and sensors.

Servocontrol. Algorithms were developed for servocontrol of the critical autoloader subsystems which include the rammer mechanism, telescoping cell, and the 17-cell magazine. The primary approach used was switching zone control (SZC).

Multitasking of Events. Time slicing was used to run more than one event at the same time.

OTHER SOFTWARE FEATURES:

Source Code Written in C. C was chosen to prepare all development software.

Continuous Updating of Sensor Status. Selected sensors and output commands were updated on the screen continuously to provide the operator with real-time autoloader status.

Pull-Down Menus. A pull-down menu approach was chosen for versatility, speed, and user friendliness.

Malfunction Handling Procedure. A uniform malfunction or error handling procedure was adopted to standardize corrective actions when failures occur during autoloader operations.

On-Line Processing. All critical variables and parameters were kept in an individual file on hard disk; the file can be edited during program execution.

Other User-Friendly Features. Other software features that facilitate operations are listed.

The work on software development and applications to the autoloader was facilitated with the use of the faster 386 chip-based IBM-compatible PC with at least 1 million bytes of RAM. The faster speed was required for multitasking operations and the larger RAM proved helpful in compiling some of the larger software modules.

CONTROLLER

Most of the control logic for operating the autoloader is contained in software. This includes control logic for individual events as well as sequencing of events to make up more complicated functions such as loading or unloading a round of ammunition. Table I is a partial list of autoloader events for which software has been written. A detailed list of subevents for conducting, for example, a single-step load is shown in Table II. Other details and event lists are given in Reference 2.

TABLE I. PARTIAL LIST OF AUTOLOADER EVENTS

1. Auto Load: KE Round	16. Engage Rearm Supports
2. Auto Load: HEAT Round	17. Round Inventory
3. Manual Mode: Rammer	18. Open Chain Lock
4. Manual Mode: Inner Cell	19. Close Chain Lock
5. Manual Mode: Magazine	20. Move To KE Round
6. Motor Fault Status	21. Move To HEAT Round
7. Special Demo Program	22. Move To Empty Cell
8. Go Home And Reset	23. Move To Specified Cell
9. Open Blast Door	24. Raise Case Catcher
10. Close Blast Door	25. Lower Case Catcher
11. Engage Warhead Supports	26. Open Breech - Fast
12. Release Warhead Supports	27. Open Breech - Slow
13. Grip Ammo Sequence	28. Close Breech
14. Ungrip Ammo and Go Home	29. Open Breech - Positive
15. Check Clock Trigger	

TABLE II. SEQUENCE OF EVENTS FOR SINGLE-STEP LOAD

```
Begin

        Inhibit Fire
        Send gun to load angle
        If the proper round is not at the ram position
            - Release chain lock
            - Rotate ready magazine to advance desired round
              to ram position
            - Engage chain lock
        Check gun at load angle
        Extend ramhead to cylinder seat
        Release ram warhead supports
        Check gun in battery
        Check gun at load angle
        Engage gun elevation lock
        Inhibit gun elevation
        Engage low speed valve
        Open breech - slow
        Raise case catcher - slow
        Release low speed valve
        Open blast door
        Check path clear
        Check chamber empty
        Ram the round
        Retract ram head to home position - long
        Close breech
        Lower case catcher
        Release gun elevation lock
        Permit gun elevation
        Send gun to target angle
        Close blast door
        Release chain lock
        Rotate ready magazine to next desired round
        Permit fire

End
```

In the remainder of this section, communication between the computer and the autoloader electronics, servocontrol approach used for operating the motors, and multitasking requirements for running some events simultaneously are considered.

Data Acquisition

A short discussion is presented here on how the computer communicates in real-time with the autoloader electronics. This communication is accomplished through using data acquisition (DAC) boards that can be installed directly into a computer expansion compartment. These boards are comprised of integrated circuitry for sending out or reading in digital (on/off) or analog (continuous voltage) signals in real-time in response to computer software requests. Figure 1 is a schematic diagram of this interaction. An operator can select events or functions which can be communicated to the software using, for example, the keyboard. The software, in turn, interfaces with autoloader electronics and eventually with the hardware via the DAC boards.

