The Master Terrain Model System

JOSEPH A. STIEBER†

Synopsis

THE master terrain model system is an automatic data reduction system which will extract three-dimensional contour information from maps of various projections, aerial stereo photographs, or existing master models, and store these data in a universal format. From these stored commands, the system will automatically drive a fabrication unit and produce three-dimensional terrain models.

The master terrain model system was conceived to fill the serious need of the armed forces for a faster and less costly method of constructing terrain models. The proposed system will replace the present manual process of construction with a completely automatized system. The system will further provide a valuable means for the permanent storage of master model data and thus supplant present unwieldy storage methods and eliminate the loss of valuable models due to natural deterioration and handling.

The system, which is now in the stage of prototype construction, will consist of a map scanning unit, a recording and playback unit, and a contour cutting mechanism, all units being programmed and controlled by digital computers. The digital computer control system will interject positioning corrections into the scan data for the various map projections, so that the scanned three-dimensional information can be recorded and stored in a universal spherical format. The computer system will additionally provide a feedback error correction medium to the scanning drive and also supply an interpolation of pulse analog signals to produce faired curved surfaces.

The Naval Training Device Center has for many years been concerned with the development of better methods of producing master terrain models, reproduction models, and the surfacing of these models with mapping or photographic intelligence.

A long range program, covering many projects, has produced new techniques and equipments which have contributed greatly to the present success of many operational and training devices used by our military forces.

The development of an automatic system for the production of terrain models has been evolved through many years of research by engineers of the Center. Many methods were tried to translate contour elevation data into digestible information for recording and machine consumption. Among these have been systems using color coding, magnetic, electrochemical, photographic, and line counting techniques. Of those investigated, the photographic processes coupled with copper etching techniques appeared to offer the best possibility of meeting the desired performance characteristics from a standpoint of simplicity, speed of scanning, and accuracy.

When the determination of prime feasibility was accomplished, a contract was let to Technitrol Engineering Company to undertake a design study of one-year duration for further development of an over-all completely automatic system. As a result of the success of this design study, a second contract was let to Technitrol Engineering Company for the finalized design and construction of a prototype model of the system. This prototype is presently nearing completion and preliminary tests indicate that all specification requirements will be met successfully.

System Approach

The magnitude and complication of the initial system designed required a design study of one-year duration to adequately prove preliminary engineering concepts. The speed, accuracy, and flexibility requirements of the system presented many complicating factors which had to be solved one at a time.

A basic problem was the development of a method of translating two-dimensional positions plus a third-dimensional code into computer words.

Let us first study the physical aspects of the problem and the terms to be used. We will be dealing with maps of various projections, scales, and miscellaneous dimensional terminology all of which must be reduced to a common denominator which can be assimilated by a data reduction system. A three-dimensional model is in effect a scale map which has been deformed into the third dimension to simulate the exact contours of the earth which it represents. The problem here is to convert two-dimensional maps into three-dimensional models. A typical master model, as shown in Fig. 1, presently is produced by manual methods. Thus, a model of this type requires many months of arduous labor to produce. The objective of the master terrain model system is to produce these same models in a matter of hours with greater accuracy and with consequent savings in cost.

Map Coding Methods

The concept of an automatic terrain model system starts with the preparation of data from a flat map plate for machine acceptance. If we consider the familiar multicolor map, it has been printed from as many as a dozen separate color plates to consolidate the colors and mapping intelli-

† U. S. Naval Training Device Center, Port Washington, N.Y.

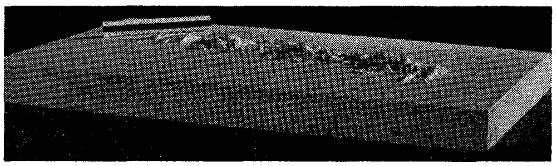

Fig. 1—Typical master model.

