Applications of the MACO 35/70 in Close-Range Photogrammetry

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Invited Paper, Commission V/1

The MACO 35/70 is a small format analytical stereoplotter, designed for use with metric or non-metric 35 and 70 mm cameras. The system is aimed at the broad range of users who are not photogrammetrists--people such as archaeologists, architects, doctors, and engineers who need access to accurate and complete three-dimensional measurements but who cannot justify the capital and operational expenses associated with traditional photogrammetric methods and equipment.

The 35/70 is made possible by the integration of recent optical, electronic, and computer technology, coupled with comprehensive software which eliminates the need for the complex cameras and plotters of the past and allows for flexibility of data acquisition and operation and ease of use. This paper briefly describes the system and the operational procedures, then gives examples and results of recent tests. It should be remembered that, as in any state-of-the-art system, technical improvements and modifications are constantly being made to the 35/70 and for that reason, all specifications given are subject to change.

1. System description

The 35/70, like all analytical plotters, consists of several subsystems: the photo movement system, the optical system, the computer, and the software. By design, the units follow a modular philosophy to allow for ease of manufacturing, maintainence, and updating.

The photo stages have interchangeable holders for 35 or 70 mm slides, using two optically flat pressure plates to insure flatness. The stages are driven by DC motors through precision leadscrews, with positioning feedback provided by rotary encoders with a 1.25 micrometer resolution.

The high-resolution color-corrected optical train has a 5 to 1 zoom range, giving a magnification range from 8X to 40X with the 10X eyepieces. Included in the optical train is a 24-character LED display, superimposed over the imagery, used for operator prompts and data display. An optional color video camera can be incorporated into the optical train, so that the image the operator is viewing can be displayed on a monitor for group viewing, interpretation, or digital image processing.

Stage movements are controlled by a trackball and thumbwheel, housed in a small control console along with the stage on/off switches, record, and pen up/down switches. The console is designed so that the trackball and thumbwheel can be operated with one hand or the assembly split and operated with two hands, one on each side of the instrument.

The computer used with the system is the Tektronix 4050 series. The Tektronix is supplied with Basic language, 64K RAM, RS-232 interface, internal tape cartridge drive, and high-resolution graphics screen. A large number of peripherals are available, such as digitizer tablets, pen plotters, disk drives, and hard copy output.

The system software is written in Basic. The operational stages are written as a series of modules, with the transition between them based on the operator's choices. Operator interaction with the various operating sequences is through menus, interactive prompts, soft function keys, and hardwired switches. To ensure good communication with the operator, all prompts are complete sentences, often with graphical explanation, and with the proper responses listed. Prompts are also given on the eyepiece displays, when appropriate, and the stage lights are turned on and off to direct the operator's attention to the proper photograph during the setup procedure. To help prevent operational mistakes all operator inputs are checked for validity and all commands which would cause irreversible changes must be verified. A "panic button" error recovery routine is available at all times, in case of system failure or extreme operator error.

Mathematically, the system is based on a extended version of Karara's DLT (1,2). Standard deviations can be specified for all points, allowing the use of partially known control points, control points of varying precisions, and pass points. The solution is designed for use with non-metric or fully metric cameras, or cameras about which some information is known. For non-metric cameras, the number of lens distortion coefficients to be solved for can be selected, depending on the amount and distribution of control in the object. In some cases a distortion curve for the camera may be known, or a general distortion curve for a type of lens, such as the Distagon, may be known. In these cases, the lens parameters may be input and held in the solution. For a fully metric camera, the known focal length may be input and held in the solution. The singularity constraints as advocated by Bopp and Krauss are used (3). To allow the use of one photograph to map planar surfaces, the program deletes the three Z coefficients in the equations, reducing the solution to a plane projective transformation.

While any 35 or 70 mm camera may be used in the system, certain camera and lens combinations have been tested, and in some cases modified, to achieve higher levels of accuracy. The recommended 35mm camera is the Pentax Super ME, fitted with a 15mm lens and modified with a vacuum film platen to insure film flatness. The 70 mm camera is the Rolleiflex SLX, supplied with 40 mm Zeiss lens. Recommended for aerial use, or in applications requiring the highest accuracy, is the Rolleiflex SLX equipped with reseau plate and calibrated lens. Standard color transparency film, such as Kodachrome or Ektachrome, is recommended for use with the system.

