tion rates is to change the control from a rate control to a position control, that is, drop the integration completely. Many data exist for analog tracking which show position control superior to rate. Furthermore, since a position control is not time dependent, it should prove less sensitive to the solution rate. Observations indicate that a digital position control is less sensitive to solution rate, but is poorer over-all in the practical tracking range. The killing blow to digital-position control is quantization or equipment resolution. Whereas with a rate control, amplitude sampling is not particularly critical, with a position control, the analog-to-digital converters must have at least as much resolution as the final precision required in tracking.

A final proposal to the too high computer rates is one that occurred to us quite early in our program of investigations and again at the end of it.

As shown in Fig. 6, an analog control loop within the over-all digital-system loop can be instrumented by feeding information simultaneously to the display, and sampling it for the digital computer. For the operator's purposes, the system is analog, and for other computational purposes, it is digital. With such a "mixed" loop we hope that the sampled-data-tracking problem is "solved" by giving the operator an analog loop, although this instrumentation will probably create problems of its own.

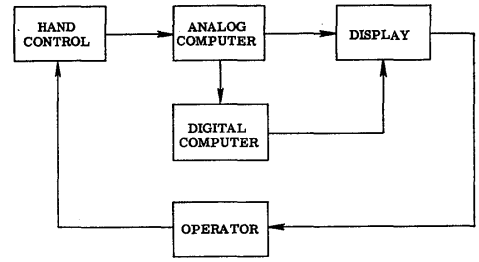

Fig. 6—Analog tracking with a digital computer.

Multiweapon Automatic Target and Battery Evaluator

D. E. EISENBERG†, A. E. MILLER†, AND A. B. SHAFRITZ‡

THE Multiweapon Automatic Target and Battery Evaluator, to be referred to from now on as the MATABE, is a large-scale, real-time, automatic-control computing system developed and built under the sponsorship of the U. S. Army Signal Corps, originally for field installation in the AN/GSG-2 antiaircraft defense system. In conducting the defense of a city against an attacking force of aircraft, the MATABE has the capability of evaluating the changing tactical data provided by the system, automatically determining and initiating individual battery assignments, and recording the detailed history of the raid. Specifically, the MATABE makes more than 136,000 calculations in six-tenths of a second in determining which, if any, of as many as 32 targets should be engaged by a given one of 20 batteries within the defense system.

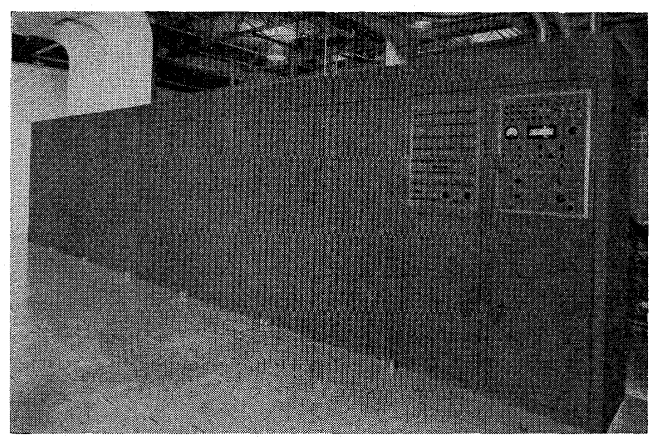

Fig. 1—The MATABE.

Fig. 1 is a picture of the MATABE. The heart of the MATABE system is a digital, binary, parallel, fixed-point, single-address, magnetic drum, tailored, electronic-control computer. Surrounding this portion of the system is an electromechanical input-output system that provides approximately 2500 signal connections to other equipment in the defense system. Table I lists the characteristics of the MATABE.

This paper will describe the information and control sources in the system, as well as the computational organization of the MATABE. Special attention will be drawn to the operational indications of possible malfunctions, since the determination of such situations by a monitor, in the midst of a complex, dynamic environment, is of the utmost importance.

