FIG. 1. The UNAMACE.

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The UNAMACE and the Automatic Photomapper

The Universal Automatic Map Compilation Equipment and its van-mounted counterpart have demonstrated that the automatic extraction of altitude data and concurrent production of orthophotos is very practical.

(*Abstract on page 570*)

INTRODUCTION

THE UNIVERSAL Automatic Map Compilation Equipment (UNAMACE), developed by The Bunker-Ramo Corporation for the U. S. Army Engineer Topographic Laboratory, was described in a preliminary paper presented to the Tenth International Congress of Photogrammetry, Lisbon, in 1964.[1] In the intervening period, four of the equipments have been completed and are being used by the U. S. Army; these have amply demonstrated the validity of the design concepts.

The success of the UNAMACE led to the development of a second instrument, the Automatic Photomapper. This unit, also for the U. S. Army Engineer Topographic Laboratory, is a small, ruggedized verison of the UNAMACE. It is designed so that it can be moved to a theater of operations and set up for use.

THE UNAMACE

The complete operational configuration of the UNAMACE is shown in Figure 1. It consists of four precision tables (left background), the computer complex including a BR-133 computer with paper and magnetic tape input/output units (left foreground), the operator's console (center), and an electronics rack (right).

Figure 2 shows a view of one of the precision tables with its cover open. The table consists of an extremely stable (and hence heavy) base in which a television-like *camera* in the form of a flying-spot scanner assembly is inserted on precision slides and locked in place. Directly above the scanner is the lens used

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to image the scanner either on a film negative for exposure of an output product or on a diapositive for extraction of image information. Directly above the lens, visible in the open cover, is the photomultiplier used to convert the light transmitted through a diapositive, and therefore modulated by the imagery, to an equivalent electrical signal.

Figure 3 shows the table with its cover removed so that the diapositive carriage can be seen. The lower carriage moves through 18 inches rolling on a precision ball-bearing *V*-groove way assembly (foreground) and on a roller and floating way assembly (background); the associated measuring element is mounted alongside the *V* way. The upper carriage moves through 9 inches on a similar way assembly mounted atop the lower carriage. It is arranged to carry diapositives of up to 9-by-18-inch format or sensitized film sheets (in light-tight holders) for use in preparing the output products. Recirculating ball-nut lead screws are used to drive the carriages (upper right).

The table and its associated scanning circuitry operate in a highly coordinated manner to obtain the desired precision scanning. If, in accordance with instructions from the control, the scanning is centered on a desired area and the table is then displaced, as by a push, the scan will move with the table so that it remains centered on the intended area. This feature permits measurements to be initiated while the tables are moving to newly designated positions.

The tables, moved under operator control to center on diapositive imagery (using the stereo viewer for observation), have been shown to be repeatable in position to within 2 microns (the least count of the Moiré-fringe measuring units) and to have an absolute accuracy, as verified with a precision grid, of about 4 microns *rms*. There is evidence that this accuracy is not seriously degraded when the tables are moving at a rate of up to several inches per second.

The UNAMACE is controlled by the BR-133 computer. It is programmed to calculate the diapositive parameters from data obtained in comparator measurements made with the UNAMACE and ground control and to perform the detailed point-to-point calculations of the compilation operation. It responds to operator commands from the control console or sequences the equipment through the automatic compilation operation, utilizing the altitude measurements made by the analog equipment to keep the scanning in contact with the surface of the terrain model.

The computer complex includes a paper tape reader and punch, magnetic tape unit,

ABSTRACT: *The Universal Automatic Map Compilation Equipment (UNAMACE) is now being used by the U. S. Army Map Service to extract basic map data from a variety of aerial photography, including formats of up to 9 by 18 inches. The equipment measures altitudes of up to 80 digitally determined elemental areas per second with instrumental C-factors approaching 5000. Measured altitudes are output as drop-line charts, from which contours can be traced, and stored digitally on magnetic tape. Planimetric detail is shown on high-resolution orthophotos prepared concurrently with the altitude measurement. The AUTOMATIC PHOTOMAPPER is a compact version of the UNAMACE It is van-mounted so that it can be moved easily to a theater of operations where it can be set up quickly for use. Operation with the Photomapper is limited to 9- by 9-inch format photography, or smaller, but otherwise it operates similarly to the UNAMACE. One of these units is currently being evaluated by the U. S. Army.*

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and IBM Selectric typewriter. The program and data are read into the computer using the paper tape reader. Data tapes are prepared off-line from the computer using the typewriter and punch. The altitude data resulting from a compilation operation are stored on magnetic tape.