2. Operational procedures

After the photos are inserted into the machine and the stages referenced, measurement of the control and pass points begins. The images of the points are measured and the control coordinates and standard deviations are input or read from a data tape. On going to the solution, the operator is asked if the photography is aerial or close range, and whether the lens distortion parameters are to be input or solved for. After each iteration of the solution, the parameters and their corrections and the point residuals are displayed. A plot of the image residuals is shown at the end of the solution, to facilitate evaluation of the results. Following the solution, the operator is given a choice of operating modes--planimetric mapping, contouring, profiling, or one photo.

In all operational modes, a map of the collected data points is displayed on the graphics screen with the display parameters specified by the operator. Point coordinates and the graphic tag data (line type, symbol code, pen up/down) are stored on the internal magnetic tape as the points are displayed on the graphics screen. The collected points may be edited as desired. The recording of points may be done manually or under computer control by time or distance. Current coordinates of the floating mark or graphic tag data may be displayed in the eyepiece LED displays. Calculation of the area within specified boundaries or the length between model points is also available to the operator.

3. Operational results and data

The 35/70 has already been tested and applied to a wide variety of applications, ranging from macro to aerial. While testing is still in progress to further define and verify system parameters, the viability of the concepts of the 35/70--the use of non-metric small format cameras in a low-cost, portable stereoplotter--has been conclusively shown.

One of the main paradigms of the system is the use of non-metric small format cameras. While the standard attitude has been that no serious work can be done with such equipment, it has been demonstrated that measurements with accuracies of 1 part in 3000 can be obtained in close range setups with good control. In field situations with larger objects such as buildings, accuracies of about 1 part in 750-1000 can be obtained.

In aerial situations, the accuracy obtained is a function of the relief present in the control distribution. While good results (about 1 part in 1000) can be obtained with non-metric cameras in areas with adequate relief, attempted solutions over very flat terrain typically give poor results due to the inability to overcome the correlations between the interior and exterior orientation parameters. For this reason, use of a calibrated 70 mm camera is recommended for use in aerial work with the 35/70.

The required calibration of the camera depends on the degree of accuracy required. For medium accuracy situations, establishment of the focal length and the distortion curve appears to be adequate, while for the highest accuracies, location of the principal point and incorporation of fiducials into the camera is necessary.

It should be repeated that the non-metric camera is still more than suitable for close range work. With an adequate amount of control (8 - 10 well-distributed points), no problems are encountered in close range situations. If available, lens distortion parameters for the camera can be input and held in the solution, or typical parameters for the type of lens used can be input. Both cases result in improvements, with the use of calibration parameters for that specific lens of course giving the best results but with the use of general parameters being surprisingly effective.

Operationally, the use of the small format transparency films has turned out to be very effective. The image quality and the amount of detail present on readily available 35 and 70 mm slide films are far superior to that of aerial black and white film and even standard aerial color. The elimination of the diapositive also contributes to the image quality advantage. The new Polaroid Autoprocess 35 mm film, with its capability to produce slides in five minutes, has also been tested and has given good results.

Numerous tests have been conducted using the 35/70 in a large number of applications from macro to close-range to architectural measurement. To illustrate the range of possible applications, three examples are included.

Figure 1 illustrates a use of macro-photography. The drawing is a contour plot at 1 mm intervals of the lower mandible of the hominid fossil named Lucy. Lucy was found in Ethiopia a few years ago and is one of the oldest and most complete hominid skeletons ever found. The photographs were taken with a modified Pentax Super ME 35mm camera fitted with a 15 mm ultra wide angle lens, using Kodachrome ASA 25 film. The base/distance ratio was 0.25 with an object distance of 24 inches. The full set of X,Y,Z measurements, a subset of which was used to plot the contour map, are permanently stored for both scientific investigation and preservation. These macro-photography techniques can be employed on a wide range of objects in many disciplines, including ballistics, quality control in small part manufacturing, antique jewelry restoration, and medical measurement, among others.