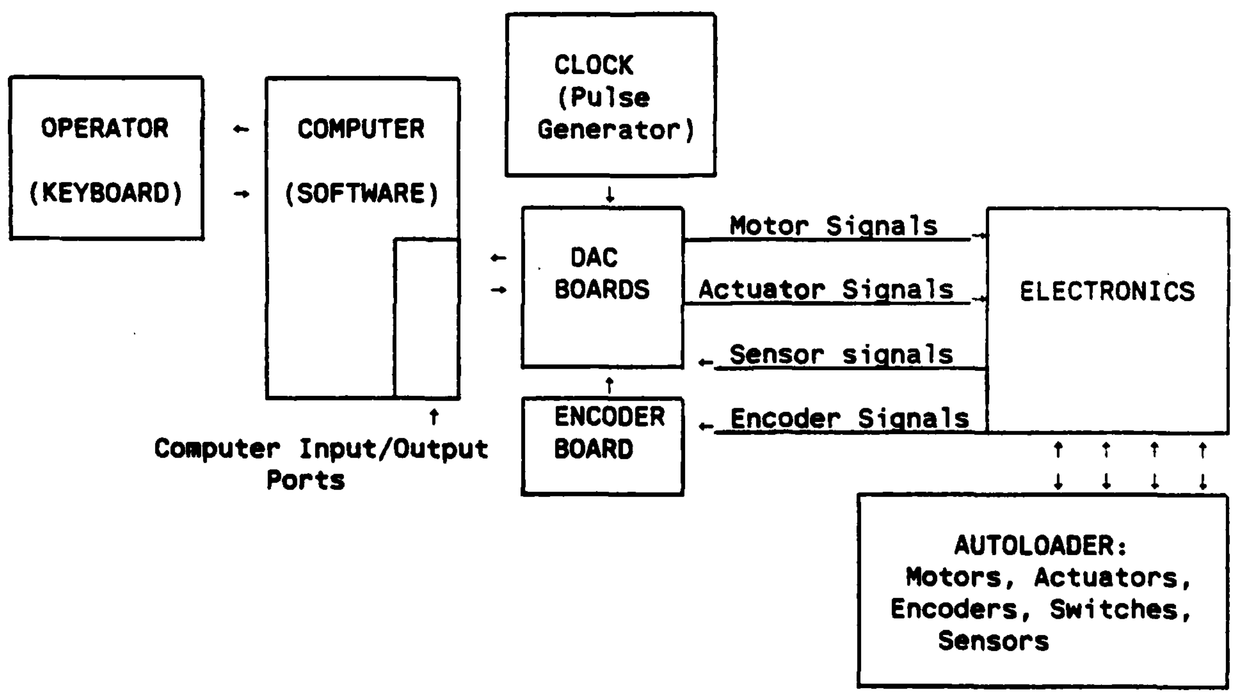

Figure 1. Data acquisition and computer interaction.

The kinds of signals that can be handled include (1) analog voltage outputs for running servomotors; (2) analog voltage inputs for reading sensors such as tachometers or thermocouples; (3) digital outputs for turning on or off some actuators such as solenoids; and (4) digital inputs for reading on/off types of sensors or switches. Signals from position encoders that monitor angular positions or distances can be sent to a separate computer board which deciphers the encoder signals and, in turn, passes the information directly to the computer or the DAC boards as a digital number. The timing for the entire control process is accomplished using an external clock or trigger for real-time sequencing.

A set of software functions, called driver functions, was written to handle input and output of control signals. These functions greatly simplify software preparation for performing all of the required events. Whenever a signal is to be sent out or read in, a subroutine is called which reads and/or writes information to the DAC boards.

The commercial DAC boards used in the XM91 autoloader were Data Translation DT2801 and DT2821 and Industrial Computer Source AOB12 and DIO216. Our experience so far indicates that the Industrial Computer Source boards were easier and faster to use than the Data Translation boards for comparable operations.

Servocontrol

One of the more important and significant characteristics of the controller developed for the XM91 autoloader was the use of SZC to operate the four servomotors. Two motors were for the rammer, one for the telescoping cell, and one for the 17-cell magazine. Research was previously conducted at Benet Laboratories to study the usefulness and limitations of SZC in the area of robotics and flexible systems (refs 3,4). This technology, along with lessons learned in prior applications, was directly transferred to the autoloader project.

SZC is a nonlinear feedback controller with the following characteristics (refs 5-8):

1. It is a near-minimum time controller which approaches the bang-bang minimum time controller in the limit.

2. Peak torques for motors can be specified to prevent excessive loads and/or saturation problems.

3. An optional maximum velocity can be specified to prevent runaways and excessive vibrations or motions.

4. It can be made as robust as desired by specifying and accounting for maximum disturbing forces derived, for example, from sources such as gravity, time delays, other coupled degrees of freedom, and changing masses.

The SZC approach eliminates the usual problems of overshoot and instability inherent in high gain linear feedback systems where saturation of motors and/or amplifiers becomes a problem.

The basis of SZC is the time optimal bang-bang theory where maximum effort is applied by motors in both negative and positive directions (accelerating and decelerating phases) to move a mechanism from one state or position to another in minimum time (refs 5-7). Instead of a switching boundary, as used in the bang-bang approach, a switching zone is used wherein the torque varies linearly. Outside this zone, the torque takes on the maximum allowable values as in bang-bang.

As will be shown shortly, there is a price to pay for the added advantages and features of SZC over linear feedback control. The price is that more parameters are required and need to be calculated or determined empirically when applied to a specific system. However, one of the biggest advantages of applying SZC to the autoloader has been the ability to use the smallest motors possible along with the least amount of peak and total electrical energy for specified or required minimal operating times. These advantages are worth spending a little more effort on parameter determination.

The remainder of this section is divided as follows: theory; derivation of controller parameters; integrator term for higher accuracy; and software implementation.

Theory

The dynamic system, which is comprised of a moving mass and various forces acting on the mass, is assumed to be a simple second-order system

$$J \ddot{x} = u_d + u \tag{1}$$

where J = system mass

x = position of the mass

u = motor force applied to the mass J

u_d = disturbing force which includes gravity, friction, coupling effects, etc.

A schematic diagram of the nonlinear switching zone controller is shown in Figure 2. The theory behind this controller and the derivation of the different control blocks are given in References 5 through 8. Only the final results are given in this report.