The typewriter is used on-line to output the coordinates of comparator-measured points or geodetic coordinates during compilation operations.

The control console (Figure 4) includes all of the operating controls for the equipment. A switching panel at the upper left permits assignment of the four tables either for diapositive scanning or for the preparation of orthophotos or altitude charts; it also allows the orthophoto signal to be obtained from either diapositive of a stereo pair.

An electronic stereo viewer (center) provides the operator with a *window* to the operation, thereby permitting him to monitor the area under consideration and to take appropriate action when needed. Pushbuttons on the switching panel permit changes in the effective magnification (×2 and ×4), interchange of the left-right images (to produce a pseudo-stereo view), and interchange of the x-y axes (to permit y-directed parallax to be observed as height displacements). An electronically developed crosshair in each view is used as a reference for x-y centering in monoscopic operations or as a height reference for stereoscopic measurements.

FIG. 2. UNAMACE scanning table.

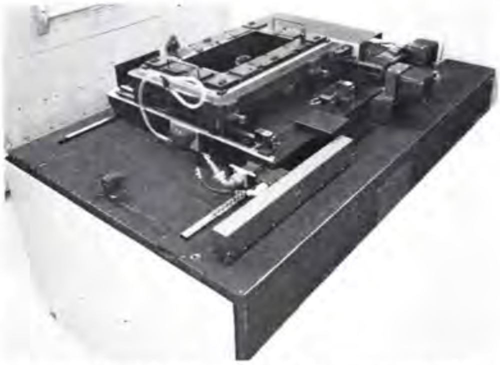

FIG. 3. Working elements of the UNAMACE table.

A reference viewer, located at the right of the console, embodies a light whose position on the viewer indicates the observation position of the selected table. During measurements, the viewer contains a print corresponding to the diapositive on one of the tables, and the light indicates the position of the field of view. Consequently, the reference viewer serves to supplement the stereo viewer whose small field of view is inadequate for some operations.

On the desk under the reference viewer is a manual positioning control which, to the operator, appears as a small *bowling ball* whose top protrudes through the desk top. Motion of the ball is communicated to the computer through appropriate codes. During comparator-type measurements, backward or forward motions of the top of the ball are used to effect y-position changes for a designated table, while cross-wise motions of the top of the ball are used to transmit x-position changes for the designated table. When op-

FIG. 4. UNAMACE control console.

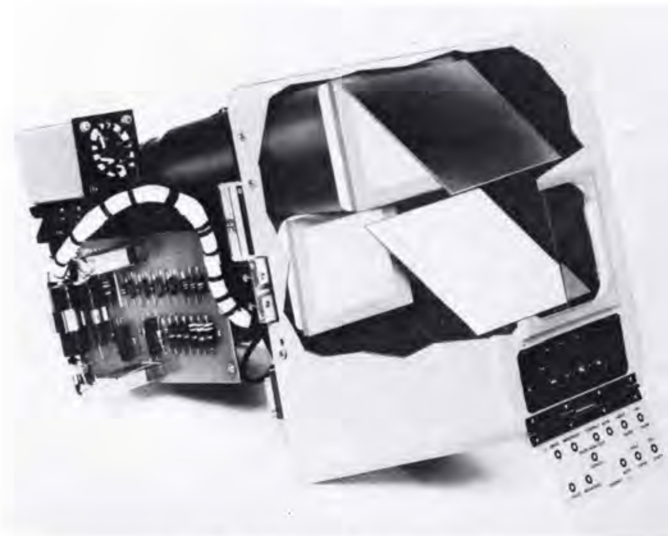

FIG. 5. UNAMACE stereo viewer.

erating in a manual stereo mode, backward or forward motions of the ball may be used to effect altitude corrections.

On the left of the desk is a keyboard for communicating with the computer. This is used by the operator to select the operating mode (e.g., comparator or compilation operation), provide for expansion of the field of view in the stereo viewer, or change the sensitivity of the position control (through successive multiplications or divisions by four). Additional keyboard operators are described subsequently in terms of related operational modes.