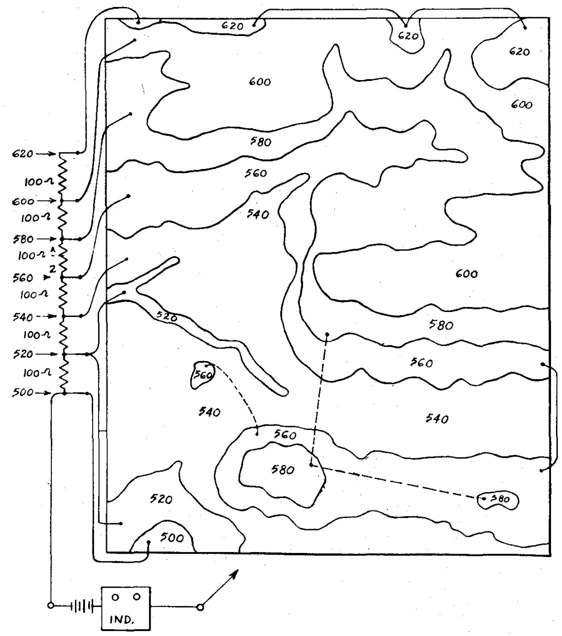

Fig. 2—Metal-map coding.

gence on a single sheet. One of these color plates (called a brown plate) has been singled out for our use because this plate contains the contour lines which represent earth contours and which will provide the three-dimensional information we require for the system. If this contour plate is used to photographically etch a copper-clad laminate sheet as is done in printed circuit techniques, a resulting map in metal will be produced which will provide terrain levels insulated from each other by the line thickness which has been etched away. If this metal map is now coded as shown in Fig. 2 by using electrical connections to supply appropriate voltage levels in ratio to map elevations, the resulting prepared metal map will provide the third dimension when scanned electrically.

Automatic Scanning

The scanning mechanism consists of a single stylus which is driven across the "metal map" by means of a servodrive. The stylus makes electrical contact with the map plate and picks up the analog signal code which represents terrain levels. The speed of the scan is proportional to the variable pulse drive in the X direction and a shift of 0.01 inch takes place in the Y direction at the end of each X scan. Thus, continuous map profile data are obtained in incremental steps of 0.01 inch and these data are converted into the binary system and passed on to the recording stage of the system.

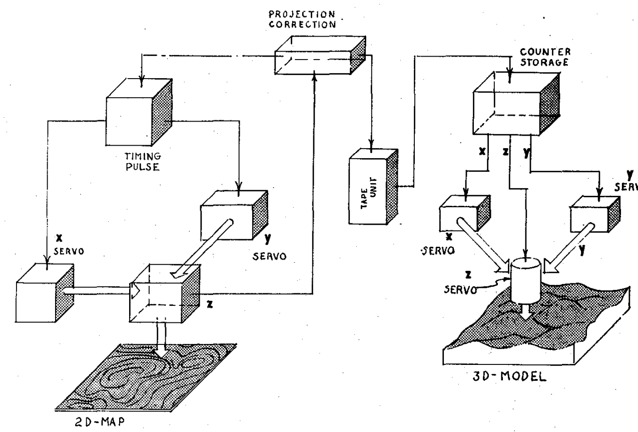

Fig. 3—Block diagram of system.

The Storage System

The 1-inch magnetic tape storage is used in the system primarily to provide a permanent storage medium for model information. This method of storage is destined to replace present methods of storing heavy molded models. A single reel of tape, representing a portion of the earth's surface at a set scale, may be used to reproduce three-dimensional models at various horizontal scales and various vertical scales or vertical exaggeration. Also, the same tape may be used to reproduce spherical model sections or flat models to various map projections. Thus, this single tape may be used to reproduce any one of possibly 25 master terrain models.

The Over-All Master Model System

Fig. 3 shows the diagram of the system. The prepared metal map is placed in a scanning mechanism and the timing generator causes the X and Y servos to position a scanner head to appropriate scan the map plate. The X and Y servo-positioning information along with the Z-code information is passed into a computer to convert the map projection coordinates into spherical coordinates which match the curvature of the earth's surface. The data are then passed on to the memory device which is a magnetic recording system. The magnetic tape is then used to drive the model cutting mechanism through a counter storage medium feeding the appropriate three-dimensional servo-drives. The cutting tool is a high-speed routing tool which is positioned in three dimensions by the servosystem and thus produces a three-dimensional model.