The 'plant' in Figure 2 is assumed to be the second-order system, Eq. (1). The variable x_r in the figure is the desired reference distance in which the mass J is to be driven to by the motor forces. The term e is the error term which is the difference between the desired and actual positions. The nonlinear blocks N_1, N_2, N_3, and N_4 are defined as follows (ξ = input variable, η = output variable):

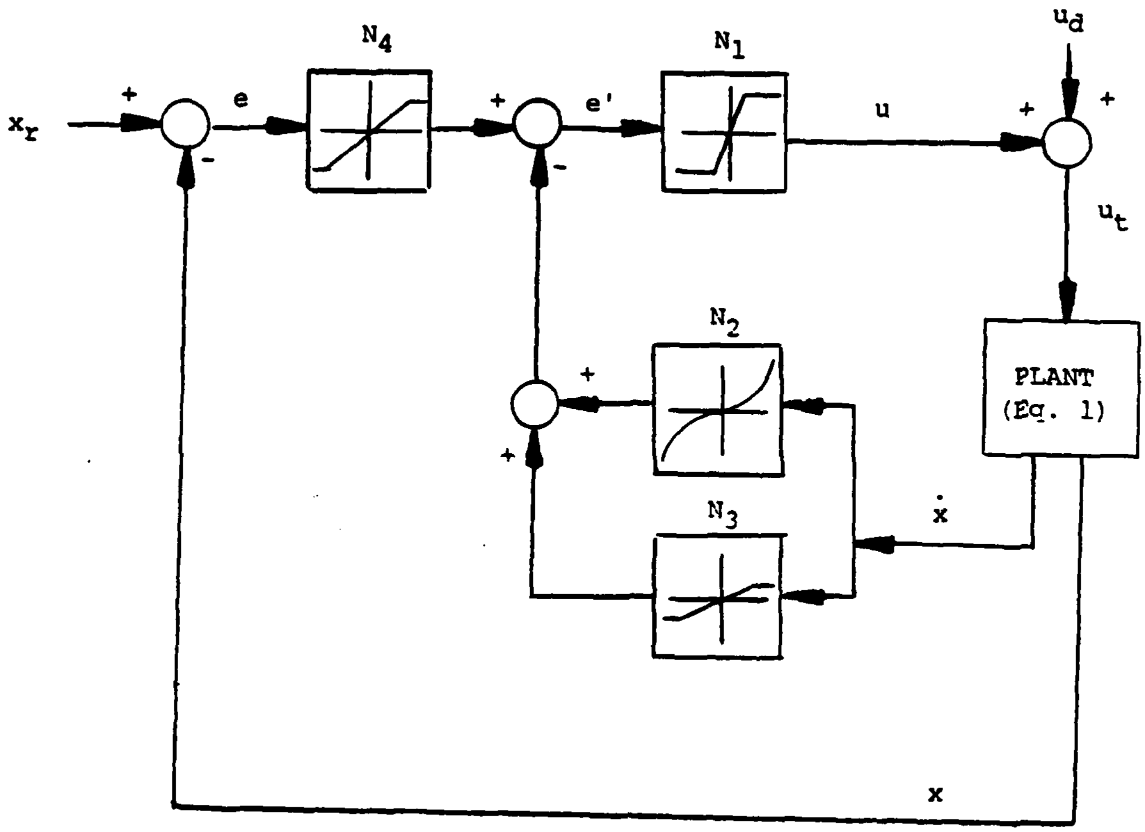

Figure 2. Block diagram of SZC system.

$$N_1: \begin{cases} \eta = k_1\xi & \text{for } |\xi| \le u_m/k_1 \\ \eta = u_m & \text{for } \xi > u_m/k_1 \\ \eta = -u_m & \text{for } \xi < -u_m/k_1 \end{cases} \quad (2)$$

$$N_2: \quad \eta = \frac{J_m}{2au_m} |\xi| \xi \quad (3)$$

$$N_3: \begin{cases} \eta = k_2\xi & \text{for } |\xi| \le b/k_2 \\ \eta = b & \text{for } \xi > b/k_2 \\ \eta = -b & \text{for } \xi < -b/k_2 \end{cases} \quad (4)$$

$$N_4: \begin{cases} \eta = \xi & \text{for } |\xi| \le \xi_1 \\ \eta = \xi_1 & \text{for } \xi > \xi_1 \\ \eta = -\xi_1 & \text{for } \xi < -\xi_1 \end{cases} \quad (5)$$

The constants J_m, u_m, a, b, k_1, k_2, and ξ_1 in Eqs. (2) through (5) are the controller gains and parameters that need to be specified by the designer. These constants for the system described by Eq. (1) are defined theoretically as follows:

J_m = dynamic mass where 'm' denotes the maximum value

u_m = specified maximum motor force or torque

a = nonlinear function term selected to guarantee sufficient force for deceleration,

= $(u_m-u_{dm})/u_m$ where u_{dm} is the maximum value of the disturbance force u_d (6)

b = constant selected to guarantee no overshoot,

= $\max(u_m/k_1 \text{ or } k_2au_m\lambda_1/(k_1(\lambda_1k_2-1)))$ (7)

$$\text{where } \lambda_1 = \frac{k_1k_2 + \sqrt{(k_1k_2)^2 - 4k_1J}}{2J} \quad (8)$$

k_1,k_2 = positional and velocity gains where

$k_2 \geqslant 2\sqrt{J/k_1}$ is required for no overshoot when there is no friction (9)

ξ_1 = $b + J_mv_m^2/(2au_m)$ (10)

where ξ_1 is essentially determined from the specified maximum velocity v_m.

The maximum force u_m can be specified arbitrarily or can be fixed based on the motor and amplifier specifications. The positional gain k_1 is fixed high and is limited primarily by the requirement for no system chatter or instability, which are common effects in pure bang-bang control. Infinite gain k_1 reduces the control to switching boundary which is bang-bang.

A better understanding of the SZC characteristics can be obtained by examining the resulting phase diagram for the second-order system. Figure 3 is a phase diagram plot of $\dot{x}$ versus x where u_d in Eq. (1) is assumed to be zero. The controller in this case is designed to drive any given nonzero state toward the origin. The origin is assumed to be the desired new position which gives $x_r = 0.0$ in Figure 2. For example, if the initial state in Figure 3 starts at point A, the full maximum force $u = u_m$ is initially applied. The path then eventually enters the zone between full negative and positive forces. Once in the zone, the state is captured and is driven to the origin with little or no overshoot (see Reference 5 for details). Starting at any other point in the phase diagram should also drive the state toward the origin.