The stereo viewer (Figure 5) is basically a twin television set, incorporating two vertically disposed 4-inch tubes, whose images are superimposed using a half-silvered mirror. Crossed polaroid filters in the two optical paths and correspondingly crossed filters in glasses worn by the operator separate the pictures for presentation to the appropriate eyes of the operator.

OPERATION OF THE EQUIPMENT

Using the available technology, compilation requires manual attention at various points in the process. The operator is used to recognize images corresponding to features in the terrain as a step in establishing the geometry of the photographs and to locate coresponding images as an aid in difficult areas. The UNAMACE is intended to make stereo measurements automatically, with an optimum coupling of the operator into the measurement loop whenever necessary. The procedure used in comparator and compilation operations follows. It will be appreciated that the comparator operations and associated computer calculations to determine the camera parameters could be performed on other equipments, freeing the UNAMACE to perform the more demanding compilation operations. The detailed measurement procedure depends upon the nature of the available control information. The description is given in terms of an operation in which sufficient geodetic control is available to establish the basic geometry.

The photo prints are examined first to locate and measure, using a ruler, the position of images of control points whose geodetic positions are known. The positions of additional pass points may be located at the same time. The results of this operation are prepared as paper tape inputs for a UNAMACE comparator operation in which the measurements are updated to the 4-micron rms accuracy of the UNAMACE. All four of the UNAMACE tables are available for the measurements, so as many as four diapositives may be mounted on the tables at a given time. The appropriate defining tapes, including one which designates the order of measurements, are entered into the computer. The *Comparator* indicator (on the control panel) lights, and the tables having diapositives showing the first point move to bring the images into the field of view. The operator then switches the stereo viewer to one or two of the tables showing the point, depresses the keyboard button designating the table to be positioned, and centers the point on the reference mark using the position control. As the adjustment progresses, the operator reduces the control sensitivity by depressing the divide-by-four key as required to achieve the desired precise centering; this can be repeated until a significant motion of the ball is required for each 2-micron least count. Once centering is satisfactory, control is transferred via the appropriate key to the second diapositive containing the point, if any, and the process is repeated. Final centering of a selected image with respect to a second image can be achieved automatically by depressing the appropriate key; this feature is not used unless the area in the field of view is level, because automatic centering is on an average basis. If there is a third image of the point on another diapositive, the stereo viewer is switched to observe the third image and the process is repeated.

Once all of the images of a given point have been measured, the operator uses the keyboard to signal the equipment to move to the next point. The results of the measurements on the first set of points then are transferred to a more permanent point in the computer memory and, in addition, typed out as a *hard copy* record of the observations. The tables then move to rough center on the second set of images, and the overall process is repeated. When all of the specified points on a given diapositive have been measured, the results are output on paper tape; the table then may be used for another diapositive in the set. The process is continued in this manner until all of the points of interest have been measured.

The results of the measurements are used by the computer to calculate the camera orientation data. The BR-133 has been programmed to make the required calculations for single photographs and to extend this, photograph by photograph, using a relative orientation program. However, where many photographs cover a large area, the available data are usually input to a *block adjustment* program on a larger computer where they are handled on a simultaneous basis to obtain the best fit for the complete set. The output of these programs is a set of tapes, one for each diapositive, that provides an adequate mathematical description of the diapositives.

Before the compilation or altitude measurement can proceed for each stereo pair, an auxiliary set of tapes describing the desired compilation is made. These include a specification for the geographic area to be included in the measurement, the scale of the desired output product, the desired contour interval, and a list of geographic coordinates of points to be marked on the output product (such as map grid coordinates and geodetic control points).

The compilation of a given stereo pair is started by mounting the diapositives on the two selected tables, the unexposed film sheets on the other two tables, and a print corresponding to one of the diapositives on the reference viewer. The switches on the control panel are set in accordance with the table assignments, and the diapositive to be used in preparing the orthophoto is selected. The two diapositive tapes and the compilation tape then are read into the computer.