A mock crime scene is shown in Figure 2. The same camera and lens were used as in the photos of Lucy. The base/distance ratio was again approximately 0.25, with the object distance being 3 meters. The map of the scene, including 5 cm contours of the victim, is plotted from a vertical perspective, however, the photography was taken from an oblique angle of approximately 45 degrees. A control object, 2 m x 2 m x 1 m was placed in the scene and was oriented with a vertical axis. Measurements of this kind are extremely important to investigators of crimes and accidents. Other disciplines using this scale of photography are archaeology for dig sites, industrial manufacturing, small scale architectural and construction engineering projects, and others.

Illustrating stereo compilation of a considerably larger object, Figure 3 is a plot of the facade of Mission Conception, the oldest unrestored church in the United States. The object distance was 15 meters, with a base/distance ratio of .25. The modified Pentax Super ME was also used here, again with the 15 mm ultra wide angle lens. Control for this object was surveyed in using intersections from two theodolite stations. Twelve control points were used to cover the facade from the base to the tops of the two towers. Structural details, such as deterioration of the walls, were particularly evident when viewing the transparencies with controlled lighting and the variable magnification. Architectural uses of small format photogrammetry are becoming more common in many areas of the world.

It is noteworthy that all of these objects could have been photographed equally well with a 70 mm format camera.

4. Conclusions

The use of small format photography and the MACO 35/70 in the acquisition of three-dimensional measurements has been shown to be cost-effective and operationally powerful. Equipment and training expenditures necessary to establish a photogrammetric operation can now be reduced to a level where many potential users can cost-justify the use of photogrammetric techniques. The specialized, lengthy training formerly required has been reduced so that personnel at the technician level can obtain photography and successfully reduce it after a short familiarization period. Acquisition of the data in a digital format allows its direct use in many existing computer graphics programs or allows the plotting of the data using a pen plotter, eliminating the need for a draftsman.

Introduction of the MACO 35/70 system has opened new areas for photogrammetry, creating potential uses and users unthinkable ten years ago. As knowledge of the system parameters and uses increases and the user base expands to new areas and applications, even more uses which are un-imagined at this time can be expected.

References

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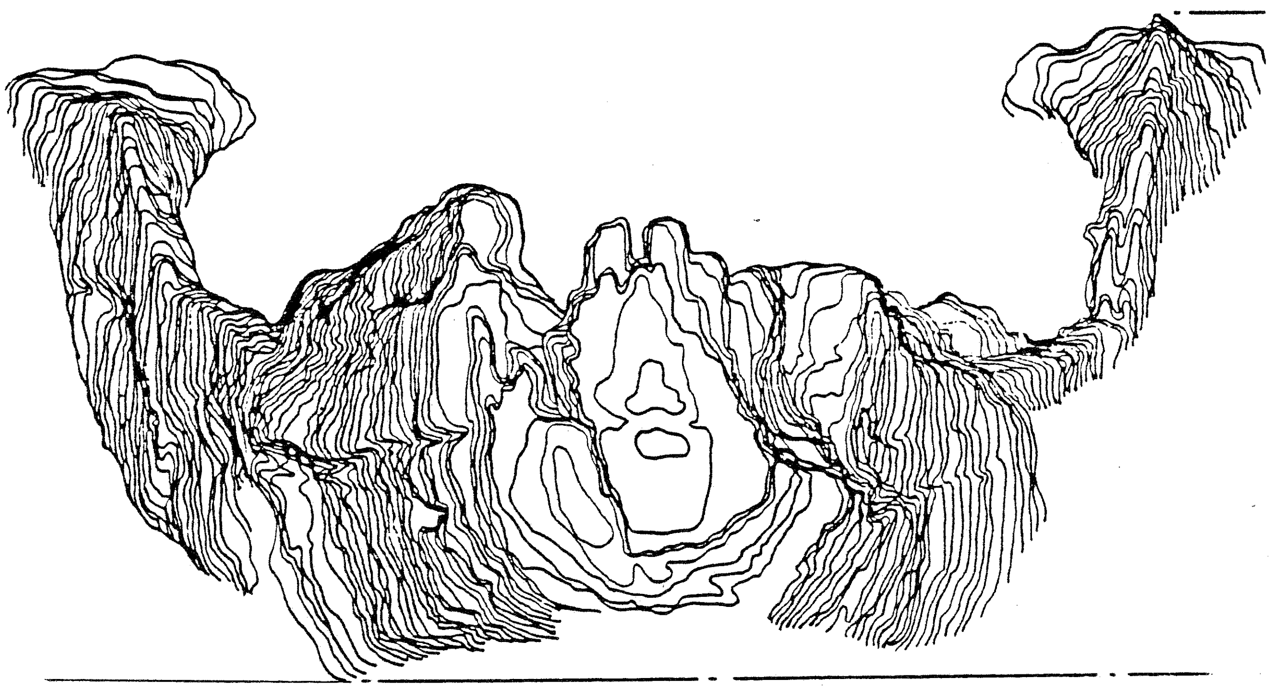