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TABLE I

PRINCIPAL CHARACTERISTICS OF THE MATABE

Word length	20 bits, including sign bit
Instruction rate	5-μsec intervals
Maximum pulse-repetition frequency	2 mc
Addition time, including access time	5 μsec
Multiplication time (two 20-bit numbers)	65 μsec
Divide time (two 20-bit numbers)	80 μsec
Square-root extraction time	160 μsec
Magnetic register storage (nondestructive access)	400 bits (twenty 20-bit registers)
Magnetic drum storage	150,000 bits
Number of different instructions	64
Number of instructions on the drum	3770
Electronic package complement	511
Electron tube complement	2200
Crystal diode complement	13,803
Relay complement	1100
Signal connections to external equipment	approximately 2500
Total power required	29 kw
Total cooling required	9 tons
Volume of cabinets	450 cubic feet

The logical design of the MATABE differs sufficiently from that of other large-scale computers. Consequently, a thorough explanation of any one of its operational aspects would consume more time than is available for a single paper. The MATABE was designed to apply a great quantity and variety of real-time data to a highly complex program, and to perform this function rapidly and accurately. To accomplish this capability, a great many self-checking features and unique computational techniques were incorporated in the design of MATABE. These special features and their integration into the overall MATABE function will be described in this paper; the many details involved in each of the special features will not.

RELATION OF THE MATABE TO THE SYSTEM

The integration of the MATABE into the defense system can be better appreciated by looking at Fig. 2. The MATABE is paralleled by a group of human operators who shall be referred to as tactical monitors. Their function is to monitor the MATABE when it is being used as a tactical tool for target evaluation. The battery and target information sent to the MATABE is the same sort of information that is sent to the tactical monitors. In addition to the control lines used by the monitors in operating the MATABE, a monitor type of communication between the MATABE and these operators is also required. In passing, it should be noted that the information content of the displays to the human beings is very similar to the information content of the channels to the MATABE, although obviously in different form. Thus, we find the monitors and the MATABE aware of the deployment and status of the batteries defending the city, as well as the changing configurations of targets and other information associated with evaluating the attacking air threat.

BATTERY ELIGIBILITY FOR EVALUATION

When a battery has completed an engagement, it indicates this fact to the tactical monitors and to the MATABE which stores the information that this particular battery is in a position to initiate an engagement. This, in effect, places the battery's eligibility for an evaluation in a "waiting line." When it becomes time for the battery to be evaluated, the MATABE, on the basis of current strategy, determines which, if any, of as many as 32 targets this battery should engage. This decision is stored in the input-output system of the MATABE which can then communicate with the battery to effect the specific engagement, while the heart of the MATABE is available to evaluate another battery.

There is storage within the MATABE to retain indications of whether each of the 20 batteries is eligible for an evaluation. The electronic portion of the MATABE uses this information to determine which of the 20 batteries should next receive an evaluation. It should be noted that this "waiting" for an evaluation seldom constitutes more than a few seconds. The battery commander requesting an evaluation is seldom aware of any wait at all.

In addition to the 20-battery eligibility circuits, there is also a twenty-first eligibility circuit which represents a fictitious battery used by the MATABE to standardize its computational routines and to effect certain types of error-checking features.

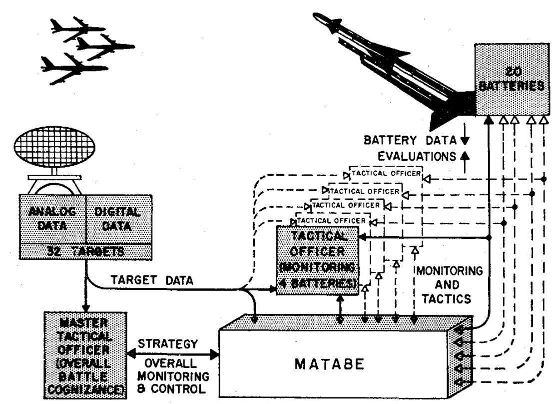

Fig. 2—Functional integration of the MATABE into the AN/GSG-2 system.

BASIC MATABE COMPUTATIONS

It is appropriate, at this time, to describe some of the basic types of computation made by the MATABE. We shall concern ourselves only with 22 of these types of computation. The first is a scheduling program that determines which of the other 21 routines the MATABE should embark upon. Twenty of the remaining 21 programs are evaluations for the 20 batteries; the twenty-first program is an evaluation for the fictitious test battery. The test-battery evaluation is basically the same as the other battery evaluations except for error-checking features which will be mentioned later. References to the organization within an evaluation program will thus apply to the test-battery program as well as to the 20 battery programs.