Design Factors of the System

(See Fig. 4.) The three-dimensional models will be constructed from Hydro-cal plaster blocks approximately $30 \times 30 \times 3\frac{1}{2}$ inches thick. Hydro-cal plaster has been

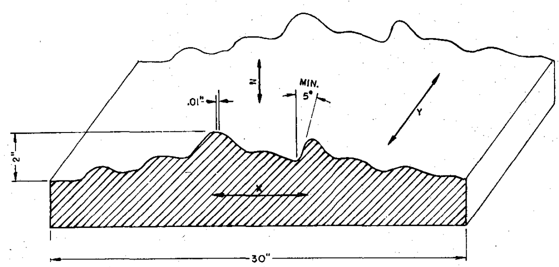

Fig. 4—Typical model section.

used in the system in combination with inert agents and lubricating agents to produce the model blocks. Because of the dimensional stability of plaster, its good machining properties at very high speeds, and the ease of reducing residue to small dimensions, it provides a good material for the system.

Profile cuts will be taken at each 0.01 inch. A cutting speed of 30,000 to 50,000 rpm is required to maintain deflection within tolerance limits and reduce the size of residue chips to micro dimensions for ease of residue evacuation.

Maximum cutting depth is 2 inches, and accuracy is maintained to 0.01 inch in any dimension.

Digital coding is used to obtain more accurate computation for projection corrections, interpolation of profile coordinates, and storage recording. All the standard map projections will be incorporated into the system, both in the map scanning portion, and in the model input section. Thus, flat models to various map projection coordinates will be produced as well as curved models simulating scale curvature of the earth.

The Control System

(See Fig. 5.) The control system uses serial type SEAC circuits. A 1-inch wide magnetic tape is used for information storage utilizing binary pulse coding of 3 channels, thus allowing 4 separate runs on the tape to use 12 channels. Ten bits are used on the tape for each position or word. The scanning/recording portion of the control system is programmed by means of a timing pulse generator. This generator impresses a timing pulse channel on the magnetic tape and pulses the X and Y counter units. The counter units in turn operate the X and Y servos for scanning the map plate and feed the binary positioning code for the X and Y channels on the tape. A single channel on the tape is used for both X and Y positioning code, since a single profile X scan produces no Y change until the end of the scan run. Then the Y increment shift takes over on the same channel using 4 pulses of time on the channel to effect the 0.01-inch physical shift of the axis and a new X profile scan then proceeds on the same channel. While this XY scanning operation is proceeding, the Z-code information is being recorded on a third channel of the tape.

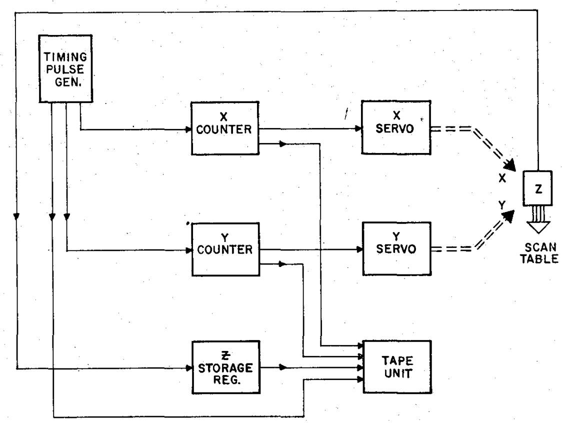

Fig. 5—Recording system block diagram.

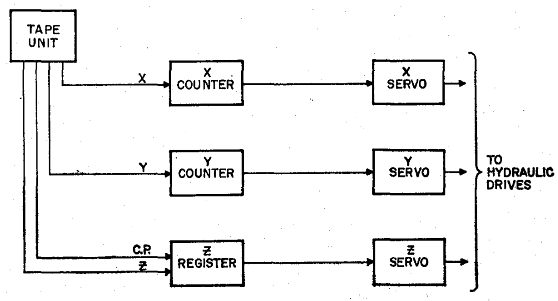

Fig. 6—Reproduction system block diagram.

(See Fig. 6.) The tape output drive system is actuated by the three-channel pulses of the tape unit. The XY channel activates the X and Y counters alternately which energizes the X and Y servodrives. The timing pulse channel controls the register and the Z-dimension channel activates the Z servosystem concurrently with the XY systems.

The Machine Section

The mechanical portion of the equipment consists of a heavy base table which carries the three-dimensional drives, the milling head housing, and the residue exhaust system. The hydraulic power supply unit provides power to the hydraulic motors at approximately 3000 psi.