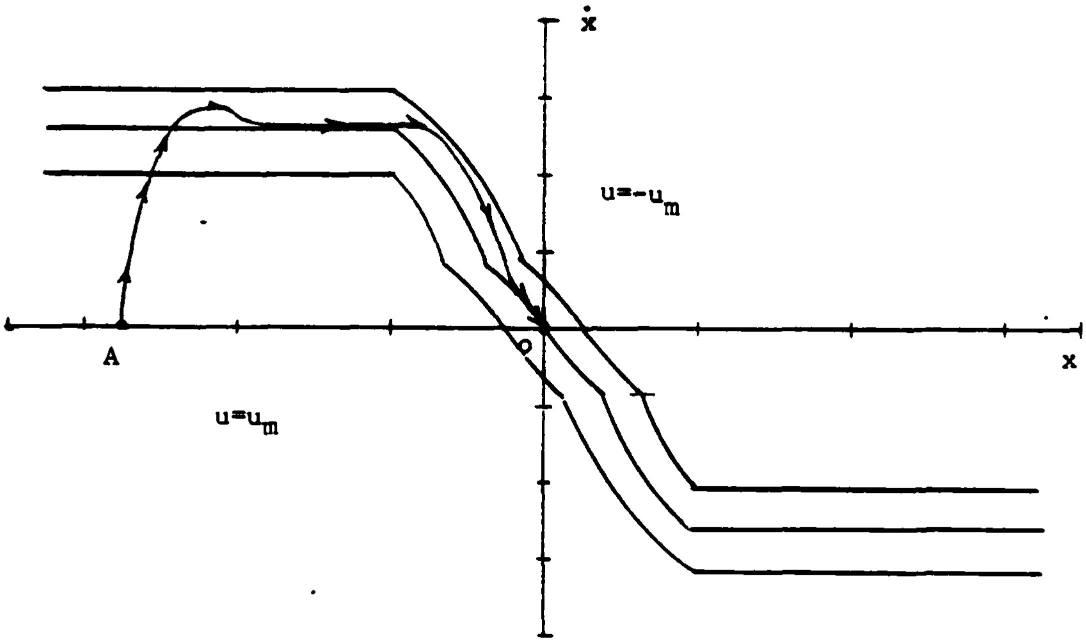

Figure 3. Phase diagram of SZC system showing typical trajectory.

Derivation of Controller Parameters

Some experience has been gained in attempting to apply the switching zone controller described above to actual systems including the XM91 autoloader. A short discussion is given here describing the procedure developed and used for deriving the required controller parameters J_m, u_m, a, b, k_1, k_2, and ξ_1. Each parameter required is considered in turn.

<u>J_m</u>: In Eq. (1), J represents the moving mass that is to be driven by the motor force u. The mass can be based in angular or linear dimensions, but care needs to be taken to insure consistent dimensions throughout all calculations and equations. In most cases, we assumed linear dimensions where motor forces are converted to pounds of force rather than in.-lbs of torque. This is generally a simple conversion using an appropriate moment arm or gear radius.

In any dynamic system, the mass J may vary because of coupling effects with other degrees of freedom or from mass changes from other sources. In this case, J_m represents the maximum value that J can take during motion. Specifying J_m ensures that enough force will be available to move the maximum mass that might occur. For the autoloader there are no coupling terms, therefore, J_m represents the actual mass J to be moved except for the magazine. For the magazine, mass may vary as rounds of ammunition are added or removed. The maximum mass J_m in this case would be for a fully-loaded magazine.

From our experience, the actual J can vary from the specified J_m by some amount and still have the system function satisfactorily. If J varies too much, other control parameters that depend on J_m become too much in error and instability of motion ensues. When variations in J become too high, all parameters need to be recalculated using a new J_m. A rule of thumb is to change J_m in the parameter calculations if J varies by more than say 50 to 75 percent of J_m.

J_m is estimated using the weights of moving masses and parts <u>plus</u> equivalent inertias of the motor rotor and any gears or chains used. The equivalent weight of motor rotor and gears is surprisingly high and should always be estimated or measured. In addition, it is highly recommended that J_m be validated for an actual system by using empirical tests. This testing is accomplished by applying a known constant motor force and observing the resulting change in velocity over a given period of time:

$$F(\text{force}) = Ja = Jd\dot{x}/dt = J\Delta\text{velocity}/\Delta t \rightarrow J = F\Delta t/\Delta\text{velocity} \qquad (11)$$

A word of caution--in English units, be sure to divide weights by 'g' (e.g., 386 in./sec²) to yield mass J.

$\underline{u_m}$: u_m is the maximum motor force or equivalent motor torque allowed in moving the mass J. This maximum force can be derived from motor power and size requirements if these are to be minimized in a given application or from reliability and safety requirements where maximum forces need to be limited. For example, the force used to accelerate a live and relatively fragile round of ammunition cannot exceed some maximum value. Also, the mechanism itself may not be able to withstand excessive loads due to potential buckling, wear, or damage problems. For the autoloader, for example, the rammer boom has a buckling load when fully extended that should not be exceeded.

$\underline{a}$: From Eq. (6), $a = (u_m - u_{dm})/u_m$ where u_{dm} is the maximum value of the disturbing force u_d in Eq. (1). Disturbing forces are all forces other than the motor forces and can include gravity, coupling effects, friction, and changing mass. The numerical value of 'a' is less than or equal to 1.0. This parameter basically contributes to the robustness of the switching zone controller by guaranteeing sufficient force for deceleration even in the presence of disturbing external forces. The disturbing force u_d is assumed to be random at any specific time. It is further assumed that the maximum value that this force can reach is predictable.