Let us consider how the MATABE reads and uses its program. There are 3772 instructions stored around the drum. Each of these instructions is read from the drum each revolution. Each time an instruction is read from the drum, a decision is made to perform the instruction, or to ignore it. Whether a given instruction is performed may depend upon previous computation results and upon the contents of various registers, particularly the battery register (which identifies the battery being evaluated) and the revolution register (which identifies the number of drum revolutions that have occurred thus far in the program). The type of operation called for by each instruction also may be dependent upon the information currently stored in these registers; for example, some of the instructions carry out different operations in different drum revolutions. In this way, rather than by using jump instructions, the MATABE differentiates between, and carries out, its required programs.

Each of the MATABE instructions is carried out within a 5-μsec interval. The operations which correspond to the more complicated instructions in a general-purpose computer (such as multiplication and division) are compiled by using several of these 5-μsec instructions. The data that are required from the drum are obtained within a 5-μsec period. Thus, during a 5-μsec interval, an instruction and a corresponding address are read from fixed tracks on the drum, and the associated operation specified by the instruction is carried out. If this instruction were the add instruction, and the specified address were one of the twenty 20-bit random-access magnetic-core registers, the contents of this specified register would be added to the accumulator. The same register would again be available during the next 5-μsec interval.

When data are to be read from the drum, the information is available from the location on the drum which corresponds in time to the instruction specifying the use of the data. For example, if during a 5-μsec interval, we wish to read the information on the temporary storage tracks, the instruction would enable the data then available from the temporary storage tracks to be read into the accumulator. Thus, there is no addressing system associated with the drum.

In summary, there are 3772 instructions stored around the drum. The instructions effective in a particular revolution of the drum are determined primarily by three factors: first, the contents of the battery register; second, the contents of the revolution register; and third, the results of previous calculations in the revolution.

Returning to the discussion of the types of programs, Fig. 3 illustrates the evaluation and scheduling programs. The MATABE repeats a cycle of operation for each battery evaluation. The drum revolutions are numbered 0 to 34. One revolution is used for each of the 32 target computations in a battery evaluation. Revolution 33 is used for several special checking operations, including the computation of a figure of merit for the engagement of a fictitious test target by the battery. The figure of merit for the engagement of the test target by any of the real batteries is made zero during all evaluations except that of Battery 21. Revolution 33 is also used to specify to output equipment the choice of engagement selected by the MATABE for the battery under evaluation. Revolution 34 is used in performing the scheduling program, and revolution 0 the setup routine which differentiates the various evaluations. Note that some drum revolutions are actually only part of an actual, physical revolution of the drum.

As a typical example, consider the battery 17 has been selected for evaluation. The setup routine manipulates the various constants associated with battery 17, making them ready for the actual evaluation to take place. During each of the next 32 drum revolutions, a figure of merit is computed. This figure corresponds to the predicted results of the engagement by the battery of the target corresponding to the drum revolution number. The highest figure of merit obtained in these 32 revolutions is retained. For example, during the twenty-eighth drum revolution after the setup revolution in an evaluation for battery 17, a figure of merit is computed for the engagement of target 28 by battery 17 at this time. If a previously computed figure of merit was higher than that for target 28, the latter would be ignored; if the figure of merit for target 28 was higher than the previous maximum, the prior figure retained would be replaced by that for target 28.

The thirty-third drum revolution is used for checking purposes which will be discussed in a few moments. The end of revolution 33 is used to indicate, to the input-output equipment, the number of the target which the MATABE has determined the battery should engage, or a number indicating that the battery should not engage any target at this time. In the latter case, the MATABE makes the battery eligible for an evaluation, after a suitable delay.

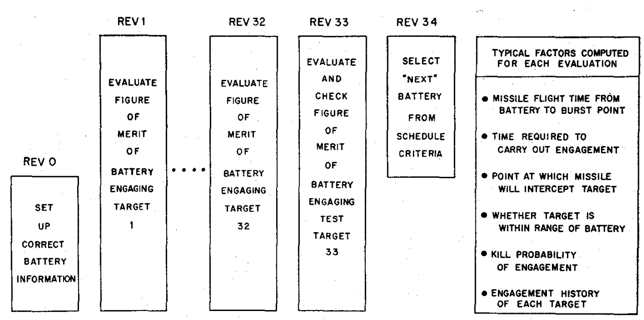

Fig. 3—MATABE evaluation cycle.