When the tapes are entered, the *Compilation* indicator lights and the two diapositive tables move to the indicated position of a first-measurement point to be used in determining the orientation of the photographs on the table (usually a camera fiducial mark). The operator uses the position control to accurately center the selected mark on each diapositive, then signals the computer via the keyboard to move to a second mark where the operation is repeated. The computer uses the resulting data for *interior orientation*; i.e., to relate the coordinate systems of the diapositives to the coordinate systems of the respective tables. As a check on this operation, the computer uses the geographic coordinates of an easily recognized control point to calculate the coordinates of the corresponding image points and then centers the tables on the calculated positions. If the operator observes the control point to to be well centered on the reference mark, he signals the computer to proceed. If it is not well centered, the operation is aborted and various phases are repeated until satisfactory centering is observed. The operation provides a simultaneous check of the diapositive data and the setup measurements. During the setup operation, the operator indexes the photo print on the reference viewer so that the print provides an accurate indication of the position of the field of view.

If the operator signals a satisfactory orientation, the equipment prints out the designated symbols on the output film sheets.

At this stage, the operator may choose to delineate potentially troublesome regions within the area to be compiled. This is accomplished by placing (using the position control) the light on the reference viewer at a low point on the region to be defined, depressing a button to designate the automatic action to be taken in the region during compilation, and then (using the position control) moving the light on the viewer around the boundary of the region to be delineated. When the operation has been completed, the operator may choose to describe other regions or to proceed with the compilation.

Routines available for this *adverse-area* operation include slowing down for difficult areas, ignoring indicated altitude changes (for use over large bodies of water), and stopping after moving out of an area to permit the operator to make an altitude correction (such as might be required in moving over a cliff). It is anticipated that the available routines will be augmented as experience indicates other desirable modes of operation.

When the operator signals the equipment to begin compilation, the four tables move to their respective starting points—the two carrying film sheets to the designated X, Y-values, and the diapositive tables to positions corresponding to the starting X, Y-values and the estimated altitude for the point. The operator then uses the position control to adjust the effective observation altitude, observing the results on the stereo viewer until the image on the viewer appears to be at the level of the reference mark. He then actuates the *GO* button and, generally, waits until the area is covered by a closely spaced set of measurements, with concurrent printout of the orthophoto and altitude chart.

During a compilation, the equipment requires manual attention only in areas where it is in danger of *getting lost*, as defined in the adverse-area mode, or when it has probably become lost, as evidenced by an excessive difference between the currently measured altitude and the altitude for the same Y-value on the previous profile. In either of these cases, the equipment stops automatically and the *Manual Intervention* indicator lights. The operator then corrects the altitude, using the position control so that the terrain again appears at the reference level in the stereo viewer, and signals the equipment to proceed. If the area is particularly difficult, the operator may choose to move in small increments after the stop, observing the surface after each increment, until he is confident of the automatic tracking. Alternatively, he may choose to have the equipment move through the area slowly so that he can observe the detailed operation.

The Automatic Photomapper

The *Automatic Photomapper*, delivered to the U. S. Army Engineer Topographic Laboratory in December 1966, is a militarized map compilation instrument that performs virtually the same operations as the larger UNAMACE. It is van-mounted for mobility and may be quickly transported to a military theater of operations.

Restriction of the format size to 9 by 9 inches or smaller permitted the precision operating functions (i.e., diapositive scanning and preparation of the output products) to be performed on a single master table. This table, shown in Figure 6, provides independent orthogonal motion through 9-by-9 inches for a surface carrying the two diapositives and the output film sheets. The faces of the flying-spot scanners associated with the diapositives are imaged on the diapositives by associated lenses that can be independently positioned through orthogonal motions covering a 3-by-3-inch field. The various carriages are precisely controlled by using recirculating ball-nut lead screws as drives and direct-coupled optical encoders for position reporting.

An artist's version of the complete *Photomapper* assembly is shown in Figure 7 (the van mounting did not permit a reasonable composite picture of the assembly to be taken). It consists of the scanning table (foreground), operator's console (right rear), computer with paper tape unit (behind table) and associated electronics (rear).

Operation of the Photomapper is quite similar to that of the UNAMACE except for the detailed positioning of the scans. During compilation operations, the large table moves in orthophoto coordinates while the two diapositive lenses move to positions calculated to center the image of the scans on the diapositives to correspond to the orthophoto X, Y and the altitude estimated for the point.