The only disturbing forces that need to be considered in evaluating 'a' are those that would tend to unexpectedly accelerate the moving mass in the decelerating phase of motion and consequently cause overshoot or collisions.

Consequently, any disturbing forces that tend to slow down motion, such as friction, need not be considered.

An excellent example of a disturbing force that can be estimated for the autoloader is the gravity force when the autoloader is to be operated at different elevations. The elevation of the autoloader at any given time will not be known, but the worst-case condition can be estimated or specified. This occurs when loading ammunition at a high negative elevation angle of say -30.0 degrees, which is a specified requirement. In this case, gravity tends to force the rammer plus the attached ammunition and the telescoping cell to move faster when loading, resulting in a potentially high overshoot or collision at the end of the cycle. The additional gravity force in this case can be estimated

$$u_{dm} = \text{weight} * \text{sine}(30 \text{ degrees})$$

This equation gives the u_{dm} that is used in the equation for 'a'. Other similar types of forces need to be calculated or estimated and used in the estimation of 'a'.

<u>b and k_2</u>: The parameters b and k_2 are required to define the control block N_3 in Figure 2. The primary purpose of this block is to provide velocity feedback, and hence damping, near the reference endpoint x_r in order to prevent overshoot. The constant 'b' provides a horizontal shift of the decelerating trajectory away from the vertical axis in the phase diagram. This shift allows the velocity feedback term to become active soon enough with enough decelerating torque available to prevent overshoot. Away from the endpoint, the block N_3 does not take an active control role.

In calculating 'b', Eq. (7) is applied directly. The velocity gain k_2 requires special care since too high a value can cause chattering, unstable, or unsmooth motions near the endpoint. Using Eq. (9) to calculate k_2 gives too high a value because of the presence of friction. Generally, k_2 is first estimated from Eq. (9) and then is reduced empirically by running the system until smooth motion is achieved near the command endpoint. For the autoloader, for example, it was necessary to reduce the theoretical values of k_2 by factors of about 0.5 to 0.6 for the cell and rammer and by a factor of 0.1 for the magazine. For the magazine, very high friction nearly negates the need for a velocity feedback term to prevent overshoot.

$\underline{k_1}$: k_1 is one of the more important parameters to be determined insofar as providing smooth and stable overall motions are concerned for a given system. k_1 is essentially a positional gain. A useful approach to determine this parameter is to write it in terms of the maximum specified force u_m

$$k_1 = u_m/dele \qquad (12)$$

In this equation, dele is an estimate of the half-width of the switching zone shown in Figure 3. If the system is at rest, for example, dele is the minimum error distance $e = x_r - x$ at which the maximum force u_m will be applied to drive the system from its current position x to the desired reference position x_r. For 'e' less than dele, the motor force will be proportionately less than the maximum value.

The variable dele can also be considered as a measure of the positioning accuracy. In general, the smaller the value of dele, the more accurate will be the final endpoint position. If dele goes to zero, the controller reduces to infinite k_1 which gives pure bang-bang control as discussed earlier. If dele becomes too small, however, unstable and chattering motion will be experienced. This parameter, therefore, needs to be determined empirically by running the mechanical system and finding the smallest value of dele for which the motion is smooth and satisfactory. For the autoloader, this procedure yielded dele values of about 1 to 2 inches.

ξ_1: The parameter ξ_1 is simply determined from Eq. (10) and depends directly on the specified value for maximum velocity v_m. If ξ_1 is very large (e.g., infinity), then there is no velocity restriction and the system can continue to increase in velocity until motor saturation is reached. Motor saturation may be desirable for minimizing operation cycle times if excessive motions and vibrations are not experienced as a result. For the autoloader, velocity restrictions were found to be necessary for all functions concerned to limit excessive motions.

Table III lists a typical set of parameter values used to successfully operate the XM91 autoloader.

TABLE III. CONTROLLER PARAMETERS FOR THE XM91 AUTOLOADER

Parameter	Rammer	Cell	Magazine
J_m	0.207 lbs/in./sec²	0.376 lbs/in./sec²	3.886 lbs/in./sec²
u_m	75.0 lbs	200.0 lbs	500.0 lbs
a	0.85	0.85	1.0
b	2.0 in.	1.0 in.	1.0 in.
k_1	37.5 lbs/in.	100.0 lbs/in.	500.0 lbs/in.
k_2	0.074 in./in./sec	0.086 in./in./sec	0.018 in./in./sec
ξ_1	25.4 in.	25.9 in.	3.4 in.
v_m	120.0 in./sec	150.0 in./sec	25.0 in./sec

Integrator Term for Higher Accuracy

The SZC depicted in Figure 2 has a serious limitation for systems with high friction as is the case for the autoloader: relatively low positional accuracy. Low accuracy is not necessarily a problem for cases where a mechanism is driven up against a hard stop and some small collision velocity is tolerable or required. This is the case when operating the rammer and telescoping cell where some finite endpoint velocity is required to properly seat the round in the gun tube and to dock the cell against the breech face. In this case, the target reference point can be set at some value beyond the hard stop.