The three-dimensional servocontrol system controls hydraulic motors which turn ball-screw actuators to position a milling head carriage in the X and Y positions. The third Z motion is accomplished by hydraulically activating a piston which positions the milling head drive in vertical motion. The milling head, which rotates a tapered fluted tool at high speed, produces a profile cut of approximately 0.01-inch width and varying in depth as the drives produce the profile motion.

The combination of precise tolerance "ball-screw actuator drives" and the fast acting hydraulic motor drives provides accuracies of speed and acceleration in excess of the original requirements.

Conclusions

The research program outlined in the foregoing paragraphs has been geared to meet the over-all requirements of the master model program. This research program has been divided into three phases as follows.

Phase I

This phase was devoted to a detailed analysis of the problems in the form of a design study. This included studies relating to mapping and cartographic techniques, data programming, data storage, machining or forming methods, and systems study to correlate these units into a workable design.

Phase II

Preparation of design drawings, specifications, and the construction of a prototype model of the design to prove feasibility of the over-all system were covered here.

Phase III

The final phase included the addition of complete computer control to the prototype model and reworking of components as necessary to carry the project through the various research phases, which were proceeding in close conformity to the original program schedule.

This project is believed to be the first step in a series of completely automatic devices for the correlation of cartographic and photographic intelligence to maps and models.

It is expected that this equipment when used for model production will consist of scanning units located in a centralized location, with model production units at various activities concerned with model usage.

Discussion

In answering the questions on the model terrain system, Mr. Stieber had with him R. E. Hock, of Technitrol Engineering Co., Philadelphia, Pa., which is reducing this technique to practice.

J. S. Seely (Southern Railway System): Can overhanging cliff configurations be handled?

Mr. Hock: We can handle anything up to approximately 85 degrees; anything greater than that is so vague in our mapping that we don't worry too much about it.

E. L. Harden (Westinghouse Electric Corp.): Is there interpolation between contour lines or does the cutter make steps corresponding to the contour lines?

Mr. Hock: In one method of coding, which is to etch away the areas between the contour lines, we coat the map with a conducting paint, a resistive paint in which you get contour smoothing between the lines. We actually convert this smooth analog voltage to digital steps between lines so that if you are cutting an exaggerated scale, you do get digital changes between your contour lines. In the method in which you are etching away the lines and leaving the areas, there is no easy way of interpolating between contour lines.

Mr. Ebeling (Otis Elevator Co.): What is the maximum map scale ratio?

Mr. Hock: On the XY axis, they are in the ratios of one half, 1, 2, and 4, in the Z axis, one half, 1, 2, 4, and 8. It was easiest to obtain binary values at some later date. These will probably be converted to decimal.

Mr. Maetra (RCA Labs., Princeton, N.J.): What is the limit of the smallest change delta Z that can be recorded? Is this comparable with the precision that an operator can obtain manually?

Mr. Hock: The smallest increment of movement in any axis is five thousandths of an inch and it is better than manual accuracy.

Question: How do you take into account the cutter center offset correction? It would appear that no correction is made, in which case the three-axis part will be in error.

Mr. Hock: The cutter is a tapered tool, tapering down to fifteen thousandths at its tip and has a fifteen-to-one aspect ratio. So, the offset is approximately seven and one-half thousandths. Now, we are trying to obtain accuracies of plus or minus one one-thousandth of an inch so we have almost really taken up our accuracy in the cutter offset.

However, we do ignore it, as you have stated.

Question: When will the system be producing three-dimensional maps?

Mr. Hock: We actually have the Z axis at the plant. We are working on the servosystem at the present time and the X and Y axes are under construction at a subcontractor. However, we have a prototype of the XY axis which is a converted milling table that gives us limited travel of approximately three by six inches and this we hope to be operating in January, 1958.

Mr. Winslow (ABMA): In the preparation of the original map for photographic work, do you use a color or line to indicate the contour line?

Mr. Hock: The original map is a black line map and it is a transparent negative with the contour lines in black and from this we produce the etched—either the area map or the lined map.

Question: What are the common contour intervals used?

Mr. Hock: These vary from ten feet up to several hundred feet, depending upon the horizontal scale of the map. The elevations are stored as earth-centered spherical coordinates.

Question: Do you use the output computer to convert to flat projection?

Mr. Hock: Actually this conversion of the coordinate system is the next step in the program. Presently, we are working on using the existing projection in reading and storing in that projection and cutting in that projection.