Results of Tests

The results of tests on the UNAMACE have been reported in *Photogrammetric Engineering*[2]. They are summarized below:

- Operating as monocular comparators, none of the eight tables of the first equipments was more than 1.6 microns outside the 4-micron specification when first measured. Linear scaling corrections are applied in the computer

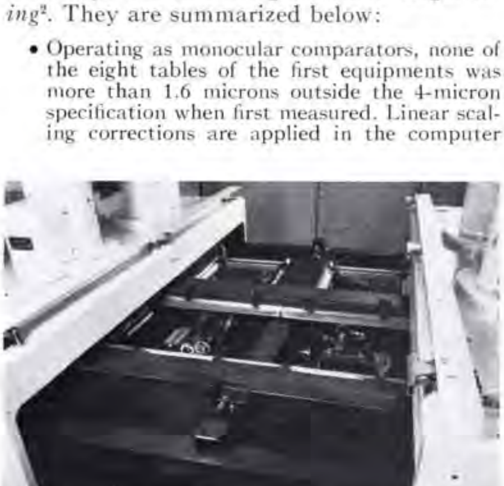

FIG. 6. Automatic Photomapper table (showing master carriage, two positionable diapositive lenses, and two fixed output lenses).

calculations to bring all tables within the desired tolerance.

- Operating with a fictitious model (but real photography) to minimize the effects of errors from other sources, the first two UNAMACEs had reported C-factors of 4400 and 4800.
- Operating with a real model, the two equipments had reported C-factors of 1470 and 1500.

The models reported above were obtained using 6-inch focal length, 0.6 base-height ratio photography.

Output Products

Figure 8 shows an orthophoto and altitude chart produced by the equipment. They were prepared at an original scale of 1:25,000 twice the nominal photographic scale, from 27,000-foot photography. The altitude chart shows 20-foot contour intervals (the region between adjacent contour lines) as bands of a given gray level, with the trinary sequence white, gray, black, white representing contour intervals of increasing value. The boundaries between regions of different gray level are currently traced in a subsequent manual operation to obtain the contour lines. The outputs show the results of approximately 500,000 measurements and an equal number of elemental image transfers to prepare the orthophoto.

Figure 9 shows part of an orthophoto mosaic prepared from portions of 22 stereo models. The individual model outputs were prepared on a common film sheet in a total operating period of about 8 hours. An altitude chart for the combined area was output concurrently with the orthophoto shown.

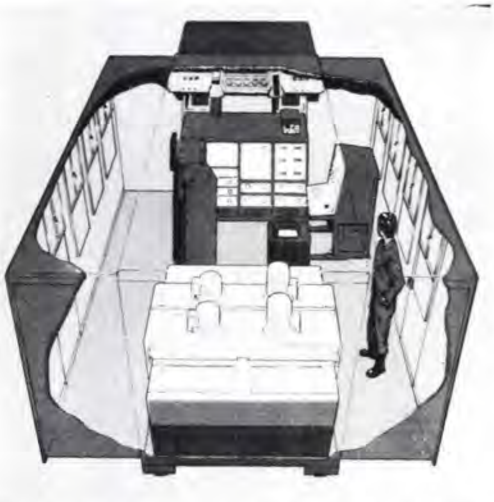

FIG. 7. Artist's drawing of operational configuration of Automatic Photomapper.

Conclusion

The UNAMACE has been established as an exceedingly useful tool for the extraction of basic map data from a variety of input photography. Three are now being operated by the Army Map Service. A fourth unit is being