For the case of the magazine, however, increased positional accuracy was required and could not be achieved with SZC alone. A satisfactory solution to this problem was to use an integrator term near the desired endpoint. Essentially, another block, N_5, is added right after block N_4 in Figure 2. N_5 is defined as follows (ξ = input and η = output):

$$N_5: \begin{cases} \eta = 0 \quad \text{for } |\xi| > c \\ \eta = K_I \int_{t_1}^{t} \xi dt \text{ otherwise} \end{cases} \tag{13}$$

where c is some distance from the endpoint within which the integrator term becomes active, t_1 is the starting time that this happens, and K_I is the integrator gain constant. For the autoloader magazine, c was set at 0.5 inch and K_I at 15.0 inches. Block N_5 for this case is evaluated numerically in software.

The variable ξ in Eq. (13) is essentially the error term $e = (x_r - x)$. If there is a positive error, the term N_5 results in the motor torque being gradually increased with time t driving the system toward the desired endpoint x_r. Once the endpoint x_r is reached, the integrator term N_5 is zeroed out, and t_1 is reinitialized to the current time. This zeroing out of the integrator term accounts for overshoot, if any. Some oscillation may be experienced about the endpoint if very high accuracy is required. For some set of K_I values, which can be determined empirically, acceptable positioning accuracy can be achieved in this manner in most cases. For the magazine, a value of K_I equal to 15.0 was found to be satisfactory.

Software Implementation

Implementing SZC in software is relatively straightforward. Block N_2 in Figure 2 is determined by mathematically computing Eq. (3). Blocks N_1, N_3, and N_4 are all computationally similar. Each of these blocks can be defined symbolically by Figure 4. In this figure

ξ = input into the block

η = output from the block

η_m = maximum allowable absolute value of the output η

K = gain or slope within the linearly varying zone

ξ_m = maximum absolute value of ξ corresponding to η_m

= η_m/K

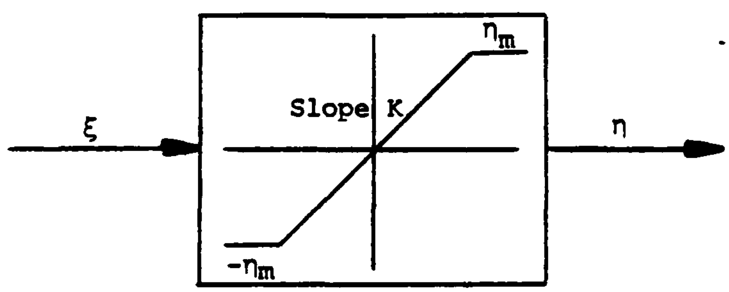

Figure 4. Typical SZC block.

Figure 5 is the computational flow chart for the case shown in Figure 4 which can be directly implemented into software.

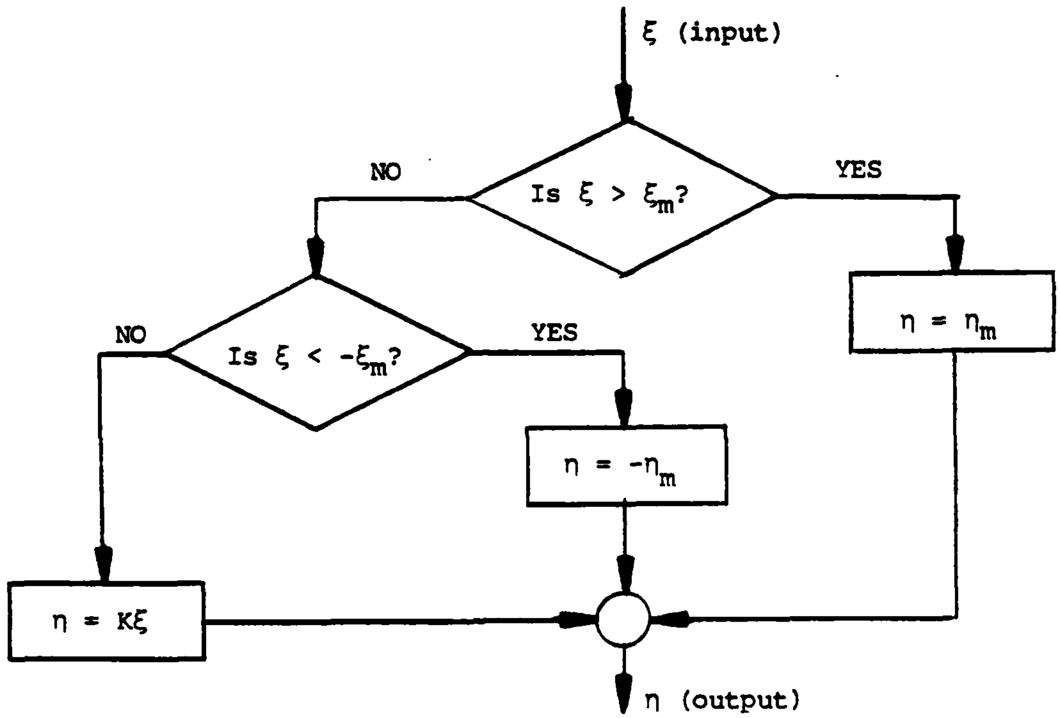

Figure 5. Flow chart for computing block N_1, N_3, or N_4.

Multitasking of Events

Time slicing is used to run more than one event at the same time and is accomplished through the use of a clock (pulse generator) that generates trigger voltage pulses at a fixed sampling rate. For the autoloader, for example, we used a sampling rate of 100 cycles per second which gives a sample time interval (time slice) of 10 milliseconds (0.010 second). The occurrence of a trigger pulse can be determined in software by continuously monitoring the appropriate DAC channel in real-time until a voltage pulse is detected. As soon as a trigger pulse is detected, a number of different software subroutines are called in sequence, each of which runs one event and performs one time increment worth of work per call. After the last event subroutine is called, control is returned to the beginning to await the next trigger pulse. This process is repeated until all required events have been completed. Figure 6 is a schematic diagram showing this sequence of operations.