Figure 1

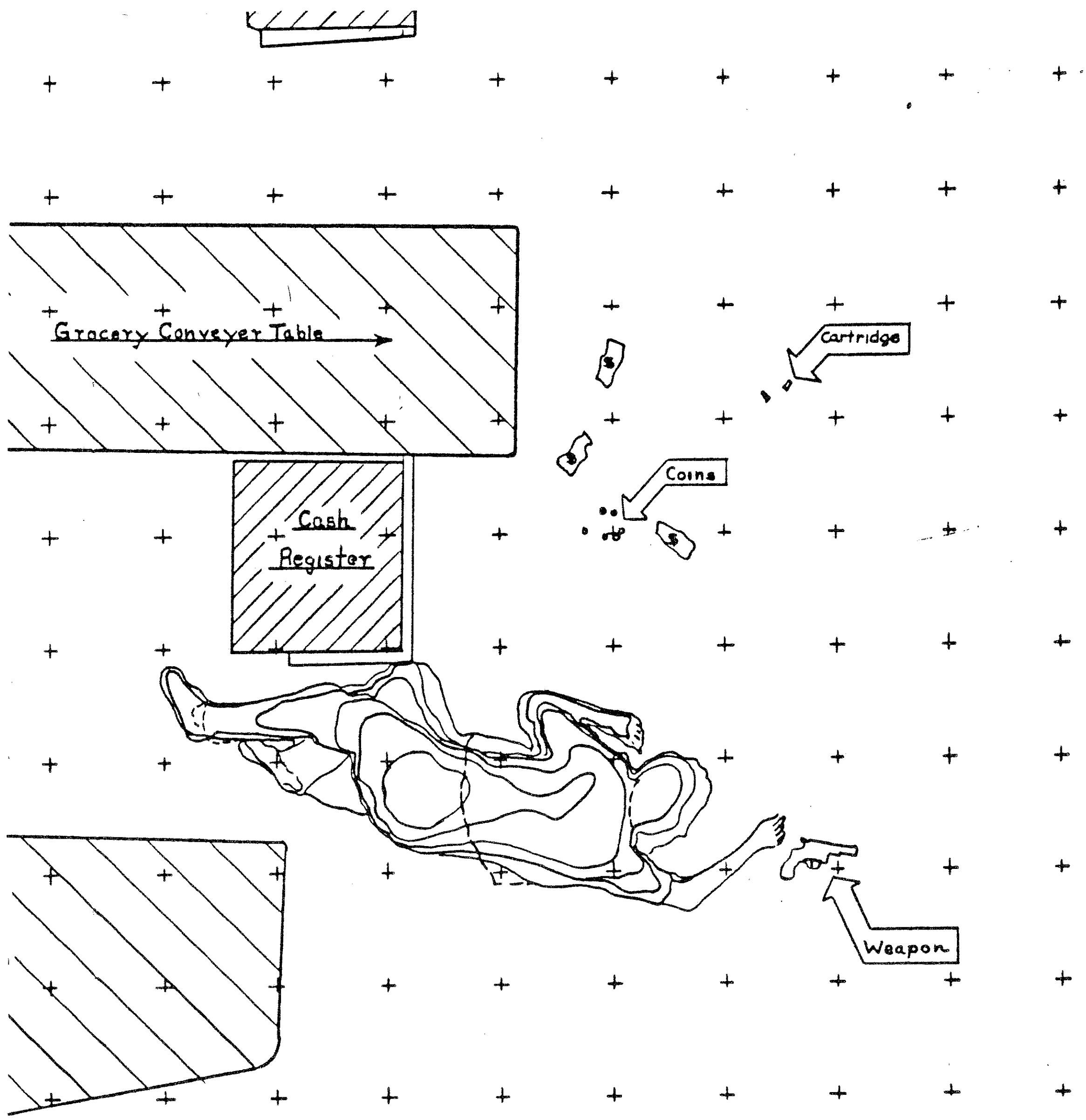
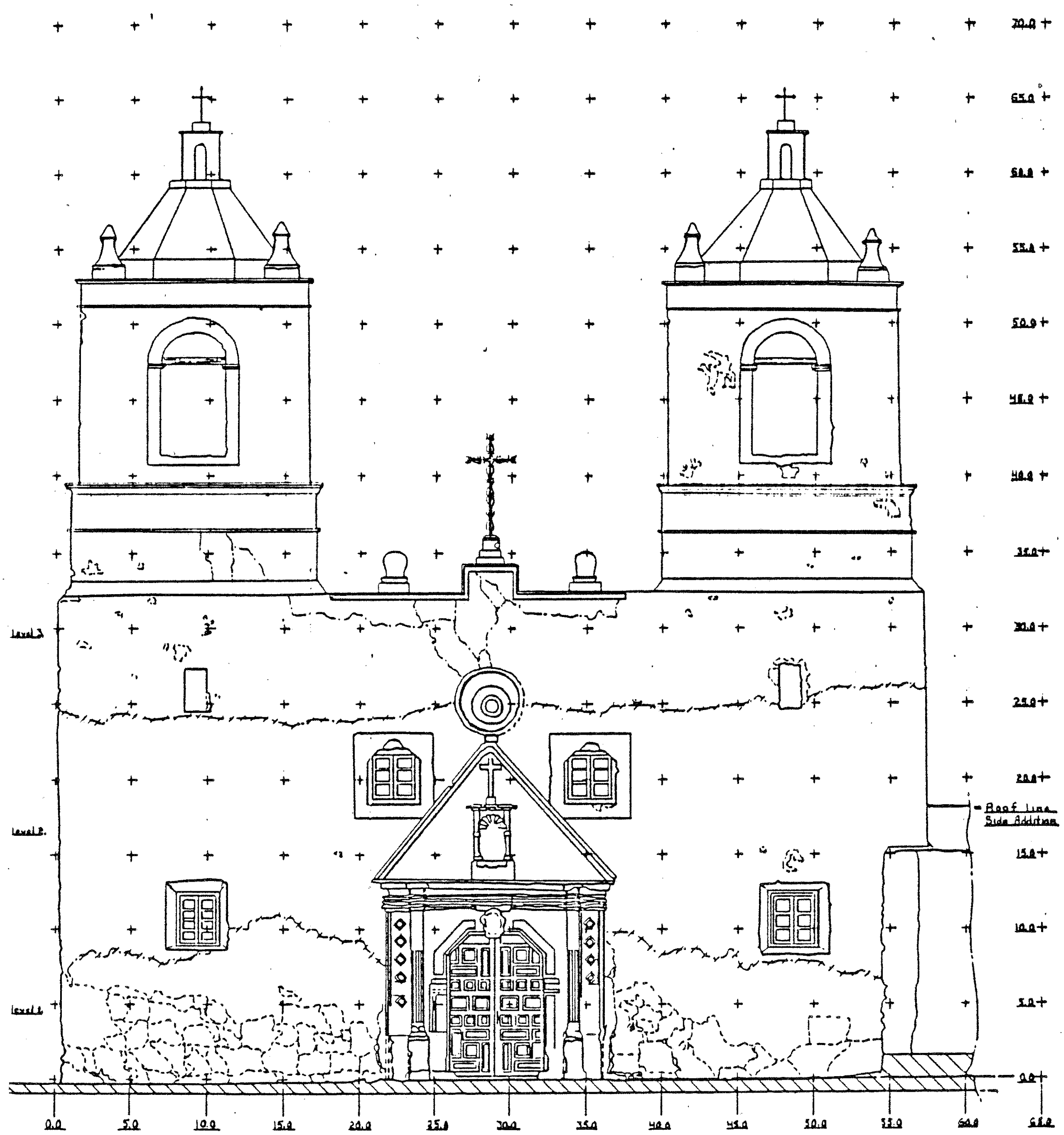

Grocery Conveyer Table
Cash Register
Cartridge
Coins
$
Weapon

Figure 2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Side Addition
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
55.0
60.0
65.0

Figure 3