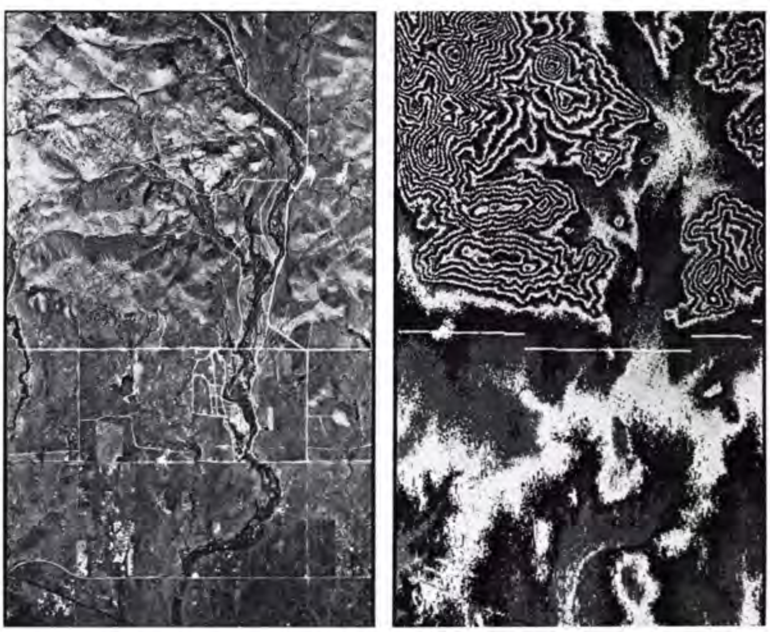

FIG. 8. Orthophoto and altitude charts prepared by UNAMACE. Altitude of photography—27,000 feet. Scale as output—1:25,000. Contour Interval—20 feet.

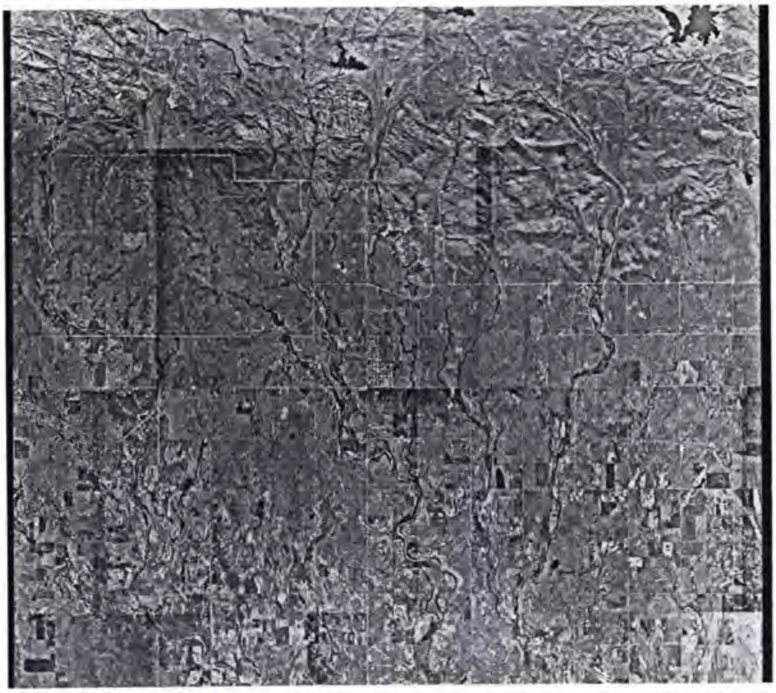

FIG. 9. Orthophoto mosaic prepared by UNAMACE. Altitude of photography—27,000 feet. Scale as output—1:100,000. Input—22 stereo pairs.

used by the U. S. Army Engineer Topographic Laboratory to evaluate new techniques and procedures.

The *Automatic Photomapper* currently is being tested and evaluated by the Engineer Topographic Laboratory. It is expected that additional units of this configuration will be constructed for use in near-site mapping throughout the world.

These equipments have demonstrated dramatically that the automatic extraction of altitude data and concurrent production of orthophotos is very practical. They will form the nucleus of an increasingly automated map production operation.

ACKNOWLEDGMENT

The UNAMACE and *Automatic Photomapper* have resulted from automatic mapping efforts conducted by The Bunker-Ramo Corporation since 1960 and from earlier related activities. The Automatic Stereomapper, an automated Kelsh plotter, was operational in 1962[3]. The Automatic Map Compilation System[4], a laboratory equipment having many of the features of the UNAMACE, was producing good orthophotos and altitude charts in 1963.

We have been indeed fortunate that the small team responsible for these developments has been able to stay together over this period. Mr. M. L. Baker, electronic engineer and now Manager of the Automatic Mapping Department at Bunker-Ramo, was project engineer for the Automatic Stereomapping System, for the first UNAMACEs, and for the *Automatic Photomapper*; the success of these equipments attests to his engineering skill and devoted labors. Mr. George Miller, mechanical engineer, was responsible for the precision design of all of the equipments; these have been proven to be very accurate and remarkably trouble-free. Mr. Glenn Kimball, electronic engineer, did much of the detailed electronic design on both the UNAMACE and the Automatic Map Compilation System.

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