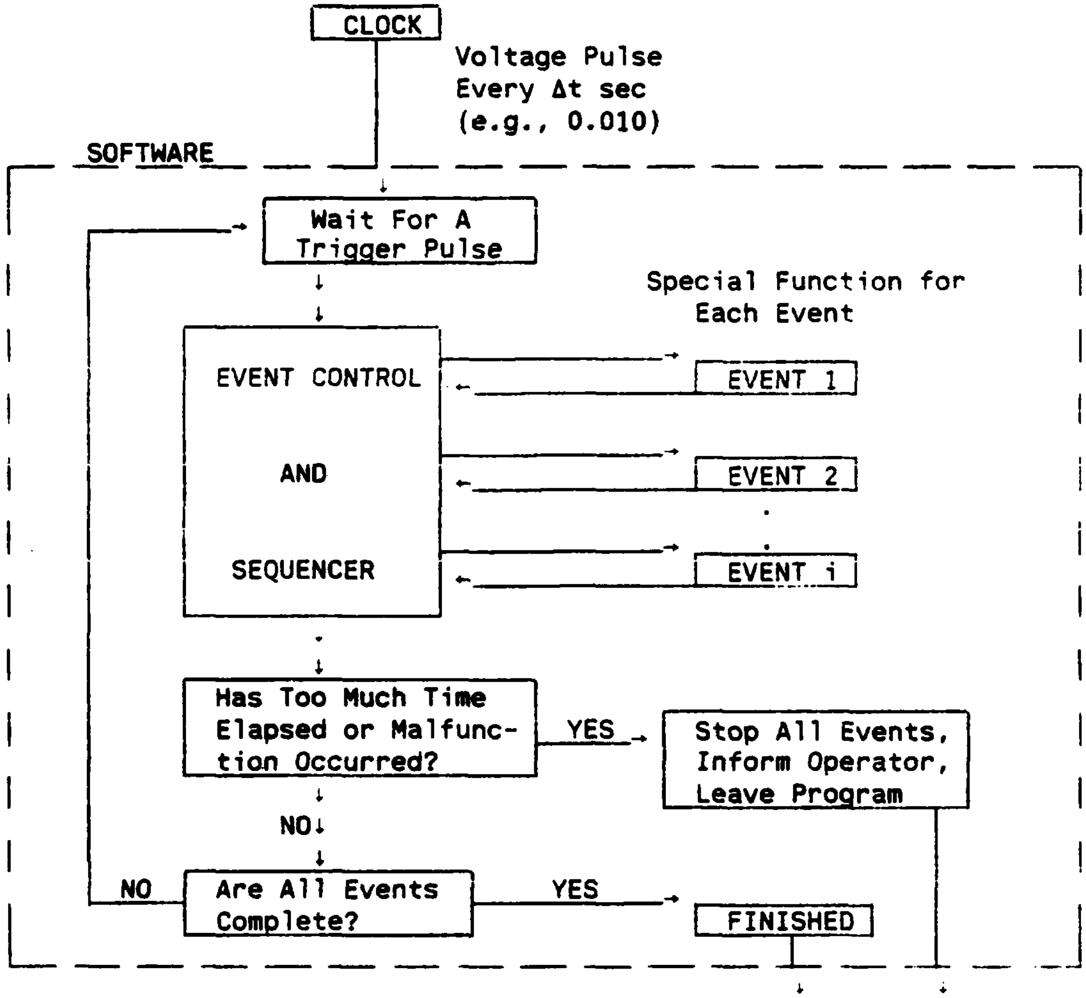

Figure 6. Schematic diagram of multitasking of events.

Each event subroutine in the multitasking mode needs to be written in such a way that it performs its task in an efficient and timely manner. Sensors need to be read and voltages or digital signals sent out to operate motors and actuators. If the task is completed, the calling software program is informed, and the subroutine for the completed task is deactivated. The sum total of computer time required for all simultaneous events must be less than the sample time interval allowed. The sample time interval should be chosen to assure that all required events will indeed take place.

OTHER SOFTWARE FEATURES

The software package developed for testing and operating the autoloader contained a number of features other than those directly related to control functions. Some of the more significant and interesting characteristics of this software are presented here to provide a summary of lessons learned for future software development projects. These items proved to be very useful and will be used in other research and development work.

Source Code Written in C

The C programming language was chosen to prepare all development software. It is a widely accepted language for applications using personal computers and has all the capabilities necessary for writing real-time control software. Large libraries of tested subroutines and extensive software support are readily available in the open literature and in the open market, and a sizeable number of experienced C programmers are available to help write software. Equally important, efficient modern-day compilers and debuggers such as Turbo C simplify code preparation for large multimodule programs.

Continuous Updating of Sensor Status

When the autoloader software is first activated by the computer operator, the information displayed on the console screen is as shown in Figure 7. This display contains four main windows, each of which has a specific purpose: (1) COMMANDS: used for choosing various commands to perform different functions or events; (2) DATA I/O: used for entering some data when required and for displaying messages and help prompts as the software runs; (3) COMMAND STATUS: displays some of the current command output signals; and (4) SENSOR STATUS: displays the real-time status of a number of selected sensors.