MATABE Input Functions

Let us now focus our attention on the input portion of the MATABE system. Consider the case in which a battery has been selected by the scheduling program from those eligible for evaluation. From among the 20 sets of control and information lines associated with the 20 batteries, the MATABE must select those which correspond to the battery selected. At the same time, the MATABE must proceed to obtain correct information about the attack as it is seen by the defense system at this time. This target information is brought into the MATABE in both digital and analog form. Furthermore, the electronic portion of the MATABE does not indicate different input addresses to differentiate between any two real targets; that is, during the calculation of the figure of merit, the same input addresses for target information are repeated exactly, once per drum revolution, during a given battery evaluation program. The differing figures of merit that result for different targets are caused by the input information that is available at the input addresses. Therefore, the input-switching system of the MATABE must present, to the electronic portion of the MATABE, the information associated with a given target at the time that this information is needed by the electronic portion. Thus, information on target 1 must be switched into the MATABE so that it is available during drum revolution 1, target 2 during drum revolution 2, and so on, up through target 32 during revolution 32.

During the time that specific target information is being made available in a given revolution, the MATABE samples the digital sources of information and converts the analog data into digital form. Possible changes in the digital data, that might occur during a sampling, are taken care of by means of multiple sampling of the same source, or by using gray code on the input information. The input switching is realized by means of a relay ring counter which is stepped once per drum revolution.

Error-Checking Features

Prior to considering MATABE output functions, it is appropriate to turn to the questions concerning error checking. First, the MATABE is programmed in such a way as to prevent the same battery from being evaluated twice in a row. Thus, in an evaluation for a particular battery, an error caused by something peculiar to that battery will not occur in the next evaluation. Because of this feature, those troubles which concern only one battery are isolated. If, however, the MATABE makes an error in two consecutive evaluations, such an error is considered to be *significant*. Since the MATABE can perform evaluations for any of the batteries independently of the others, the ability to isolate nonsignificant errors is obviously very important in the over-all operation of the machine. Thus, if the part of the MATABE which is associated with a specific battery should become faulty, the MATABE can continue to perform evaluations for the other batteries successfully. In the design of the machine, this isolation was carried down to the level of individual fusing for the battery circuits.

Let us now look, in further detail, at the error-checking facilities within a particular evaluation. Reading and writing associated with the drum include a parity check. The ability of the instruction and address registers to set up properly is checked periodically. During each drum revolution, a diagnostic program is carried out. If any mistake is discerned, the whole evaluation can be automatically discarded, and the battery automatically made eligible for another evaluation.

During drum revolution 33, the ring-counter switching is checked, since it should now be in a position corresponding to target 33, the fictitious target. The information that is read through the switching system is compared with the correct value for target 33 (which is stored in another part of the MATABE) in order to determine whether this switching has been adequate. The analog-to-digital conversion is also checked at this time.

In the case of battery 21, the fictitious battery, a merit number is computed for the battery 21/target 33 combination. This number and the subcalculations derived to produce the number are known by the computer, so the whole computation can thus be checked. Since battery 21 receives an evaluation the majority of the time, the MATABE spends quite a bit of its time checking itself. At this time one might ask why the MATABE is so fast; why must battery evaluations be carried out in only six-tenths of a second if the MATABE is to spend most of its time checking itself by means of fictitious battery evaluations? The reason for this apparent luxury is that, while this great speed is not needed in carrying out a specific battery evaluation, the speed is necessary in order to avoid a considerable delay caused by a waiting line. In other words, the MATABE is designed to handle a peak-load problem.

MATABE Output Functions

We are now in a position to consider the output system of the MATABE and the man-machine relationship associated with monitoring the operation of the MATABE. The batteries go about performing their engagements and, at the end of each of these, indicating to the MATABE their eligibility for another engagement. As was mentioned, this eligibility is also indicated to the tactical monitors. At this point it is well to differentiate between two types of tactical monitors as related to the MATABE. There are six of these monitors. One of these, the master tactical monitor, is concerned with the over-all battle situation, and with the operation of the MATABE. Each of the other five is associated with monitoring the operation of four batteries. These latter five monitors receive information indicating that batteries are eligible for evaluation and also receive information relating to the operational effectiveness of batteries. The master tactical monitor is concerned with the decision to use the MATABE, as well as with its over-all operation. Thus, if the MATABE were making significant errors—that is, errors in two successive evaluations—the master tactical monitor would receive this information.

Now consider a situation in which a specific battery is eligible for an evaluation. This information is sent to the MATABE as well as to the appropriate tactical monitor. The tactical monitor is advised of the battery's eligibility by the lighting of an eligibility lamp on his console. When the MATABE proceeds to carry out the evaluation for this battery, the eligibility lamp on the tactical monitor's