AUTOLOADER TEST STAND --- RAMMER/INNER CELL/MAGAZINE

COMMANDS:

F1 RAMMER/CELL FUNCTIONS
F2 MAGAZINE FUNCTIONS
F3 GUN FUNCTIONS
MANUAL MODE: 1 RAMMER
2 INNER CELL
3 MAGAZINE
AUTO LOAD: 4 KE ROUND
5 HEAT ROUND
AUTO UNLOAD 6
7 INPUT/OUTPUT REQUEST
8 MOTOR FAULT STATUS
9 SPECIAL DEMO PROGRAM
EXIT PRESS ESC

DATA I/O:

COMMAND STATUS:

RAMMER:	MAIN VOLTAGE	-0.000
	DRUM VOLTAGE	-0.000
INNER CELL:	VOLTAGE	-0.000
MAGAZINE:	VOLTAGE	-0.000

SENSOR STATUS:

RAMMER	POSITION	3.6635
	AT HOME?	NO
	MAIN MOTOR FAULT	OK
	DRUM MOTOR FAULT	OK
CELL	POSITION	0.0280
	AT HOME?	YES
	EXTENDED?	NO
	MOTOR FAULT	OK
BLAST DOOR:		OPEN
WARHEAD SUPPORT:		RETRACTED
RAM GRIPPER MECH:		CLOSED
MAGAZINE:	POSITION	6.00
	CHAIN LOCK	CLOSED
REARM SUPPORT:		NEUTRAL

Figure 7. Main display screen for autoloader software.

The continuous updating and display of COMMAND and SENSOR STATUS proved to be extremely helpful for monitoring the current real-time conditions of the autoloader and for pinpointing malfunctions and potential safety hazards. In addition to that shown in the SENSOR STATUS window of Figure 7, other sensors were continuously monitored and if a fail condition arose, a warning message would be automatically written to the DATA I/O window. This additional checking of sensors also proved very helpful.

Pull-Down Menus

Choosing which function or command to execute was simplified through the use of pull-down menus. Pull-down menus are a convenient means of offering a large number of easy to use options to the operator. In the computer display shown in Figure 7, the COMMANDS window offers some initial options. The commands written on any line in this window can be selected for execution in two ways. First, a colored or highlighted bar can be moved up or down to any line in the COMMANDS window by using the up and down arrow keys. Pressing the "ENTER" key executes the highlighted command. Second, simply pressing the designated key shown on one of the command lines executes that command directly no matter where the highlighted bar happens to be. In Figure 7, for example, these keys are F1, F2, F3, and the numbers 1 through 9.

Some of the more often used autoloader functions are shown in the initial COMMANDS menu of Figure 7: automatic loading of a round of ammunition, unloading, manual operations, a special demonstration program and overall input/output functions. Pressing the F1, F2, or F3 keys pulls down other command windows for more options as shown in Figure 8. Commands are chosen from these other menus in the same manner as in the initial window.

```
F1  RAMMER/CELL FUNCTIONS
        RAM/CELL FUNCTIONS:
    1  GO HOME AND RESET
    2  OPEN BLAST DOOR
    3  CLOSE BLAST DOOR
    4  ENGAGE WARHEAD SUPPORTS
    5  RELEASE WARHEAD SUPPORTS
    6  GRIP AMMO SEQUENCE
    7  UNGRIP AMMO AND GO HOME
    8  CHECK CLOCK TRIGGER
    9  ENGAGE REARM SUPPORTS
  EXIT  PRESS ESC
```

```
F2  MAGAZINE FUNCTIONS
        MAGAZINE FUNCTIONS:
    1  ROUND INVENTORY
    2  OPEN CHAIN LOCK
    3  CLOSE CHAIN LOCK
    4  MOVE TO KE ROUND
    5  MOVE TO HEAT ROUND
    6  MOVE TO EMPTY CELL
    7  MOVE TO SPECIFIED CELL
  EXIT  PRESS ESC
```

```
F3  GUN FUNCTIONS
        GUN COMMANDS:
    1  RAISE CASE CATCHER
    2  LOWER CASE CATCHER
    3  OPEN BREECH - FAST
    4  OPEN BREECH - SLOW
    5  CLOSE BREECH
    6  OPEN BREECH - POSITIVE
  EXIT  PRESS ESC
```

Figure 8. Pull-down menus for other command options.

Malfunction Handling Procedure

A uniform malfunction or error handling procedure was adopted for standardizing corrective actions when failures occur during autoloader operations. All event subroutines were written with self-checking and monitoring capabilities to detect failures. Whenever a critical failure occurs during execution, a standard function is called which immediately shuts down all autoloader motors and actuators. In some cases, emergency braking is applied to prevent collisions. A message is then printed to the DATA I/O window explaining the malfunction. Execution is then returned to the calling program with an error code set so that no other functions will be inadvertently called. This error handling procedure proved invaluable and worked extremely well during our development testing.

On-Line Processing

Another convenient feature programmed into the software was the capability of performing input and output editing functions without leaving the currently executing program. All critical variables and parameters were kept in an individual file on hard disk which could be edited during program execution. In conducting a test, then, if one or more parameters needed to be varied to determine their effect on the functioning of some event, this could be done quickly and efficiently without leaving the executing program to change the input file or recompiling the entire program. Also, output data generated during the running of an event such as loading a round, could be viewed immediately and edited if necessary, for example, to add other observations and stored for later printing.

Other User-Friendly Features

Other features programmed into the autoloader software that proved helpful are listed as follows:

1. On-screen DATA I/O window for messages and for inputing some data.

2. Some on-line help messages.

3. Prompts for the next step to be taken by operator in running some sequential events or if a mistake is made.

4. Two-key inputs required for confirming the continuation of critical operations (i.e., ctrl + g) to prevent accidental keystrokes causing an unwanted or unsafe event.

5. Reserving the ESC (escape) key for leaving all active functions or programs.

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